ECOLOGY AND MANAGEMENT OF *ARUNDO DONAX*, AND APPROACHES TO RIPARIAN HABITAT RESTORATION IN SOUTHERN CALIFORNIA.

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Abstract

By far the greatest threat to the dwindling riparian resources of coastal southern California is the alien grass species known as *Arundo donax*. Over the last 25 years the riparian forests of coastal southern California have become infested with *A. donax* which has spread by flood-fragmentation and dispersal of vegetative propagules. *Arundo donax* dramatically alters the ecological/successional processes in riparian systems and ultimately moves most riparian habitats towards pure stands of this alien grass.

By current estimates there are tens of thousands of acres of *A. donax* along the major coastal drainage systems of southern California, including the Santa Ana, Santa Margarita, Ventura, Santa Clara, San Diego, and San Luis Rey rivers. The removal of *A. donax* from these systems provides numerous downstream benefits in terms of native species habitat, wildfire protection, water quantity and water quality.

Introduction

Arundo (L.) is a genus of tall perennial reed-like grasses (Poaceae) with six species native to warmer parts of the Old World. *Arundo donax* (L.) (giant reed, bamboo reed, giant reed grass, arundo grass, donax cane, giant cane, river cane, bamboo cane, canne de Provence), is the largest member of the genus and is among the largest of the grasses, growing to a height of 8 m (Figure 1). This species is believed to be native to freshwaters of eastern Asia (Polunin and Huxley 1987), but has been cultivated throughout Asia, southern Europe, north Africa, and the Middle East for thousands of years and has been planted widely in North and South America and Australasia in the past century (Perdue 1958, Zohary 1962). It was intentionally introduced to California from the Mediterranean in the 1820's in Los Angeles area as an erosion-control agent in drainage canals, and was also used as thatching for roofs of sheds, barns, and other buildings (Hoshovsky 1987). Subsequent plantings have been made for the production of reeds for a variety of musical instruments including bassoons and bagpipes. Today it is an invasive pest throughout the warmer coastal freshwaters of the United States, from Maryland to northern California.

Arundo donax is a hydrophyte, growing along lakes, streams, drains and other wet sites. It uses prodigious amounts of water, as much as 2,000L/meter of standing *A. donax*, to supply its incredible rate of growth (Purdue 1958; Iverson 1994). Under optimal conditions it can grow more than 5 cm per day (Purdue 1958). *Arundo donax* stands are among the most biologically

productive of all communities. Under ideal growth conditions they can produce more than 20 tons per hectare above-ground dry mass (Perdue 1958).

Perhaps as much as 90% of the historic riparian habitat in the southern part of California has been lost to agriculture, urban development, flood control, and other human-caused impacts (Jones & Stokes 1987; Katibah 1984). The greatest threat to the remaining riparian corridors today is the invasion of exotic plant species, primarily *Arundo donax.* This alien grass readily invades riparian channels, especially in disturbed areas, is very competitive, difficult to control, and to the best of our knowledge does not provide either food or nesting habitat for native animals. *Arundo* competes with native species such as *Salix* (willows), *Baccharis salicifolia* Ruiz Lopez & Pavon (mulefat), and *Populus* (cottonwoods) which provide nesting habitat for the federally endangered bird, the least Bell's vireo (*Vireo bellii pusillus*), the federally threatened bird, the willow flycatcher (*Empidonax traillii eximus*) and other native species (Hendricks and Rieger 1989; Franzreb 1989; Zembal 1986 and 1990).

Ecological value of native riparian systems

Like most riparian systems, the cottonwood/willow riparian forest is a dynamic community, dependent upon periodic flooding to cycle the community to earlier successional stages (Warner and Hendrix 1985). Periodic floods of large magnitude and migration of the river channel are essential to depositing fresh alluvium where seeds and vegetative propagules of *Baccharis*, *Salix*, and *Populus* can germinate and take root (Gregory et al. 1991; Richter and Richter 1992).

Adequate moisture and an absence of subsequent heavy flooding is critical to the survival of the young trees through their first year. As these seedlings mature they increase channel roughness and alter flow during small flood events, increasing sediment deposition (Kondolf 1988; Richter and Richter 1992; Stromberg *et al.* 1993). Sediment deposition builds river terraces and, as they elevate, other plant species colonize resulting in further diversification in the floodplain community (Richter and Richter 1992).

When *Populus/Salix* riparian scrub, which may include such species as *Baccharis salicifolia*, *Vitis californica* (Benth.), *Rubus ursinus* (Cham. & Schldl.), and *Urtica dioica* ssp. *holosericea* (Nutt.) Thorne, reaches four or five years of age, it begins to exhibit the structural diversity required for breeding by the bird, the least Bell's vireo (Franzreb 1989, Hendricks and Rieger 1989). Least Bell's vireo, along with the riparian birds, southwestern willow flycatcher, yellow-breasted chat (*Icteria virens*), yellow warbler (*Denroica petechia*), and many other species may continue to use this diverse community for another ten to twenty years. Gradually the canopy of the maturing willows and cottonwoods begins to shade out the diverse understory of vascular plants required by these birds. Older riparian gallery forests will continue to be used by western yellow-billed cuckoo (*Coccyzus americanus occidentalis*), Cooper's hawk (*Accipiter cooperii*), warbling vireo (*Vireo gilvus*) and other species (Zembal 1990; Zembal *et al.* 1985), but as the stand ages the diversity of the flora and fauna within the forest declines. Annual flooding, channel migration, and occasional large flood events maintain this cycle of succession and therefore maintains a mosaic of diverse natural communities (Gregory *et al.* 1991).

Arundo donax as a competitor

Within its introduced range, *A. donax* is an aggressive competitor. *Arundo donax* flowers in late summer with a large, plume-like panicle. Fortunately for California land managers, the seeds produced by *A. donax* in this country are seldom, if ever, fertile. It is not known if this is because of clonal isolation or because of the physiological effects of climate as has been observed in the related *Phragmites communis* Trin. (common reed) (Haslam 1958; Rudescu et al. 1965). *Arundo donax* is well adapted to the high disturbance dynamics of riparian systems as it spreads vegetatively. Flood events break up clumps of *A. donax* and spread the pieces downstream. Fragmented stem nodes and rhizomes can take root and establish as new plant clones. Thus invasion, spread, and therefore management, of *A. donax* is essentially an intra-basin and downstream phenomenon.

Once established *A. donax* tends to form large, continuous, clonal root masses, sometimes covering several acres, usually at the expense of native riparian vegetation which cannot compete. Root masses, which can become more than a meter thick, stabilize stream banks and terraces (Zohary and Willis 1992), altering flow regimes. *Arundo donax* is also highly flammable throughout most of the year, and the plant appears highly adapted to extreme fire events (Scott 1994). While fire is a natural and beneficial process in many natural communities in southern California it is a largely un-natural and pervasive threat to riparian areas. Natural wild fires usually occur during rare lightening storm events in late fall, winter, and early spring. Under these

conditions the moist green vegetation of riparian areas would normally act as a fire break. Human-caused wild fires, in contrast, often occur during the driest months of the year (July through October). Drier conditions in riparian zones at this time of year make them more vulnerable to fire damage. Because *A. donax* is extremely flammable, once established within a riparian area it redirects the history of a site by increasing the probability of the occurrence of wildfire, and increasing the intensity of wildfire once it does occur. If *A. donax* becomes abundant it can effectively change riparian forests from a flood-defined to a fire-defined natural community, as has occurred on the Santa Ana River in Riverside County, California. *Arundo donax* rhizomes respond quickly after fire, sending up new shoots and quickly outgrowing any native species which might have otherwise taken root in a burned site. Fire events thus tend to help push riparian stands in the direction of pure *A. donax.* This results in river corridors dominated by stands of giant reed with little biological diversity.

Arundo donax **as habitat**

All evidence indicates that *A. donax* provides neither food nor habitat for native species of wildlife. *Arundo donax* stems and leaves contain a wide array of noxious chemicals, including silica (Jackson and Nunez 1964), tri-terpines and sterols (Chandhuri and Ghosal 1970), cardiac glycosides, curare-mimicking indoles (Ghosal *et al.* 1972), hydroxamic acid (Zuñiga *et al.* 1983), and numerous other alkaloids which probably protect it from most native insects and other grazers (Miles *et al.* 1993, Zuñiga *et al.* 1983). Areas taken over by *A. donax* are therefore largely

Control Methods

A suite of methods is needed to control *A. donax* depending upon the presence or absence of native plants, the size of the stand, the amount of biomass which must be dealt with, the terrain, and the season.

The key to effective treatment of established *A. donax* is killing of the root mass. This requires treatment of the plant with systemic herbicide at appropriate times of the year to ensure translocation to the roots. Only one herbicide is currently labeled for wetlands use by the EPA; Rodeo®, a tradename formulation of glyphosate, produced by Monsanto Corporation. Glyphosate is a broad-spectrum herbicide which can be used on *A. donax*, *Tamarix ramosissima* (saltcedar), and most other monocots and dicots. It has proven very effective against *A. donax* (Finn and Minnesang 1990; Jackson 1994; USDA Forest Service 1993). Other herbicides might also be used as labels and conditions allow. Monocot-specific chemicals, such as Fusilade-DX® (fluazapop-butyl) and Post® (Sethoxidan), might be particularly useful for treating *A. donax* in stands with a substantial component of native dicots; however, neither is currently labeled for wetlands use.

The most effective treatment on *A. donax* is the foliar application of a two-to-five percent (2-5%) solution of Rodeo applied post-flowering and pre-dormancy at a rate of 0.5 to 1 L/hectare. During this period of time, usually mid-August to early November, the plants are actively translocating nutrients to the rootmass in preparation for winter dormancy which results in

effective translocation of herbicide to the roots. Recent preliminary comparison trials on the Santa Margarita River (Omori. 1996) indicate that foliar application during the appropriate season results in almost 100% control, compared with only 5-50% control using cut-stem treatment. Two to three weeks after foliar treatment. treatment the leaves and stalks brown and soften creating an additional advantage in dealing with the biomass: cut green stems might take root if left on damp soil and are very difficult to cut and chip. Treated stems have little or no potential for rooting and are brittle. They may be left intact on the ground or chipped *in situ* for mulch.

Cut-stem treatment requires more time and man-power than foliar spraying and requires careful timing. Cut stems must be treated with concentrated herbicide within one to two minutes in order to ensure tissue uptake (Monsanto 1989). This treatment is also most effective post-flowering. The chief advantage of the cut-stem treatment is that it requires less herbicide that can be more-or-less surgically applied to the stem. Because of its reduced efficacy, and due to the labor required, it is rarely cheaper than foliar spraying except on very small, isolated patches or individual plants.

A popular approach to dealing with *A. donax* has been to cut the stalks and remove the biomass, wait three to six weeks for the plants to grow to about one meter tall, then apply a foliar spray of herbicide solution. The chief advantage of this approach is that less herbicide must be applied to treat the fresh growth compared with tall, established plants, and that coverage is often better because of the shorter and uniform-height plants. However, cutting of the stems may result in the plants returning to growth-phase, drawing nutrients from the rootmass.

As a result there is less translocation of herbicide to the roots and less root-kill. Therefore many follow-up treatments must be made which negates any initial savings in herbicide and greatly increases the manpower costs.

Pure stands (>80% canopy cover) of *A. donax* or *T. ramosissima* are most efficiently treated by aerial application of an herbicide concentrate, usually by helicopter. Helicopter application can treat at least 50 hectares per day. Special spray apparatus produces extremely fine droplets (400 microns) of concentrated herbicide which actually reduces herbicide use, minimizes over-spray, and results in greater kill.

In areas where helicopter access is impossible, where *A. donax* makes up the understory, where patches are too small to make aerial application financially efficient, or where weeds are mixed with native plants (<80% cover), herbicides must be applied by hand. Street-vehicles with 400 liter spray tanks are a good alternative where road access is available, but small "quad-runner" vehicles equipped with 60 liter sprayers are the preferred approach where the streambed is not so rocky as to prevent access. Twenty liter backpack sprayers are the final alternative where the vegetation is too dense, or the landscape too rugged for vehicles to be effective.

Methods for vegetation removal include use of prescribed fire, heavy machinery (e.g. bulldozers), handcutting by chainsaw or brushcutter, hydro-axe, chipper, biomass burning or removal by vehicle. Removal of the biomass should only be done where the weed cover is so dense as to prevent recovery by native vegetation after treatment, or where cut vegetation might create a debris-dam hazard during flood events. Prescribed fire, or burning piles of stacked biomass, is the most cost-effective way of removing biomass as long as it does not threaten

native vegetation or other resources. Chipping is more costly in terms of equipment and labor, and cut, dried chips pose no threat for regeneration or for forming debris dams. Hauling of biomass by vehicle is extremely expensive and should only be done as a last resort. Most landfills will not accept *A. donax* and those that do will only accept if cut into short lengths and bagged into plastic trash bags, making the labor costs far too great. The use of heavy machinery such the Hydro-ax® is extremely expensive. The machines are very slow - a Hydro-ax can only cut about 3-4 acres per day.

Riparian restoration and management

One of the prime incentives for riparian habitat restoration has been endangered species recovery, including the federal Endangered Species Act (ESA). The ESA has focused attention on declining species and sought to protect those species in greatest risk by provisions against take (Under the ESA the term "take" means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct.). Focus of the legislation has been on individual protected species with little attention given to the dynamics of the natural systems of which these species are a part. There are important historical and legislative reasons for this approach. In the 1970's, when the ESA was drafted, ecologists and wildlife managers were highly focused on single species; system-oriented approaches were not widely applied. In addition, it is far easier to attach legal definition to something tangible, such as an individual animal, than it is to the more vague concept of ecological processes (Gregory *et al.* 1991).

been successful in terms of establishing a matrix of riparian habitat which is used by some native species, re-vegetating is the not necessarily the best way to create habitat.

The best way to address habitat loss in southern California riparian systems is through a comprehensive program of eradication of *A. donax, T. ramosissima*, and other invasive aliens, and relying on natural physical processes, especially flood dynamics, for the recovery of native natural communities and species. This approach might be just as easily argued for other high disturbance-adapted communities.

This strategy is based upon two of important factors. First, riparian habitats are flood-dynamic communities, dependent upon natural cycles of flood scouring and sediment deposition to create the proper conditions for community establishment (Gregory *et al.* 1991; Richter and Richter 1992; Stromberg *et al.* 1991). The Santa Ana, Santa Margarita, San Luis Rey, and many other southern California streams have all of the factors necessary for the recovery and maintenance of healthy riparian communities and riparian species. These watersheds retain flood regimes sufficient to move and sort sediment and extensive sources of seed and vegetative propagules for *Salix* and other native riparian plants. Second, the only real threats to the integrity of the system are (1) habitat fragmentation by development and (2) introduced exotic species which have altered the successional dynamics and stability of the natural communities. In other words, the native riparian communities of the Santa Ana and other major riparian corridors (and thus riparian-dependent species such as least Bell's vireo) are limited, not by the capacity of the community to regenerate, or the available area of riparian zones, but by the capacity of native species to compete with aggressive invasive exotic species, chiefly *A. donax.*

The majority of the limited resources available for riparian management on these rivers should therefore be directed at managing for the process of riparian systems: removing the key perturbation from the system, thereby allowing natural flood dynamics to operate and the natural communities to recover. Attempts to re-vegetate riparian species in floodplains that retain both native riparian species and flood regimes are redundant, and resources spent to this end are largely wasted. This is not to imply that riparian (and other habitat) re-vegetation efforts should not be applied; however, they should be applied judiciously and only in situations where specific management goals are achieved by carrying out a re-vegetation project (e.g. closing up an important corridor or re-establishing native species in a depauperate watershed). Relying on natural processes for the recovery of the riparian communities has the following major benefits:

a. Cost-effectiveness. Riparian forest restoration is extremely expensive, often on the order of tens of thousands of dollars per hectare. This necessarily limits the size, and therefore the biological value, of any funded restoration project. *Arundo donax* can be removed from most areas of a river for a fraction of the cost of revegetation, opening up areas for natural re-colonization by native riparian species.

b. Biological value. As indicated above, the high cost of re-vegetation limits the size of restoration projects. Additionally, artificially-produced riparian habitat lacks the high stem densities characteristic of naturally regenerating riparian habitat, making the actual biological value of re-vegetated sites questionable. Much higher value may be achieved by removing invasive exotics such as *A. donax* from the system. Areas opened up for

tributaries to prevent reinfestation of treated downstream sites from upstream sources. Removal of *A. donax* requires treatment with systemic herbicides in order to kill the large root mass.

Past practices of riparian restoration have focused on re-vegetation of small sites without consideration of natural riparian processes. Resources should be spent on managing for the natural dynamic processes of these systems on a watershed-wide scale. In coastal southern California the primary perturbation to the natural riparian succession process in invasion by *A. donax*, and its removal from river systems will have a far greater beneficial effect on most riparian species than planting of riparian vegetation.

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Figure 1. *Arundo donax.* Plant X 1/3; spikelet and floret X 3 (from Hitchcock and Chase 1950).

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List of Figures

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Abbreviations and Acronyms

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Foreword

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Chapter 1
Plan Preparation and System Description

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Table 1-1
Agency Coordination

Agency	Participated in UWMP Development	Received Draft Report and Public Hearing Notice	Attended Public Meetings	Received Final Report[1]
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Table 1-2
CMWD Purveyors

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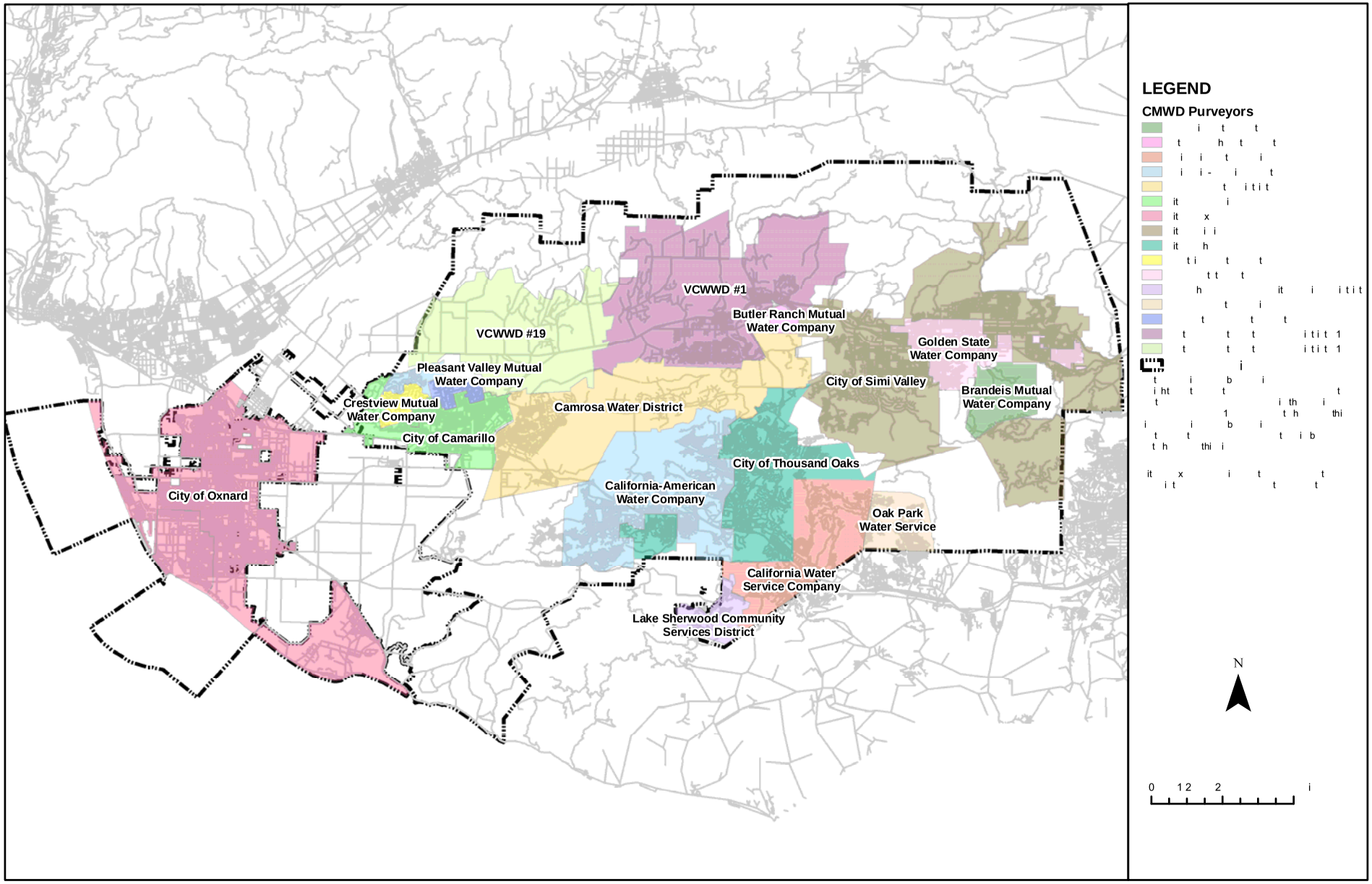

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CMWD 2010 Urban Water Management Plan

CMWD Service Area and Purveyors

Figure 1-1

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B. Demographics

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1. Population Projections

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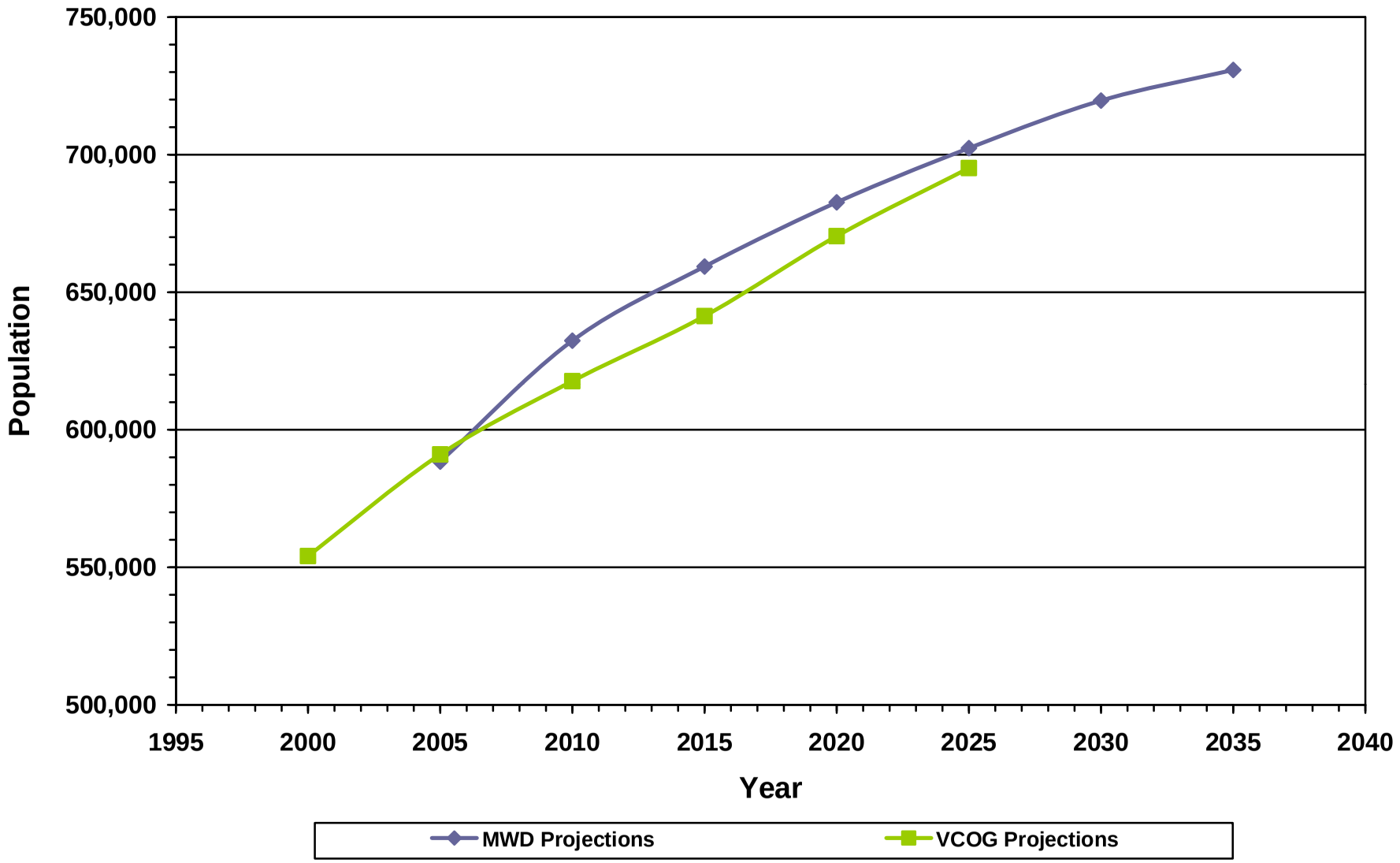

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Population Projections

Figure 1-2

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Table 1-3
CMWD Service Area Population Projections

Year	MWD Projections [1]	VCOG Projections [2]
200		1 0 0
2010	2	1 2
201	0	1 2
2020	2 1	0
202	02	1 1
20 0	1	-
20	0	-
	0	0

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2. Dwelling Unit Projections

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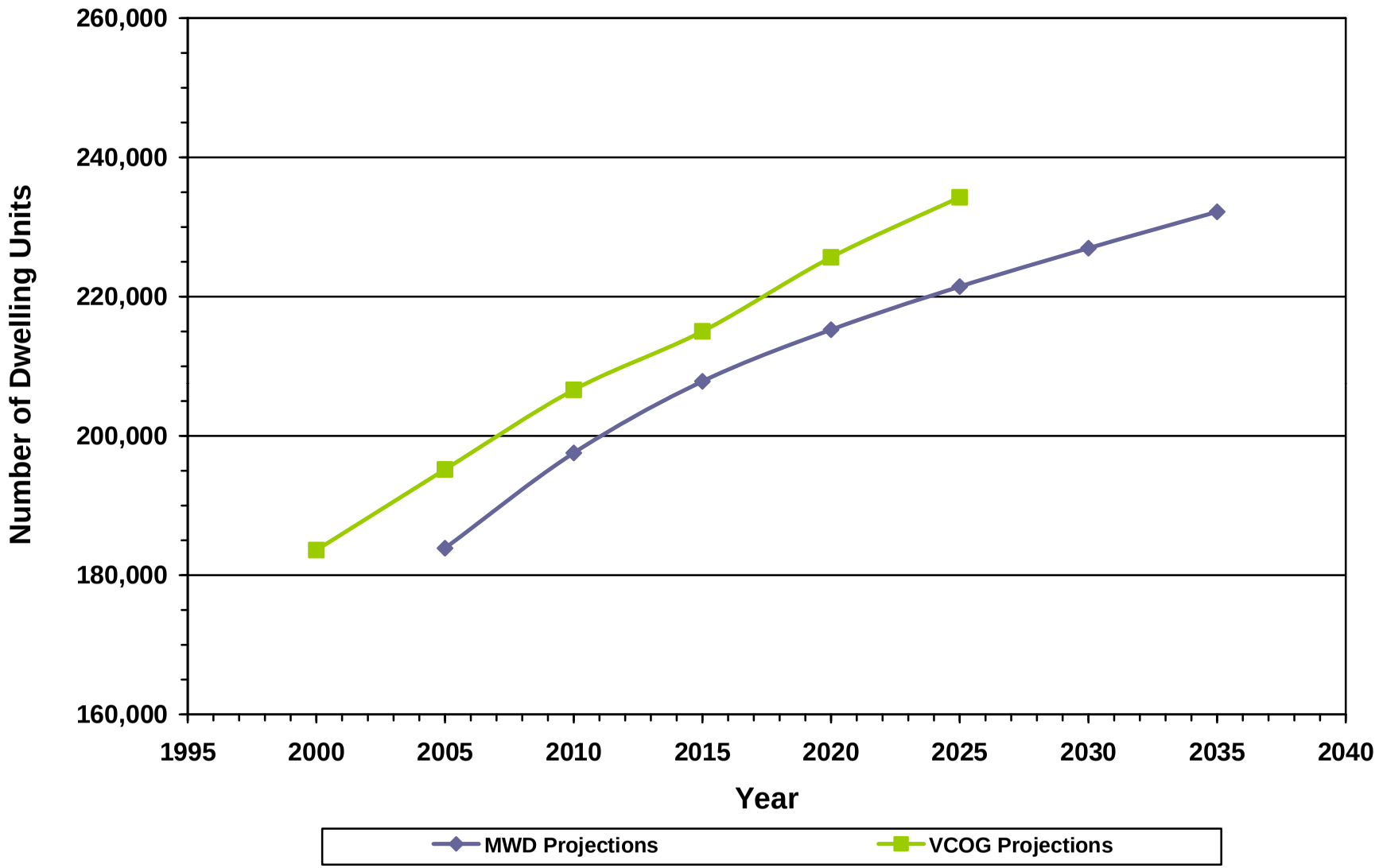

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CMWD 2010 Urban Water Management Plan

Dwelling Unit Projections

Figure 1-3

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Table 1-4
CMWD Service Area Dwelling Unit Projections

Year	MWD Projections [1]	VCOG Projections [2]
200	1	1 1 0
2010	1	20 10
201	20 2	21 01
2020	21 2	22 2
202	221	2 2
20 0	22	-
20	2 2 1	-
	0	0

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3. Employment Projections

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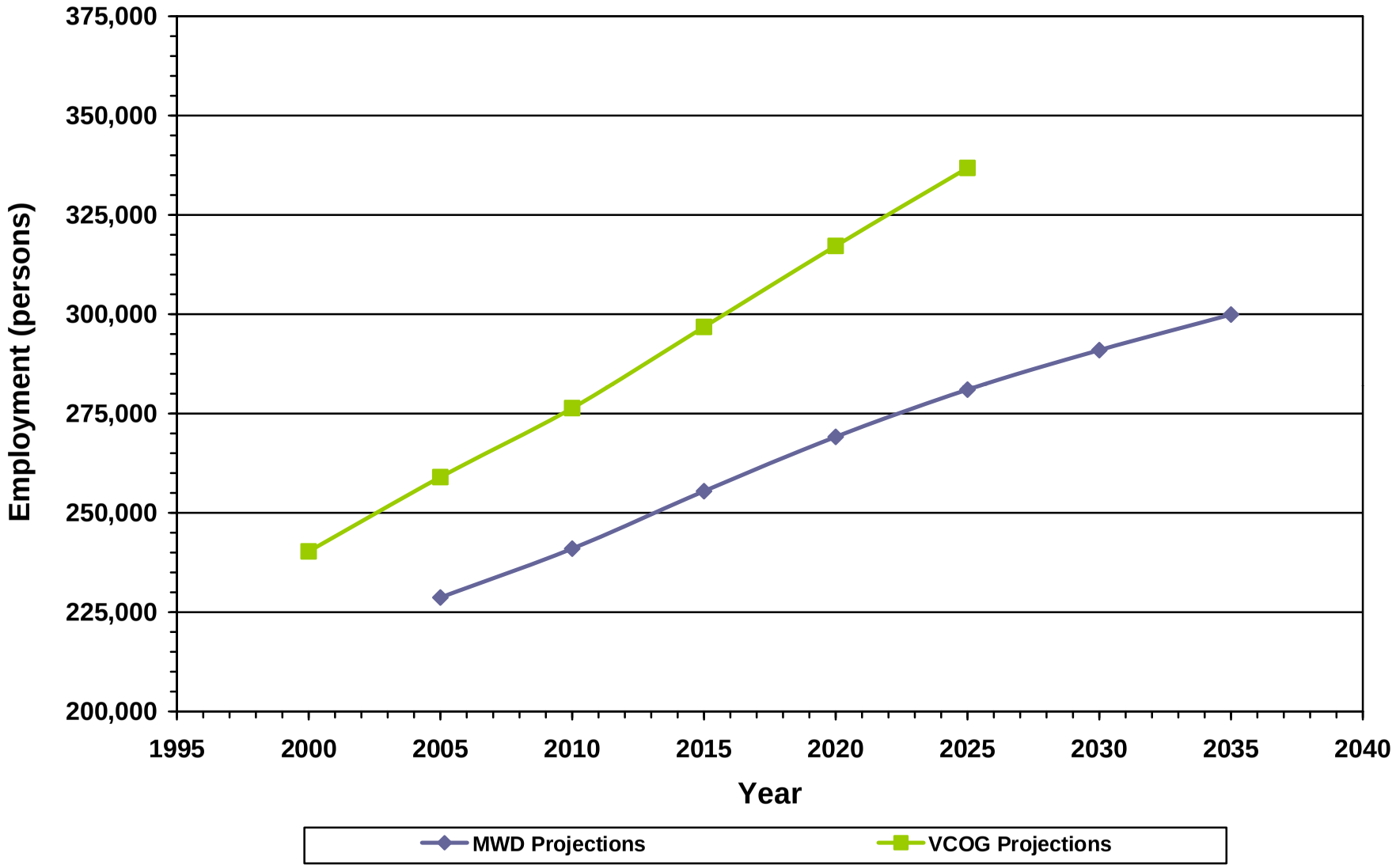

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Employment Projections

Figure 1-4

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Table 1-5
CMWD Service Area Employment Projections

Year	MWD Projections [1]	VCOG Projections [2]
200	22	2
2010	2 0	2
201	2	2
2020	2 12	1 1
202	2 1 002	1
20 0	2 0	-
20	2 21	-
	0	1

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Table 1-6
Monthly Average Climatic Data – Coastal (Western) Ventura County

Month	Average Evapotranspiration Rate [1] (inches per month)	Average Maximum Temperature [2] (°F)	Average Minimum Temperature [2] (°F)	Average Total Precipitation [2] (inches)
	1			2 1
b	2 2			
h	2			1
i			1	1 2
	2	0	2	0
		2		0 0
				0
t	1		2	0
t b				0 1
t b	2			0
b	2	0		1 1
b	1			1
Total	**46.43**	**N/A**	**N/A**	**13.64**

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Table 1-7
Monthly Average Climatic Data - Inland (Eastern) Ventura County

Month	Average Evapotranspiration Rate [1] (inches per month)	Average Maximum Temperature [2] (°F)	Average Minimum Temperature [2] (°F)	Average Total Precipitation [2] (inches)
	2 2	1	2	2
b	2			1
h				0
i		1	2	0
			1	0
		0		0
			0	0
t				0 01
t b		1	1	0 0
t b			2	1 2
b	2	1		0 21
b	2 0	2		0
Total	**51.0**	**N/A**	**N/A**	**10.48**

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Chapter 2
Water Supplies and Quality

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1. Water Quantity Challenges

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2. Water Quality Challenges

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B. Groundwater

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1. Fox Canyon Groundwater Management Agency

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Table 2-1
FCGMA Pumping Allocations [1]

Basin	Number of Wells	Historical Allocation [2] (ac-ft per year)	Baseline Allocation [3] (ac-ft per year)	Total Allocation (ac-ft per year)
t	1		-	
x i b	1 0	2 1	21	2
x i			2 2 0	
t	1	21 2	1 0	22
E t	1	1 0		1
t		1 0	0	1 1
th	0	2 0	2	2 10
t	1 1	1 1	1	1

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2. Groundwater Storage Strategies and Transfer Agreements

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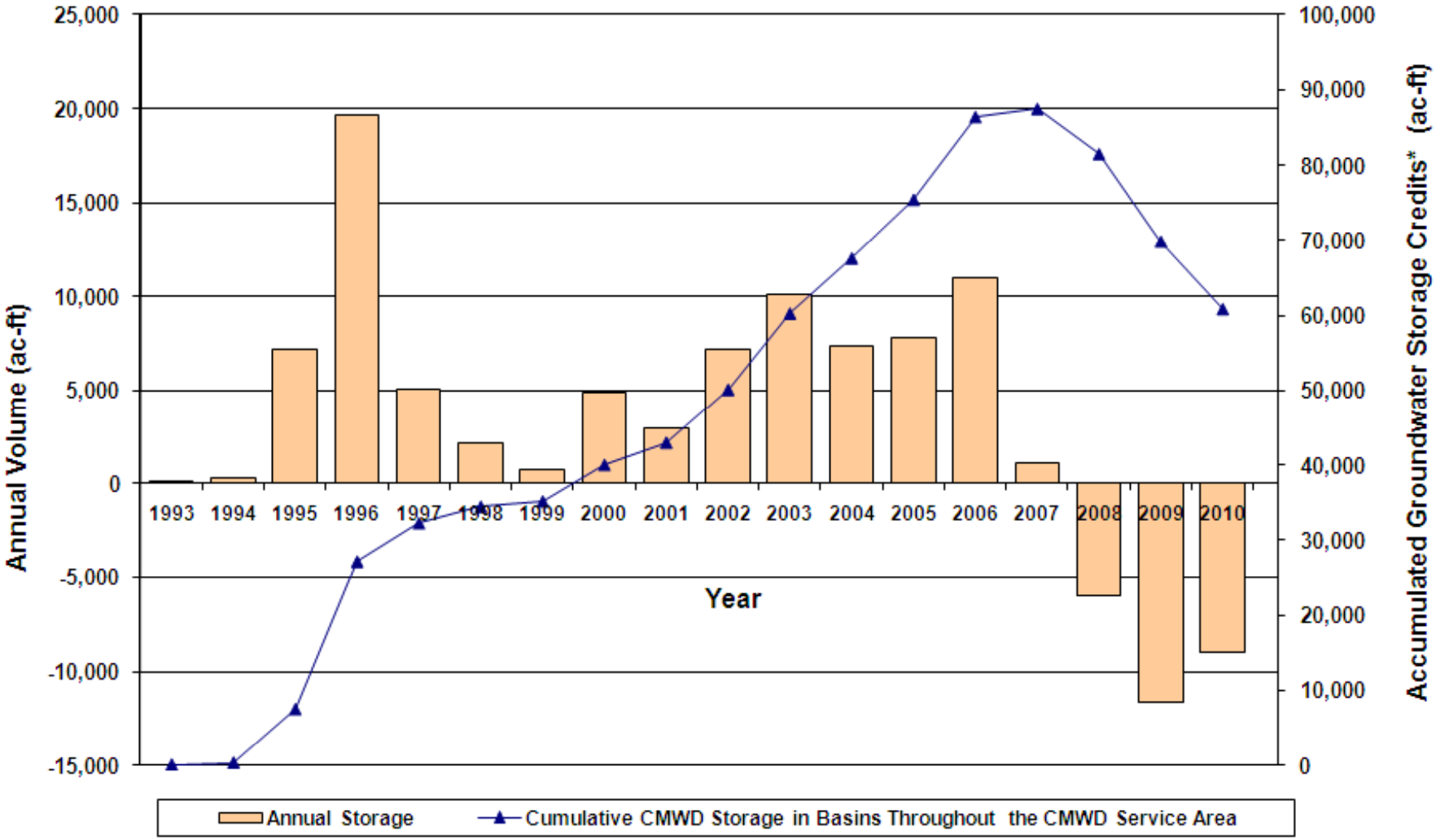

* Accumulated groundwater storage credits in FCGMA Approved Programs. Extraction of credits is subject to FCGMA's policies and conditions of adopted storage programs.

CALLEGUAS MUNICIPAL WATER DISTRICT	BLACK & VEATCH building a world of difference™	**CMWD 2010 Urban Water Management Plan**	**Figure 2-1**
		Historical CMWD Groundwater Storage Data	

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3. Groundwater Quality

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Table 2-2 Groundwater Basin Water Quality Summary		
Groundwater Basin	**Average/ Maximum TDS Level (mg/L)**	**Average/ Maximum Nitrate Level (mg/L)**
t	11 0	11
i i	1 2 0 0	0
th	1 0 1 20	21
th E t t	2 1 00	2 1 2
t	1 0 0	1 121
x b	1 1 0 1 210	22
x i	1 2 10	1 1 2
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C. Recycled Wastewater

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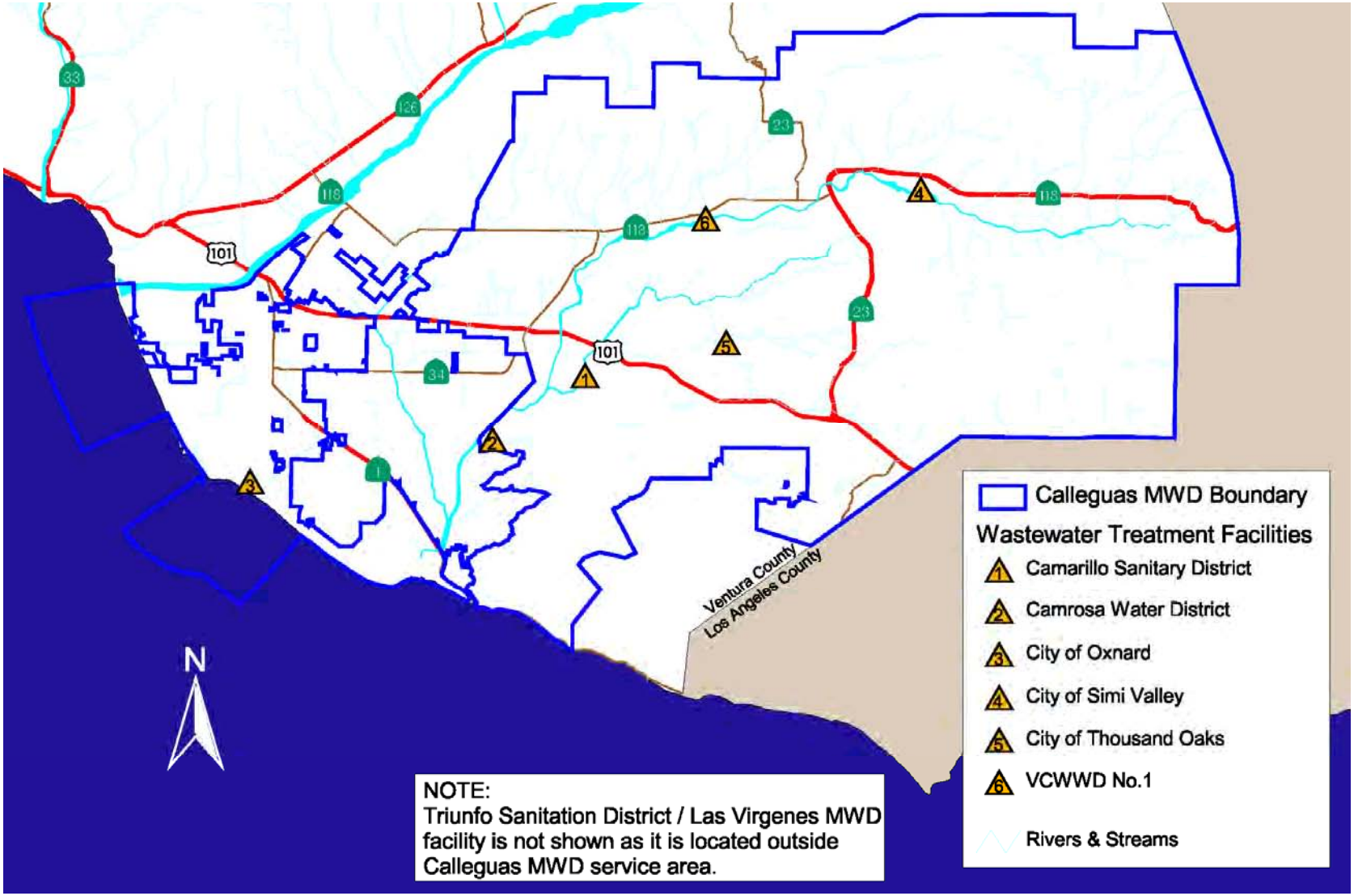

CALLEGUAS MUNICIPAL WATER DISTRICT

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CMWD 2010 Urban Water Management Plan

Wastewater Service Providers in CMWD's Service Area

Figure 2-2

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Table 2-3
Recycled Wastewater in CMWD's Service Area

Wastewater Service Provider	Treatment Level	Method of Disposal for Non-Recycled Wastewater	Uses of Recycled Wastewater	Methods to Encourage Use
i it i t i t i t ti t	ti		i ti	t i b
t i t i t t ti i it	ti	[1]	i ti	t i
it x t i i ti [2] i it	t ti ith xi ti i i 2011		t i i i ti t b i	t t i
it i i	ti	i i	i ti h t t b t t	t i
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Table 2-4
Wastewater Treatment in CMWD's Service Area [(1)]

Wastewater Service Provider	Annual Average Wastewater Flows (ac-ft)						
	2005	2010	2015	2020	2025	2030	2035
i it i t i t i							
t i t i t	1 0	1 22	1	1 0	2 0	2 0	2 0
it x E	2	2 1	2	0	2		
it i i		10	11 2	12 0	1	1 000	1 2
it h i	10	10	10	10	10	10	10
i it ti i t i t i i t i t i t i	1	1	1	1	1	1	1
1	1 0	1 1 0	1 1	1 0	1	1 2	1 1
t	22	2	2			2	1 0 1

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Table 2-5
Available Recycled Wastewater in CMWD's Service Area

Recycled Water Service Provider	Approximate Annual Recycled Water (ac-ft)					
	2010	2015	2020	2025	2030	2035
i i t i [1]	2	2			1	
i it i t i t	0	00	00	00	00	00
t i t i t	2	110	0	1 0	00	0
i it ti i t i t h it [1 2]	00	00	00	00	00	00
i it ti i t i t t i [1]	0	0	0	0	0	0
it x	0	2 00	0 0	0 0	0 0	0 0
it i i	0	0	110	110	110	110
it h	-	-	-	-	-	-
i it ti i t i t i i i t i t i t	-	-	-	-	-	-
1		1 100	1 100	1 100	1 100	1 100
t		12 00	1 2	1	1 0 1	1 1

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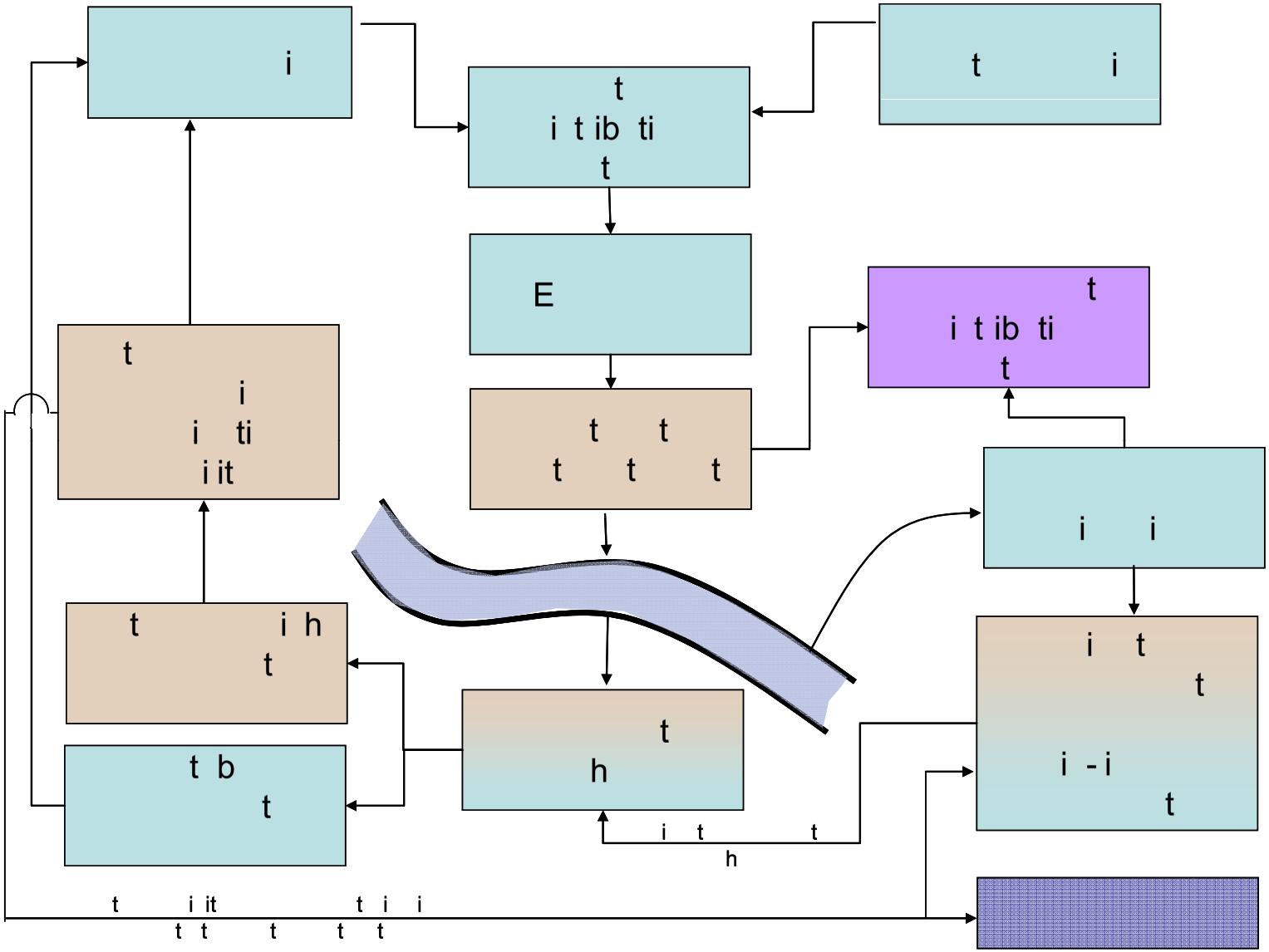

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CMWD 2010 Urban Water Management Plan

Water Cycle for CMWD's Service Area

Figure 2-3

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D. Projected Water Supplies

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1. Imported Supply Projections

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Table 2-6
MWD's Imported Supply Projections for the CMWD Service Area

Hydrologic Condition	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
	11	12 00	1	1 0	1 2	1
	121 1	1 1	1	1 1	1	1 01
ti	-	1 1 10	1	1 2	1	1

2. Local Supply Projections

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Table 2-7
MWD's Local Supply Projections for the CMWD Service Area [(1),(2)]

Hydrologic Condition	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
	0 0	0	1		0 2	1 12
	0		2			1 2
ti	-			0	0	1 0

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Table 2-8
CMWD's Local Supply Projections for Average Year Conditions [1]

Source	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
t b t	0 0		1	0	1	1
i t i h t	00	1	1 0 2	1 0 0	1 0	1 0
t t [2]		12 00	1 2	1	1 0 1	1 1
- t b t	0	1		1 2	0	2
t	0		0 0	0		0

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Table 2-9
CMWD's Local Supply Projections for Dry Year Conditions [1]

Source	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
t b t	0 0	1	1	0	1 0	1 1
t	00	1 1	1 0	1 0 0	1 11	1 1
t t [2]	212	12 2	1 1	1 1	1 1	1
- t b t	1	2	0	2	20	10 21
t	11		1 11	2 0	2	10

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Table 2-10
CMWD's Local Supply Projections for Multiple Dry Year Conditions [1]

Source	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
t b t		2 20	2 00	2 0	2 0	2 0
i t i h t	00	1 0	1 0	1 1 2	1 1	1 2
t t [2]	2 2	12 0	1 20	1 2	1 11	1
- t b t	0	0	2 0			0
t		0 01				

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E. Regional Water Supply Programs

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1. Recycling

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3. Competitive Local Resources Program

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4. Surface and Groundwater Storage Programs

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5. Central Valley Transfer and Storage Programs

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7. State Water Project

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F. Local Supply Programs

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Table 2-11
Summary of Future Local Supply Projects [(1)]

Project	Impact to Supplies	Project Timing
i t	iti 00 - t b 201	-t
t i t i t t	iti 1 020 - t b 201	-t
x E	iti 2 00 - t i 201 i i t 000 - t i 20	-t -t
1 i t i t ib ti t Ex i	iti 00 - t b 201	-t
t i t t	1 000 - t	-t
i t t	000 - t	t i -t
t t	000 - t	i - t -t

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1. Regional Recycling Projects

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a. *Camarillo Recycled Water*

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b. *Camrosa Water District Recycled Water*

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c. *Lake Sherwood / Oak Park Recycled Water*

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d. Oxnard GREAT Program

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e. Simi Valley Water Quality Control Plant

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f. VCWWD No. 1 Reclaimed Water Distribution System Expansion

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3. Brackish Groundwater Recovery Projects

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a. Round Mountain Desalter

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b. Camarillo Desalter

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c. *Moorpark Desalter*

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d. *Other Potential Regional Desalters*

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4. Watershed Management Plans

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Chapter 3
Water Use and Demands

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A. Past Water Use

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B. Water Use

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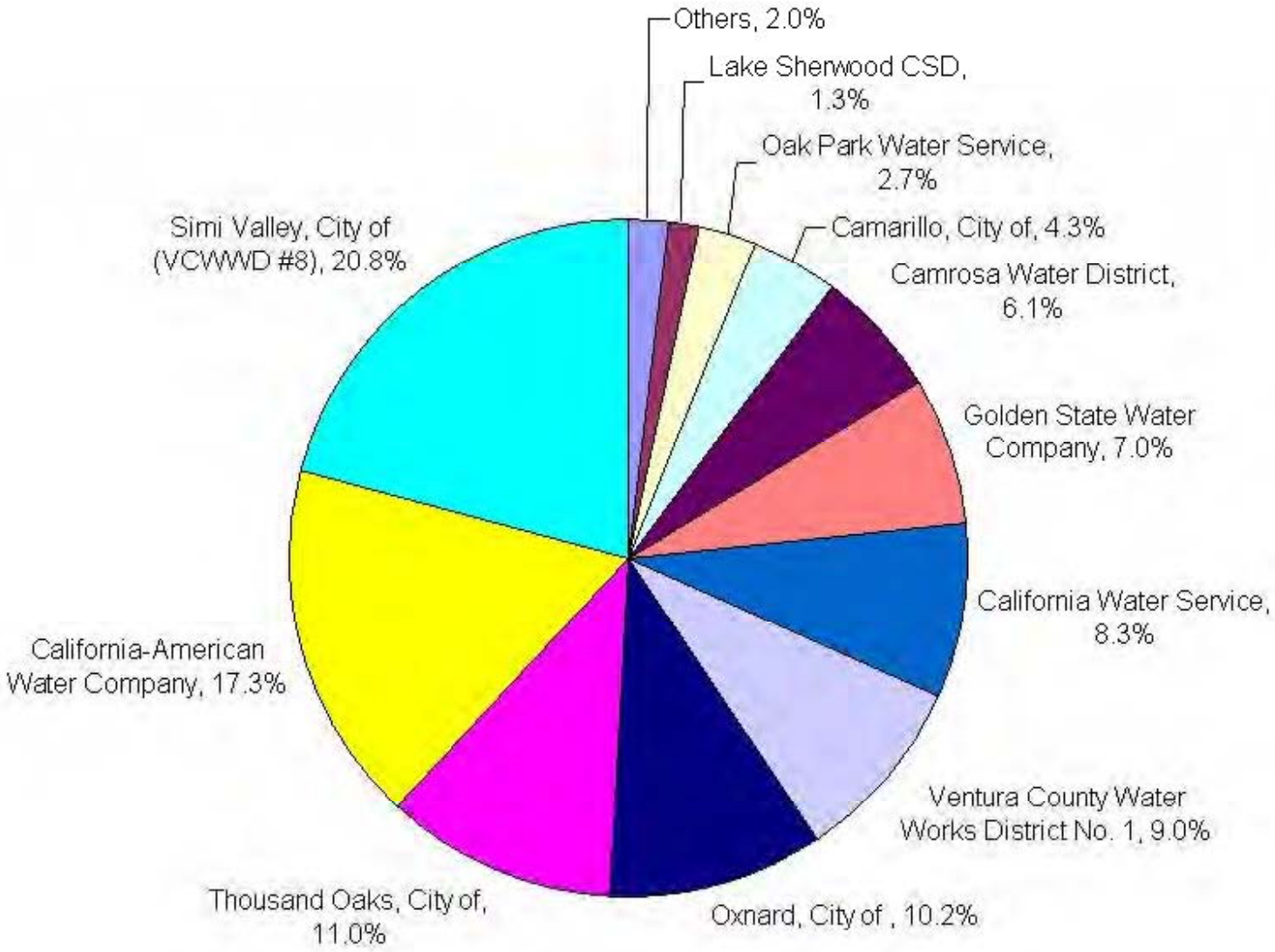

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CALLEGUAS MUNICIPAL WATER DISTRICT	BLACK & VEATCH building a world of difference™	**CMWD 2010 Urban Water Management Plan**	**Figure 3-1**
		Distribution of CMWD Imported Water Deliveries	

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Table 3-1
CMWD's Water Use by Sector [(1), 2]

Sector	Percentage					
	2010	2015	2020	2025	2030	2035
i i			2	2	2	2
ti- i						
- i ti	21	21	21	21	21	21
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C. Demand Projections

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1. Total Demand Projections

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Table 3-2
MWD's Total Demand Projections for CMWD's Service Area (1)

Hydrologic Condition	Volume (ac-ft per year)					
	2010 (2)	2015	2020	2025	2030	2035
	1 1	1	1	1	1 2 21	1
	1 1 2	1 0	1	1 1 12	1 0	1
ti	-	1 1 0	1	1 2	1	200 1

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Table 3-3
CMWD's Total Demand Projections [1]

Hydrologic Condition	Volume (ac-ft per year)					
	2010 [2]	2015	2020	2025	2030	2035
	1 1	1 1	1	1 2 121	1 1	202 1 0
	1	1 0	1	1	20	211
ti	1 2	1	1 0	1	20	210 20

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2. Imported Demand Projections

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CMWD Imported Demand = Total CMWD Demands – Local Supplies

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Table 3-4
MWD's Imported Demand Projections for Average Year Conditions

Parameter	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
t	1 1	1	1	1	1 2 21	1
	0 0	0	1		0 2	1 12
t	11	12 00	1	1 0	1 2	1

Table 3-5
CMWD's Imported Demand Projections for Average Year Conditions

Parameter	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
t	1 1	1 1	1	1 2 121	1 1	202 1 0
	0		0 0	0		0
t	11	11	11 2	121 1	12 10	12 10

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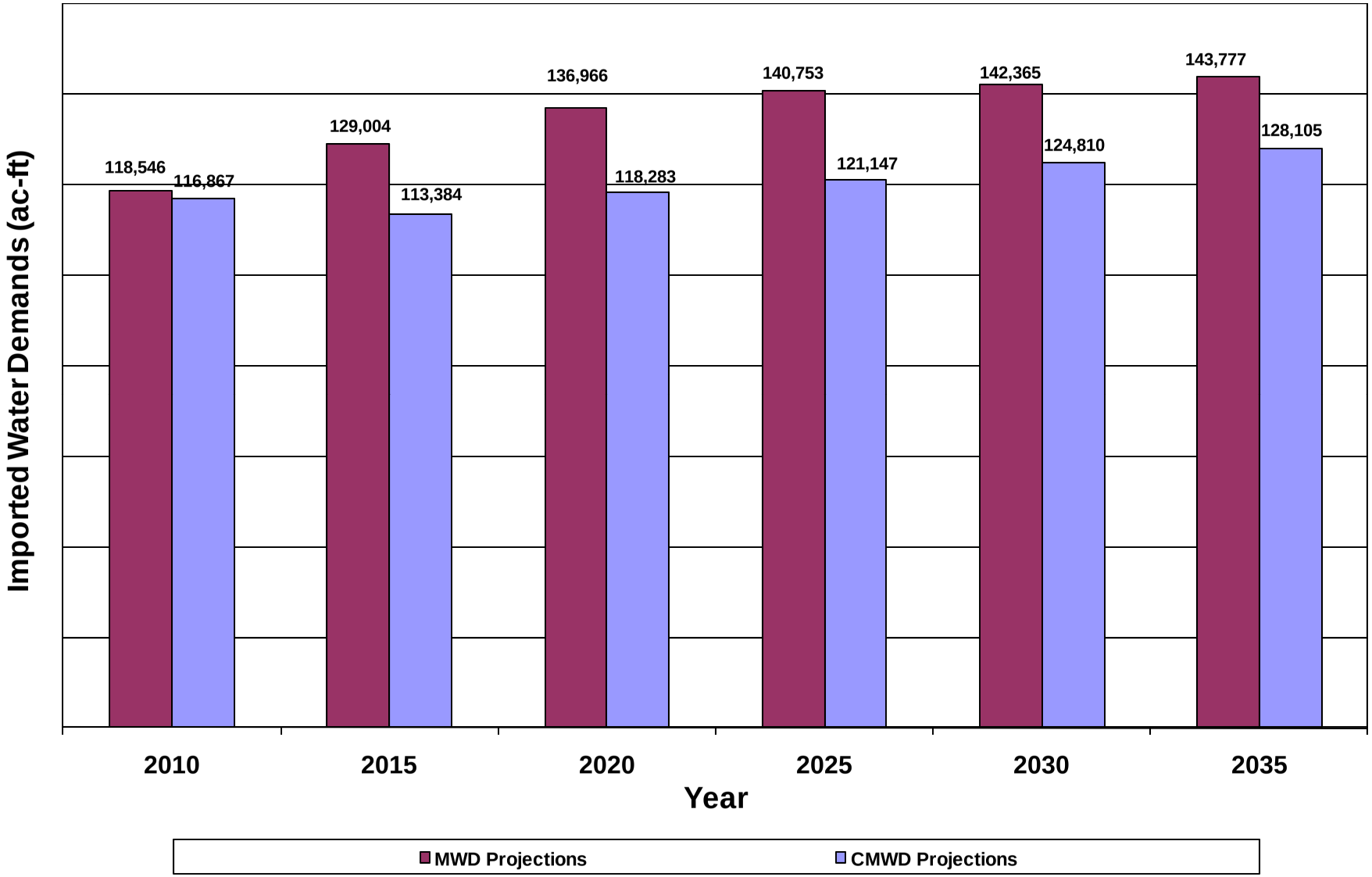

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CMWD 2010 Urban Water Management Plan

Imported Water Demand Projections for Average Year Conditions

Figure 3-2

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Table 3-6
MWD's Imported Demand Projections for Dry Year Conditions

Parameter	Volume (ac-ft per year)					
	2010 (1)	2015	2020	2025	2030	2035
t	1 1 2	1 0	1	1 1 12	1 0	1
	0		2			1 2
t	121 1	1 1	1	1 1	1	1 01

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Table 3-7
CMWD's Imported Demand Projections for Dry Year Conditions

Parameter	Volume (ac-ft per year)					
	2010 (1)	2015	2020	2025	2030	2035
t	1	1 0	1	1	20	211
	11		1 11	2 0	2	10
t	120	11 2	12 1	12	1 1	1 2

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Table 3-8
MWD's Imported Demand Projections for Multiple Dry Year Conditions

Parameter	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
t	-	1 1 0	1	1 2	1	200 1
	-			0	0	1 0
t	-	1 1 10	1	1 2	1	1

Table 3-9
CMWD's Imported Demand Projections for Multiple Dry Year Conditions

Parameter	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
t	-	1	1 0	1	20	210 20
	-	0 01				
t	-	12	12 1	1 2	1 22	1 2 1

3. Comparison of Imported Demand Projections

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Table 3-10
Comparison of Imported Water Demand Projections for Average Year Conditions

Year	MWD	CMWD	2006 Master Plan [1]
2010	11	11	120 2
201	12 00	11	12 01
2020	1	11 2	1 0
202	1 0	121 1	1 2
20 0	1 2	12 10	1 2 21
20	1	12 10	1 0 0

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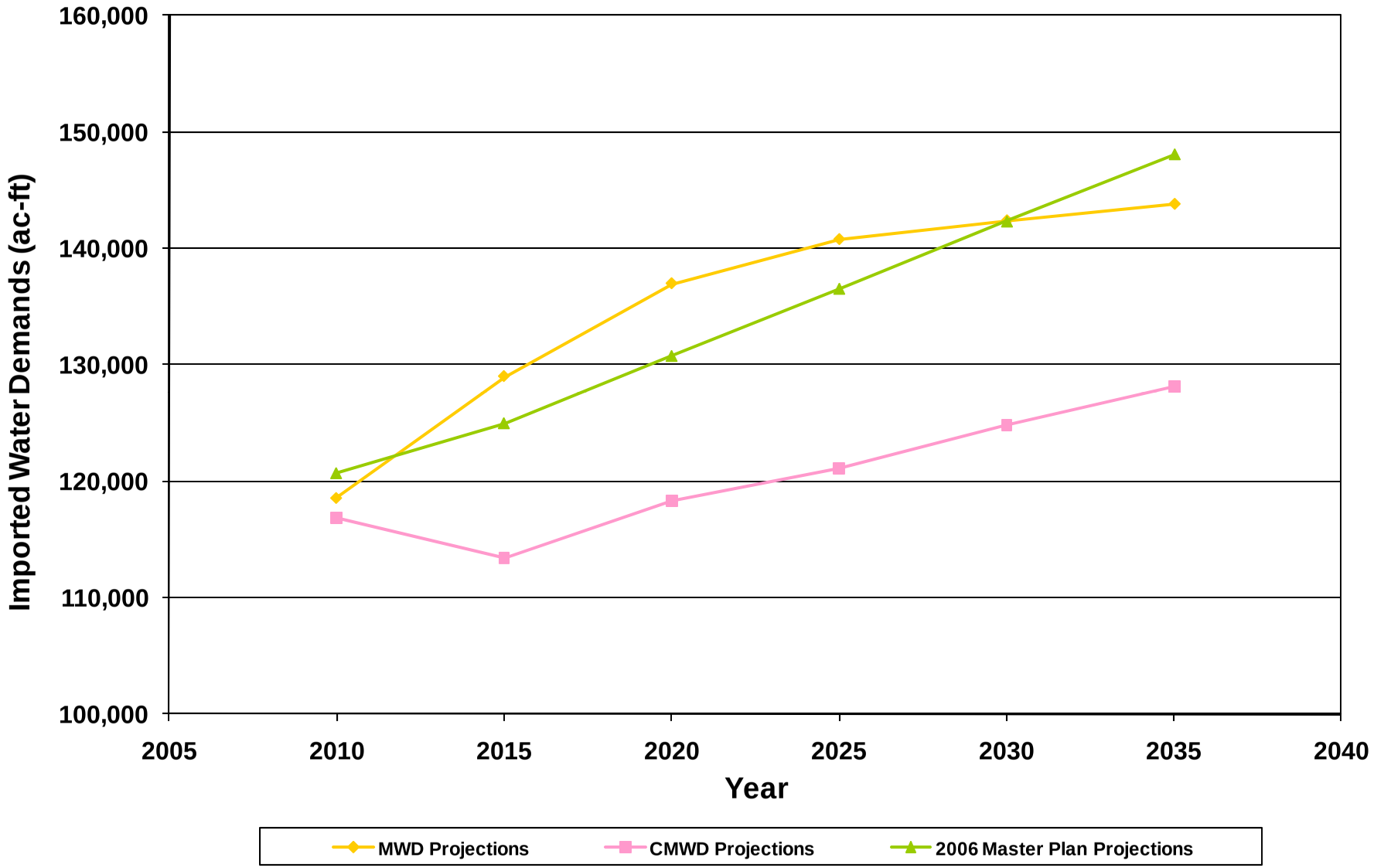

CALLEGUAS MUNICIPAL WATER DISTRICT

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CMWD 2010 Urban Water Management Plan

Comparison of CMWD Imported Water Demand Projections for Average Year Conditions

Figure 3-3

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Chapter 4
Water Demand Management

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A. Demand Management Measures

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Table 4-1
CUWCC Demand Management Program BMP Naming Changes

Old BMP Names and Number	New BMP Category
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12 ti i t	ti ti it ti
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B. CMWD Conservation Programs

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1. Water Loss Control (Formerly BMP-03)

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2. Public Information Programs (Formerly BMP-07)

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3. School Education Programs (Formerly BMP-08)

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4. Wholesale Agency Assistance Programs (Formerly BMP-10)

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5. Conservation Coordinator (Formerly BMP-12)

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C. Effectiveness of Conservation Measures

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D. Water Reduction Target

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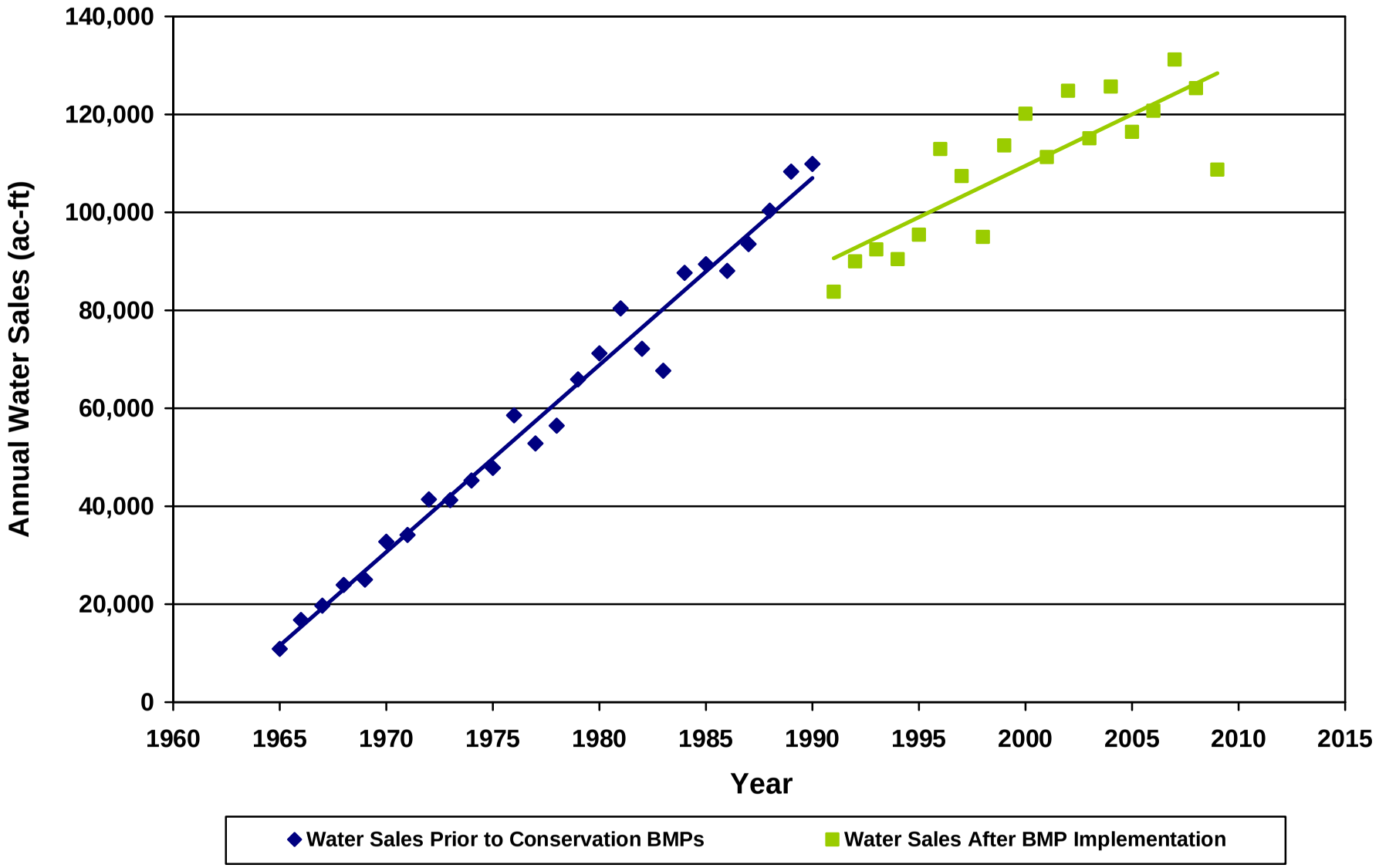

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CMWD 2010 Urban Water Management Plan

CMWD Historical Water Sales

Figure 4-1

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Table 4-2
High-Level Analysis of 20x2020 Compliance in CMWD Service Area [(1)]

Compliance Component	Value
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2020 t t	1 2 - t
2020 t	1 0 - t
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Chapter 5
Reliability Planning

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A. Supply versus Demand Evaluation

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1. Average Year Hydrologic Conditions

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Table 5-1
CMWD Supply versus Demand for Average Year Conditions

Parameter	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
	1 1	1 1	1	1 2 121	1 1	202 1 0
	0		0 0	0		0
t	11	11	11 2	121 1	12 10	12 10
i b i	11	12 00	1	1 0	1 2	1
i it	1	1	1	1	1	12

2. Single Dry Year Hydrologic Conditions

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Table 5-2
CMWD Supply versus Demand for Dry Year Conditions

Parameter	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
	1	1 0	1	1	20	211
	11		1 11	2 0	2	10
t	120	11 2	12 1	12	1 1	1 2
ti	112 0 2 [1]	1 1	1	1 1	1	1 01
i it	- [2]	11	1	1	10	

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3. Multiple Dry Year Hydrologic Conditions

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Table 5-3
CMWD Supply versus Demand for Multiple Dry Year Conditions

Parameter	Volume (ac-ft per year)					
	2010	2015	2020	2025	2030	2035
ti	1 2	1	1 0	1	20	210 20
ti		0 01				
t	122 2	12	12 1	1 2	1 22	1 2 1
i b i [1]	-	1 1 10	1	1 2	1	1
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B. Supply Reliability Strategies

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1. DWR Strategies

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2. MWD Strategies

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3. CMWD Strategies

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a. CMWD Stored Groundwater

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b. Lake Bard and Lake Bard Water Treatment Plant

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c. Salinity Management Project

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d. Transfer Opportunities

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Chapter 6
Contingency Planning

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A. Severe Drought Planning

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Table 6-1
MWD Resource Conditions and Action Stages

Resource Stage	Action
	i i i
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h t 1	ti i i i
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1. CMWD Water Shortage Stages of Action

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Table 6-2
CMWD Water Shortage Stages of Action Guidelines

Resource Stage	Actions [1]
	t t i t b i th h t i
	ti i [2]
t 1 h t	t xi i i t t ti
t 2 h t	i ith t t
t h t	xt i ti t
t h t	t ti

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[2] i i i i t i i i it ti ti x i

2. Three-Year Minimum Supply Evaluation

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Table 6-3
Estimated Three-Year Minimum Supply (2010 – 2015)

Parameter	Volume (ac-ft per year)			
	2010 Average Year	2011 Multiple-Dry Year	2012 Multiple Dry Year	2013 Multiple-Dry Year
t i [1]	11	10 00	10 00	10 00
i [2]	0			
t i t	1	1 0	1 0	1 0
t	1 1	1 1	1 0 2	1 2 0
i it	1	-	-10	-10

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Table 6-4
Estimated Three-Year Minimum Supply (2015 – 2020)

Parameter	Volume (ac-ft per year)			
	2015 Average Year	2016 Multiple Dry Year	2017 Multiple Dry Year	2018 Multiple Dry Year
t i [1]	12 00	1 2 0	1	1
i [2]		0 01	0 01	0 01
t i t	1	1 1 1	1	1
t	1 1	1	1 12	1 0 0
i it				

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Table 6-5
Estimated Three-Year Minimum Supply (2020 – 2025)

Parameter	Volume (ac-ft per year)			
	2020 Average Year	2021 Multiple Dry Year	2022 Multiple-Dry Year	2023 Multiple-Dry Year
t i [1]	1	1 1 0	1 2 0	1 1
i [2]	0 0			
t i t	20 0	20 2	20 2	20
t	1	1 1	1	1 01
i it	10			

[1] i i t t 2020 202 t t

[2] t b ht i b t 2021 202

Table 6-6
Estimated Three-Year Minimum Supply (2025 – 2030)

Parameter	Volume (ac-ft per year)			
	2025 Average Year	2026 Multiple Dry Year	2027 Multiple Dry Year	2028 Multiple Dry Year
t i [1]	1 0	1 1	1 1	1 22
i [2]	0			
t i t	211 2	211 0	212	21 022
t	1 2 121	1	201 2 1	202 12
i it	10			

[1] i i t t 202 20 0 t t

[2] t b ht i b t 202 202

Table 6-7
Estimated Three-Year Minimum Supply (2030 – 2035)

Parameter	Volume (ac-ft per year)			
	2030 Average Year	2031 Multiple Dry Year	2032 Multiple Dry Year	2033 Multiple Dry Year
t i [1]	1 2	1	1	1 1
i [2]				
t i t	21 1	21 0	21 0	21 1
t	1 1	20	20 1	20
i it				

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B. Catastrophe Planning

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1. MWD Catastrophe Plan

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2. CMWD Catastrophe Strategies

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Table 6-8
Strategies for Meeting 2015 Average Year Demands
During Interruptions of MWD Deliveries

Source of Supply	Short-Term MWD Interruption [(1)] (cfs)	Long-Term MWD Interruption [(2)] (ac-ft per year)
	0	0
	100	000
t t	0	0 000
iti	0	10 0
t	1 0	0
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3. CMWD Emergency Pipeline Repair Protocol

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C. Water Quality Contingency Planning

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1. MWD Water Quality Contingency Planning

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2. CMWD Water Quality Contingency Planning

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D. Provisions to Reduce Water Consumption

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1. Guidelines for Meeting Reduced Consumption Mandates

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2. Monitoring and Enforcing Reduced Consumption Mandates

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3. Fiscal Impacts from Reduced Water Deliveries

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Appendix A
UWMP Checklist

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Urban Water Management Plan Checklist				
No.	**UWMP Requirement**	**California Water Code Reference**	**UWMP Location**	**Additional Comments**
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Appendix B
FCGMA Documentation

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Fox Canyon Groundwater Management Agency
Ordinance Code

Adopted July 27, 2005
Amended July 28, 2010

CHAPTER 1.0
Definitions

As used in this code, the following terms shall have the meanings stated below:

1.1. **"Actual Applied Water"** – means the total water applied by the grower to the crop over the course of a calendar year without regard to the water source. Examples of actual applied water include the sum of well water, water delivered from a water supplier, and or from surface water diversions. Total applied water does not include precipitation.

1.2. **"Agency"** means the Fox Canyon Groundwater Management Agency.

1.3. **"Agency Boundary"** shall be as depicted on the map adopted by the Board and recorded as an official record with the County Recorder's Office on January 14, 2002 (Document No. 2002-0009215), and as may be adjusted as provided in the Agency's enabling legislation.

1.4. **"Agricultural Extraction Facility"** means a facility from which the groundwater produced is used on lands in the production of plant crops or livestock for market, and uses incidental thereto.

1.5. **"Annual"** means the calendar year January 1 through December 31.

1.6. **"Aquifer"** means a geologic formation or structure that yields water in sufficient quantities to supply pumping wells or springs. A confined aquifer is an aquifer with an overlying less permeable or impermeable layer.

1.7. **"Board"** means the Board of Directors of the Fox Canyon Groundwater Management Agency.

1.8. **"County"** means the County of Ventura.

1.9. **"Developed Acreage"** means that portion of a parcel within the Agency Boundary that is receiving water for reasonable and beneficial agricultural, domestic or municipal and industrial (M & I) use.

1.10. **"East Las Posas Basin"** That part of the former North Las Posas Basin that is east of the subsurface anomaly described by significant changes in groundwater levels, as described in the Groundwater Management Plan and located for record purposes on maps as provided in Section 1.20.

1.11. **"Excess Extraction"** means those extractions in excess of an operator's extraction allocation or adjusted extraction allocation.

1.12. **"Executive Officer"** means the individual appointed by the Board to administer Agency functions, or his/her designee.

1.13. **"Exempt Well Operators"** means all well operators operating extraction facilities supplying a single family dwelling on one acre or less, with no income producing operations and those operators granted an exemption by the Board.

1.14. **"Expansion Area"** means that portion of land beyond the outer limits of the Agency Boundary in the West, East, and South Las Posas Basins that lies between the Agency Boundary and the crest of the hill or 1.5 miles beyond the Agency Boundary as defined by Map Number Two, entitled Fox Canyon Outcrop, Las Posas Basin, 1995. .

1.15. **"Extraction"** means the act of obtaining groundwater by pumping or other controlled means.

1.16. **"Extraction Allocation"** means the amount of groundwater that may be obtained from an extraction facility during a given calendar year, before a surcharge is imposed.

1.17. **"Extraction Facility"** means any device or method (e.g. water well) for extraction of groundwater within a groundwater basin or aquifer.

1.18. **"Foreign Water"** means water imported to the County through the State Water Project facilities or other newly available water as approved by the Board, such as recycled water that would otherwise be lost to the Ocean.

1.19. **"Groundwater"** means water beneath the surface of the earth within the zone below the water table in which the soil is completely saturated with water.

1.20. **"Groundwater Basin"** means a geologically and hydrologically defined area containing one or more aquifers, which store and transmit water yielding significant quantities of water to wells. For the purposes of this Ordinance Code, groundwater basins that of which either all or a portion or portions thereof are located within the Agency Boundary include, but are not limited to the Oxnard Plain Forebay Basin, Oxnard Plain Pressure Basin, Pleasant Valley Basin, East Las Posas Basin, West Las Posas Basin, South Las Posas Basin and the Arroyo Santa Rosa Basin, as described in the Groundwater Management Plan. The boundaries of these basins are shown on maps that shall be adopted by a Resolution. Groundwater basin boundaries may be modified by a Resolution.

1.21. **"Groundwater Management Plan"** means the 2007 Update to the Fox Canyon Groundwater Management Plan or Board-adopted updates to this plan.

1.22. **"Historical Extraction"** means the average annual groundwater extraction based on the five (5) calendar years of reported extractions from 1985 through 1989 within the Agency Boundary. This average will be expressed in acre-feet per year. All historical extraction allocations became effective on January 1, 1991.

1.23. **"Inactive Well"** An inactive well is a well that conforms to the County Water Well Ordinance requirements for an active well, but is being held in an idle status in case of future need. Idle status means the well is pumped no more than 8 hours during any 12-month period. Inactive wells are not required to have a flowmeter. Pumping to maintain status as an active well under the County Water Well Ordinance shall not exceed 8 hours in a 12 month period, shall be for beneficial use, and shall be estimated and reported to the Agency. Prior to removing a well from idle status, the operator shall install a flowmeter in accordance with the requirements in Chapter 3 of the Ordinance Code.

1.24. **"Injection/Storage Program"** means any device or method for injection/storage of water into a groundwater basin or aquifer within the Agency Boundary, including a program to supply foreign water in lieu of pumping.

1.25. **"Las Posas Outcrop"** or **"Outcrop"** means the area of Lower Aquifer System surface exposure as defined by Map Number One, Fox Canyon Outcrop, Las Posas Basin, 1982.

1.26. **"May"** as used in this Ordinance Code, permits action but does not require it.

1.27. **"Flowmeter"** means a manufactured instrument for accurately measuring and recording the flow of water in a pipeline.

1.28. **"Municipal and Industrial (M & I) Provider"** means person who provides water for domestic, industrial, commercial, or fire protection purposes within the Agency Boundary.

1.29. **"Municipal and Industrial (M & I) Operator"** An owner or operator that supplied groundwater for M & I use during the historical allocation period and did not supply a significant amount of agricultural irrigation during the historical period."

1.30. **"Municipal and Industrial (M & I) User"** means a person or other entity that used or uses water for any purpose other than agricultural irrigation.

1.31. **"Municipal and Industrial (M & I) Use"** means any use other than agricultural irrigation.

1.32. **"Non-Operating Flowmeter"** – A non-operating flowmeter includes a flowmeter that is out of calibration by plus or minus 5%, and/or a flowmeter that has not been calibrated within the flowmeter calibration schedule adopted by the Board.

1.33. **"Operator"** means a person who operates a groundwater extraction facility. In the event the Agency is unable to determine who operates a particular extraction facility, then "operator" shall mean the person to whom the extraction facility is assessed by the County Assessor, or, if not separately assessed, the person who owns the land upon which the extraction facility is located.

1.34. **"Ordinance Code"** means the Fox Canyon Groundwater Management Agency Ordinance Code.

1.35. **"Overdraft"** means the condition of a groundwater basin or aquifer where the average annual amount of water extracted exceeds the average annual supply of water to a basin or aquifer.

1.36. **"Owner"** means a person who owns a groundwater extraction facility. Ownership shall be determined by reference to whom the extraction facility is assessed by the County Assessor, or if not separately assessed, the person who owns the land upon which the extraction facility is located.

1.37. **"Perched"** or **"Semi-Perched Aquifer"** means the shallow, unconfined aquifer that overlies the Oxnard Aquifer in Sealing Zone III, as described in the California Department of Water Resources Bulletin No. 74-9.

1.38. **"Person"** includes any state or local governmental agency, private corporation, firm, partnership, individual, group of individuals, or, to the extent authorized by law, any federal agency.

1.39. **"Recharge"** means natural or artificial replenishment of groundwater in storage by percolation or injection of one or more sources of water.

1.40. **"Resolution"** means a formal statement of a decision adopted by the Board.

1.41. **"Safe Yield"** means the condition of groundwater basin when the total average annual groundwater extractions are equal to or less than total average annual groundwater recharge, either naturally or artificially.

1.42. **"Section"** as used in this Ordinance Code, is a numbered paragraph of a chapter.

1.43. **"Semi-Annual Groundwater Extraction Statement"** is a form filed by each operator containing the information required by Section 2.2 and 2.3.1 and shall cover the periods from January 1 to June 30 and from July 1 to December 31 annually.

1.44. **"Shall"** as used in this Ordinance Code, is an imperative requirement.

1.45. **"Well Flushing"** means the act of temporarily discharging extracted groundwater through a connection located upstream of the water distribution system at the beginning of an extraction cycle. Well flushing is typically performed until the quality of the extracted water is suitable for beneficial use and/or will not damage the distribution system. In some cases, the flushing flows may be discharged upstream of the distribution system, including the flowmeter. Flushing flows discharged upstream of the flowmeter shall be estimated and reported to the Agency in accordance with the requirements accordance with the requirements in Chapter 2 of the Ordinance Code.

1.46. **"Well Rehabilitation"** means the act of restoring a well to its most efficient condition by various treatments, development, or reconstruction methods. In most cases, groundwater extracted during well rehabilitation is not discharged through the extraction facility piping and, consequently, is not flowmetered. In these cases, the volume of water extracted shall be estimated and reported to the Agency in accordance with the requirements accordance in Chapter 2 of the Ordinance Code.

1.47. **"West Las Posas Basin"** is that part of the former North Las Posas Basin that is west of the subsurface anomaly described by significant changes in groundwater levels, as

described in the Groundwater Management Plan and located for record purposes on maps as provided in Section 1.20.

CHAPTER 2.0
Registration of Wells and Levying of Charges

2.1. Registration of Wells

2.1.1. Agency Water Well Permit Requirement (No-Fee Permit) – All new extraction facilities constructed within the Agency Boundary shall obtain a no-fee permit from the Agency prior to the issuance of a well permit by the County.

2.1.2. Registration Requirement – All groundwater extraction facilities within the boundaries of the Agency shall be registered with the Agency within 30 days of the completion of drilling activities or within 30 days after notice is given to the operator of such facility. No extraction facility may be operated or otherwise utilized so as to extract groundwater within the Agency Boundary unless that facility is registered with the Agency, flowmetered and permitted, if required, and all extractions reported to the Agency as required. The operator of an extraction facility shall register his extraction facility and provide in full, the information required to complete the form provided by the Agency that includes the following:

2.1.2.1. Name and address of the operator(s).

2.1.2.2. Name and address of the owner(s) of the land upon which the extraction facility is located.

2.1.2.3. A description of the equipment associated with the extraction facility.

2.1.2.4. Location, parcel number and state well number of the water extraction facility.

2.2. **Change in Owner or Operator** - The name of the owner of each extraction facility, the parcel number on which the well is located along with the names of all operators for each extraction facility shall be reported to the Agency within 30 days upon any change of ownership or operators, together with such other information required by the Executive Officer.

2.3. **Reporting Extractions** - All extractions shall be reported to the Agency. All extractions shall be flowmetered in accordance with the requirements and methods for flowmetering extractions as specified by Chapter 3. In cases where flowmetering is not required, the volume of water extracted shall be estimated and reported to Agency. The Agency shall send a “Semi-Annual Groundwater Extraction Statement” form to each well operator on or about the first week of January and the first week of July each year. Each operator of a registered extraction facility shall enter the necessary information and return the “Semi-Annual Groundwater Extraction Statement” covering all wells they operate on or before the due date. Statements are due on or before February 1st or August 1st annually or thirty days after the date of the letter requesting submittal of the Semi-Annual Statement

for the given period. Statements shall contain the following information on forms provided by the Agency:

2.3.1. The information required under Section 2.1.2 above.

2.3.2. The method of measuring or computing groundwater extractions.

2.3.3. The crop types or other uses and the acreage served by the extraction facility.

2.3.4. Total extractions from each extraction facility in acre-feet for the proceeding six (6) month period.

2.4. **Groundwater Extraction Charges**

2.4.1. All persons operating groundwater extraction facilities shall pay a groundwater extraction charge for all groundwater extracted after July 1, 1993, in the amount as established by Resolution. Payments are due semi-annually, and shall accompany the statement required pursuant to Section 2.3.

2.4.2. Payments are due forty-five (45) days after the billing date, and payments not received or postmarked by such date due shall be charged interest from and after such date due until payment thereof at the rate of 1.5 percent per month, or part of month that the charge remains unpaid. Late Penalty. The operator shall pay a late penalty for any extraction charge not satisfied by the due and payable date. The late penalty shall be 1½ percent per month, or any portion thereof, of the amount of the unsatisfied extraction charge. The late penalty shall not exceed 100% of the original charge, provided the penalty is paid within 60 days of the due date. If the fee is not paid within the 60 days, the penalty will continue to accrue at 1.5 percent per month with a final maximum of 200% of the original penalty due.

2.4.3. Owners of extraction facilities are ultimately responsible for payment of pumping charges and penalties should an operator not pay. Consequently, owners are charged with providing for this liability in agreements entered into with well operators and water users.

2.5. **Collection of Delinquent Extraction Charges and Late Penalties** - The Board may order that any given extraction charge and/or late penalty shall be a personal obligation of the operator or shall be an assessment against the property on which the extraction facility is located. Such assessment constitutes a lien upon the property, which lien attaches upon recordation in the office of the County Recorder. The assessment may be collected at the same time and in the same manner as ordinary ad valorem taxes are collected, and shall be subject to the same penalties and the same procedure and sale, in case of delinquency as provided for such taxes. All laws applicable to the levy, collection and enforcement of ad valorem taxes shall be applicable to such assessment, except that if any real property to which such lien would attach has been transferred or conveyed to a bona fide purchaser for value, or if a lien of a bona fide encumbrance for value has been created and attaches thereon, prior to the date on which the first installment of such taxes would become delinquent, then the lien which would otherwise

be imposed by this section shall not attach to such real property and an assessment relating to such property shall be transferred to the unsecured roll for collection.

2.6. **Use of Extraction Charges and Late Penalties** - Revenues generated from extraction charges and late penalties shall be used exclusively for authorized Agency purposes, including financial assistance to support Board approved water supply, conservation, monitoring programs and water reclamation projects that demonstrate significant reductions in overdraft.

CHAPTER 3.0
Installation and Use of Flowmeters for Groundwater Extraction Facilities

3.1. Installation and Use of Flowmeters

3.1.1. Installation Requirement - Prior to extracting groundwater, the operator shall install a flowmeter. With the exception of connections used for well flushing and extraction facilities used by multiple operators, flowmeters shall be installed upstream of all connections to the main discharge line. Flowmetering is not required during well flushing and well rehabilitation; however, the volume of water extracted shall be estimated and reported to the Agency. Flowmeters are not required on inactive wells as defined in this Ordinance Code, nor are flowmeters required for extraction facilities supplying a single family dwelling on one acre or less, with no income producing operations. If more than one operator uses the same extraction facility, flowmeters shall be installed to record the water use of each operator. Well operators were required to install flowmeters on wells by July 1, 1994.

3.1.2. Flowmeter Failure and Back-up Measurement Requirements - Flowmeters occasionally fail, losing periods of record before the disabled or inaccurate meter is either replaced or repaired. When a flowmeter fails, the operator shall repair or replace the flowmeter within the timeframe specified in a separate Resolution. Flowmeter failures and associated repairs or replacements shall be reported to the Agency together with any other information required by the Executive Officer on or before the due date of the next Semi-Annual Groundwater Extraction Statement. Well operators shall be prepared to provide another acceptable method of computing extractions during these periods of flowmeter failure to avoid the loss of record on wells that require flowmetering under this Ordinance Code.

3.1.3. Back-up Methods - It is the operator's responsibility to maintain the flowmeter. Any allowable or acceptable backup measurement methods will be specified in a separate Resolution and may be changed as technology improves or changes.

3.1.4. Flowmeter Readings - Functional flowmeters shall be read and the readings reported semi-annually on the extraction statements required under Section 2.3 above.

3.1.5. Inspection of Flowmeters - The Agency may inspect flowmeter installations for compliance with this Ordinance Code at any reasonable time.

3.2. **Flowmeter Testing and Calibration** - All flowmeters shall be tested for accuracy at a frequency interval determined by the Board to meet specific measurement standards. Calibration methods and procedures approved by the Board shall be detailed in an adopted Resolution.

3.3. **Altering Flowmeters** - Any person who alters, removes, resets, adjusts, manipulates, obstructs, or in any manner interferes or tampers with any flowmeter affixed to any groundwater extraction facility required by this Ordinance Code, resulting in said flowmeter to improperly or inaccurately measure and record groundwater extractions, is guilty of an intentional violation of this Ordinance Code and will be subject to any and all penalties as described in Chapter 8.

3.4. **Costs of Testing and Calibration** - All costs incurred with flowmeter testing or calibration shall be the personal obligation of the well owner. Non-compliance with any provision of the flowmeter calibration requirements will subject the owner to financial penalties and/or liens as described below or in Chapter 8 of the Ordinance Code.

3.5. **Fees and Enforcement** - If any water production facility within the Agency's boundaries is used to produce water without a flowmeter or with a non-operating flowmeter in excess of the allowable timeframe specified in a separate Resolution, the Agency shall assess a Non-Metered Water Use Fee against the water production facility owner. The amount of the fee shall be calculated as follows:

3.5.1 Groundwater extraction facilities - The fee shall be equal to double the current groundwater extraction charge for all estimated water used. Estimates of water used shall be calculated by the operator and approved by the Executive Officer. Any delinquent extraction charge obligations shall also be charged interest at the rate of 1.5 percent per month on any unpaid balances.

3.6. Upon violation of any flowmeter provision, the Agency may, as allowed by law, petition the Superior Court of the County for a temporary restraining order or preliminary or permanent injunction prohibiting the well owner from operating the facility or for such other injunctive relief as may be appropriate.

CHAPTER 4.0
Protection of the Las Posas Basins

4.1. **This chapter has the following purpose and intent:**

4.1.1. To eliminate overdraft from the aquifer systems within the boundary of the East and West Las Posas basins and bring these basins to a “safe yield” condition by the year 2010.

4.1.2. To protect the Las Posas outcrop as a source of groundwater recharge into the East and West Las Posas basins.

4.1.3. To prevent groundwater quality degradation of the East and West Las Posas basins by influence from the Expansion area.

4.1.4. This Ordinance Code is only one means by which these goals will be met.

4.2. Anti-degradation and Extraction Prohibition

4.2.1. Extraction Facility Permits.

4.2.1.1. Permit Required - Prior to: (a) initiating any new or increased use of groundwater in the Expansion area, obtained from any source within the Agency including the Expansion area; or (b) constructing a new or replacement extraction facility in the East or West Las Posas basins, or the Expansion area, a permit must be obtained from the Agency as provided in this Chapter. For the purpose of this Chapter, a new or increased use is that which did not exist or occur before June 30, 1988.

4.2.1.2. Permit Application - Application shall be made to the Agency on the approved County Water Well Ordinance form available from the County Public Works Agency and shall include all information required by the County Well Ordinance and the following:

4.2.1.2.1. Location of each water well to be used, along with the associated state well number.

4.2.1.2.2. Location(s) of groundwater use, including acreage accurately plotted on copy of the County Assessor's Parcel Map.

4.2.1.2.3. The proposed crop type(s) or Municipal and Industrial use(s) at each location.

4.2.1.2.4. A brief description of the type of irrigation or distribution system and flowmeter to be used.

4.2.1.2.5. The estimated average annual quantity of water use proposed for each location of use.

4.2.1.2.6. An identification of the source of historical allocation to supply the proposed water use by the well.

4.2.1.2.7. An analysis of the potential impacts on the water balance in the Las Posas Basins resulting from the proposed use(s).

4.2.1.3. Findings - A permit may only be granted if the Executive Officer finds that the proposed groundwater use will result in no net detriment to the East or West Las Posas Basins by determining that:

4.2.1.3.1. The Las Posas outcrop is not exposed to potential degradation of water quality of any type, and

4.2.1.3.2. Recharge to the East and West Las Posas Basins from the Las Posas outcrop is not diminished, and

4.2.1.3.3. Neither baseline nor efficiency allocation will be used, directly or indirectly, to support groundwater use on the Expansion Area, and (an example of indirect use is using efficiency to supply a demand inside the Agency and using the replaced historical allocation on the outcrop)

4.2.1.3.4. No increased or new uses of groundwater from inside the Agency Boundary will be applied on any area outside the Expansion area (or outside the East or West Las Posas boundary).

4.2.1.4. Permit Conditions. The Executive Officer may include in the permit granted, any conditions consistent with the purpose of this Chapter, including:

4.2.1.4.1. Any proposed agricultural use shall include the installation of irrigation systems that employ irrigation best management practices consistent with then current industry standards.

4.2.1.4.2. Any proposed municipal or industrial use shall include the installation of systems that employ municipal and industrial best management practices consistent with the then current industry standards.

4.2.1.4.3. A permit term, not to exceed 10 years from the date of issuance.

4.2.1.4.4. Mitigation, monitoring, and periodic reporting, as may be appropriate given the proposed use.

4.2.2. Permit Renewal - Permits may be renewed pursuant to the requirements of Section 4.2.1.

4.3. **Registration of Existing Uses** - The owners of groundwater wells located within the East or West Las Posas basins shall register their wells with the Agency no later than January 1, 2006, through the following procedure:

4.3.1. Registration Form - The Agency shall make available a registration form which shall be completed, and filed with the Agency for each well, which shall include the following:

4.3.1.1. Location(s) of all water well(s), along with the associated state well number(s) including offsite well(s) serving the proposed use. Information concerning wells shall also include any other use for the water well.

4.3.1.2. Location(s) of groundwater use for the well including acreage accurately plotted on a copy of the County Assessor's Parcel Map.

4.3.1.3. The proposed crop type(s) or Municipal and Industrial use(s) at each location.

4.3.1.4. A brief description of the type of irrigation or distribution system and flowmeter in use.

4.3.1.5. The estimated average annual quantity of water use at each location and for each well.

4.4. **Monitoring** - The Agency shall monitor compliance with this Chapter by reviewing County well permit applications and reported groundwater extractions and by conducting field surveys as may be necessary.

4.5 **Unreasonable Uses** - The Agency may commence and prosecute legal actions to enjoin unreasonable uses or methods of use of water within or without the Agency Boundary to the extent those uses or methods of use adversely affect the groundwater supply within the Agency Boundary.

CHAPTER 5.0
Reduction of Groundwater Extractions

5.1. **Purpose** - The purpose of this Chapter is to eliminate overdraft from the aquifer systems within the boundaries of the Agency and bring the groundwater basins to safe yield by the year 2010. It is not the purpose of this Chapter to determine or allocate water right entitlements, including those, which may be asserted pursuant to California Water Code sections 1005.1, 1005.2 or 1005.4.

5.2. **Extraction Allocations**

5.2.1. General Limitations

5.2.1.1. The Executive Officer shall establish an operator's extraction allocation for each extraction facility located within the Agency Boundary. The extraction allocation shall be the historical extraction as reported to the United Water Conservation District and/or to the Agency pursuant to Chapter 2 (or its successor), reduced as provided by Section 5.4, or as otherwise provided for in Section 5.6 of this Ordinance Code. An alternative allocation, either baseline or efficiency, may also be approved as explained in Sections 5.6.1.1 and 5.6.1.2. All extraction facilities have an allocation of zero unless the Executive Officer

determines otherwise. The operator may determine whether the annual allocation used shall be either a combination of baseline and historical allocation, or based on an efficiency allocation. All wells used by an operator in any given basin shall be operated on either a combination of historical and baseline or an efficiency allocation except water purveyors as approved by the Executive Officer. As explained by Section 5.6.1.2, an efficiency allocation may not be combined with either a baseline or a historical allocation. Extraction allocations may be adjusted or transferred only as provided in Section 5.3.

5.2.1.2. Regardless of allocation, the total water use for agricultural purposes must be at least 60 percent efficient as determined by the formula described in Section 5.6.1.2.4. This 60 percent irrigation efficiency is totally unrelated to the 80 percent efficiency described in Section 5.6.1.2, “Annual Efficiency Extraction Allocation”.

5.2.1.3. Where an operator operates more than one extraction facility in the same basin, the extraction allocations for the individual facilities may be combined.

5.2.1.4. Where there is more than one operator for any agricultural extraction facility, each operator shall be entitled to a pro rata share of the facility's historical allocation based on either usage or acreage irrigated during the historical extraction period. Such pro rata shares shall be determined by the owner of the extraction facility, and this determination shall be subject to the approval of the Executive Officer.

5.2.1.5. When an operator is no longer entitled to use an extraction facility, that operator is no longer entitled to any portion of the extraction allocation attributed to that extraction facility.

5.2.1.6. A historical allocation is assigned to an extraction facility and a baseline allocation is assigned to the land, both may be used, but neither is owned by the operator.

5.2.1.7. Where there is a sale or transfer of a part of the acreage served by any extraction facility, the extraction allocation for that facility shall be equitably apportioned between the real property retained and the real property transferred by the owner of the extraction facility, This apportionment shall be approved by the Executive Officer who may modify the apportionment to assure equity.

5.2.1.8. The name of the owner of each extraction facility, the parcel number on which the well is located along with the names of all operators for each extraction facility shall be reported to the Agency with each semi-annual statement and within 30 days of any change of ownership or operators, together with such other information required by the Executive Officer.

5.2.1.9. The Executive Officer may, on written request from a land owner or well operator, waive allocation requirements for the extraction of groundwater from the Perched or Semi-perched aquifer of Sealing Zone III when the pumping of that groundwater is specifically for the purpose of lowering the water table to reduce the high water table threat to property, including the root zone of crops, or for dewatering construction sites. The Executive Officer shall require that the groundwater extraction facility used for this purpose be perforated only in the Perched or Semi-perched zone, and shall also require the landowner and/or the operator to protect the Agency from damage potentially caused by transferring water to another location.

5.2.2. General Limitations: Special Board Approval Requirements - Notwithstanding any other provisions of this Ordinance Code, the following uses of water resources associated with the aquifers within the Agency may only be undertaken with prior Board approval of and subject to the conditions and restrictions established by the Board.

5.2.2.1. Direct or indirect export of groundwater extracted from within the Agency Boundary for use outside the Agency Boundary.

5.2.2.2. The direct or indirect use of surface water or Foreign Water from within the Agency outside the Agency in a manner that may adversely affect the groundwater supply within the Agency.

5.2.2.3. Application to the Board - To obtain the approval of the Board for any use provided in Sections 5.2.2.1 and 5.2.2.2, application shall be made to the Agency describing the details of the proposed use, including all the following information:

5.2.2.3.1. The location of each water well to be used, along with the associated state well number, and/or the location of each surface diversion and a description of the associated water right.

5.2.2.3.2. Location(s) of groundwater use, including acreage, accurately plotted on copy of the County Assessor's Parcel Map.

5.2.2.3.3. The proposed crop type(s) or Municipal and Industrial use(s) at each location.

5.2.2.3.4. A brief description of the type of irrigation or distribution system and flowmeter to be used.

5.2.2.3.5. The estimated average annual quantity of water use proposed for each location of use.

5.2.2.3.6. An identification of the source of historical allocation, if any, to supply the proposed water use by the well.

5.2.2.3.7. An analysis of the potential impacts on the water balance in any Basin or Subbasin within the Agency Boundaries resulting from the proposed use(s).

5.2.2.4. Findings - The Board may approve the proposed use if, after a public hearing, it finds that the proposed use will result in no net detriment to the Basin, or any subbasin, or aquifer associated with the use, by determining that:

5.2.2.4.1. The proposed use does not result in the material degradation of water quality of any type, or

5.2.2.4.2. Recharge to any aquifer within the Agency is not materially diminished.

5.2.2.4.3. In granting approval to projects subject to this subsection, the Board may impose any conditions as may be appropriate, including limitations on the quantity of water use, term of the approval, and periodic reporting to the Agency.

5.2.3. An operator shall comply with all provisions of this Ordinance Code and Resolutions prior to receiving an extraction allocation.

5.3. Adjustments to Extraction Allocations

5.3.1. Adjustments to extraction allocations may be necessary to provide some flexibility, while still maintaining the goal of reaching a safe yield condition by the year 2010. Adjustments may be accomplished by a transfer, an assignment of historical extraction allocation, or a demonstration of a new water source.

5.3.2. Subject to the provisions in this Section 5.3, transfers of extraction allocation are authorized provided they result in no net detriment to the Basins within the Agency. In making this determination, consideration shall be given to the location of extraction facilities, the aquifer systems being used, potential groundwater quality impacts, and the overall assessment of the cumulative impacts of transfers of extraction allocation.

5.3.3. Types of Transfers of Allocation. When irrigated agricultural land(s) changes to M & I use, a basic extraction allocation of 2 acre-feet per acre shall be transferred. In addition, a historical extraction allocation shall be transferred from the agricultural extraction facility(s) operators to the M & I provider in accordance with the following conditions:

5.3.3.1. When the extraction facility is located on the land transitioning and did not serve other land during the historical allocation determination period, the M & I Operator shall receive a historical extraction allocation of 2 acre-feet per acre per year for the acreage transitioning to M & I use. Any historical allocation in excess of 2 acre-feet per acre for the land transitioning to M & I use shall be eliminated.

5.3.3.2. When the extraction facility is located on the land transitioning and served other land during the historical allocation determination period, the historical allocation associated with the transitioning property shall be allocated on a pro rata basis by acreage to the total property served. The pro rata share for the property transitioning shall be eliminated. Two acre-feet per acre per year, based upon the acreage being transferred, shall be provided to the M & I provider.

5.3.3.3. When the extraction facility serving the lands transitioning is not located on the land transitioning, the Executive Officer shall determine the allocation on an equitable basis for the remaining properties not transitioning to M & I. Two acre-feet per acre per year, based upon the acreage being transferred, shall be provided to the M & I provider.

5.3.3.4. The transfer shall be effective upon the approval of the Executive Officer, taking into account the ongoing use of the property.

5.3.3.5. Allocation originating from an agricultural extraction facility shall not be transferred to an M & I use except as provided in this Section 5.3.3.

5.3.4. Allocation may be transferred between M & I extraction facilities provided there is no net detriment to the aquifer system. In making this determination, the Executive Officer shall, at a minimum, consider the location of extraction facilities, the aquifer system being used and groundwater quality impacts of the transfer.

5.3.5. Transfer of Allocation - Upon request, the Executive Officer may transfer allocation from one agricultural operator to another agricultural operator or from one M & I operator to another M & I operator provided there is no net detriment to the basins and the transfer is equitable. The transfer of allocation will be of indefinite duration, approved on a "case-by-case" basis, and the Executive Officer shall determine the rate of extraction and the point or points of extraction. Requests for the transfer of allocations shall be submitted jointly by the parties involved and shall include the specific details of their proposal. To ensure that there is no net detriment to the aquifer systems, transfers of allocation shall be subject to other conditions as approved by the Board. Transfers of allocation from Agricultural use to M & I use shall only be approved as provided by Section 5.3.3.

5.3.6. The Executive Officer may approve a temporary assignment of allocation from one operator to another operator when there is no net detriment to the aquifer system. The temporary assignment shall not exceed one year.

5.3.7. Adjustments to M & I Allocations - The Board may adjust the historical allocation of an M & I operator when that operator has supplied groundwater to either an agricultural or M & I user during the historical allocation period and discontinues service to that user. This adjustment may be made by transferring the supplied portion of the historical allocation from the M & I operator to the new user. This adjustment will avoid increased pumping due to windfall allocations that could

otherwise result when the M & I operator discontinues service. To avoid retroactive inequities, where an M & I operator has discontinued service to a user prior to July 1, 2005, the amount of the supplied portion of the historical allocation may be allocated to both the M & I operator and the user.

5.3.8. Historical allocation is subject to adjustment as provided in Section 5.4 below.

5.3.9. Procedures for Adjustment

5.3.9.1. It shall be necessary for the operator of the extraction facility to file a verified Application for Adjustment with the Executive Officer.

5.3.9.2. Adjustments of extraction allocations, pursuant to the Applications for Adjustment, shall be considered for approval by the Board after reviewing the findings and recommendations of the Executive Officer and, if approved, shall be effective for the remainder of the calendar year and for all subsequent calendar years until modified by a subsequent Board approved adjustment.

5.4. Reduction of Extraction Allocations

5.4.1. Historical extraction allocations, adjusted or otherwise, shall be reduced in order to eliminate overdraft from the aquifer systems within the boundaries of the Agency for agricultural and M & I uses. The reductions shall be as set forth below:

1992 - 1994 extraction allocation = 95% of historical extraction, as adjusted.
1995 - 1999 extraction allocation = 90% of historical extraction, as adjusted.
2000 - 2004 extraction allocation = 85% of historical extraction, as adjusted.
2005 - 2009 extraction allocation = 80% of historical extraction, as adjusted.
After 2009 extraction allocation = 75% of historical extraction, as adjusted.

5.4.2. Following the appropriate public review, the Board may exempt historical extraction allocations from these adjustments on a basin-by-basin basis.

5.5. Exemptions from Reductions

5.5.1. The following types of extraction allocations are exempt from the reductions set forth in Section 5.4.1:

5.5.1.1. Baseline Extraction Allocations as set forth in 5.6.1.1.

5.5.1.2. Annual Efficiency Extraction Allocations as set forth in 5.6.1.2.

5.5.1.3. Non-metered Extraction Facilities. Reductions in extraction allocations shall not apply to those extraction facilities as identified in Chapter 3 that do not require flowmeters. Neither retroactive adjustments nor refunds will be made, except that any outstanding surcharges for non-metered extractions that existed prior to June 26, 2002 will be waived.

5.6. **Alternative Extraction Allocations**

5.6.1. As an alternative to historical extractions, the Executive Officer may establish a Baseline or an Annual Efficiency extraction allocation for an operator, as follows:

5.6.1.1. Baseline Extraction Allocations. If no historical extraction exists, or the historical allocation is less than one acre-foot per acre per year, a Baseline extraction allocation may be established by the Executive Officer at one acre-foot per acre per year.

5.6.1.1.1. A Baseline Extraction Allocation specifically applies to undeveloped acreage that is being developed and once approved shall remain with that developed acreage. A Baseline allocation may be combined with a historical allocation for commonly operated facilities in the same basin. A baseline allocation shall not be used with an efficiency allocation.

5.6.1.1.2. To obtain a Baseline Extraction Allocation, a detailed report must be submitted to the Executive Officer. The report shall describe the historical extraction of groundwater use, if any, during the period between the end of calendar year 1984 and the end of calendar year 1989, the type (crop type or M & I) and the amount of water use and acreage involved. The report shall include copies of Assessor's maps identifying the parcels where groundwater is presently being used. For the purpose of this ordinance, one (1) acre-foot per acre per year represents a reasonable use of water for a Baseline extraction allocation.

5.6.1.1.3. Application for the initial Baseline Extraction Allocation must be submitted prior to submission of the annual report of pumping. If approved, the Baseline Extraction Allocation shall apply beginning with the current calendar year.

5.6.1.1.4. To facilitate accounting procedures, an operator shall use Baseline Extraction Allocation before using Historical Allocation.

5.6.1.2. Annual Efficiency Extraction Allocation - If an operator can demonstrate to the Executive Officer that water used for agriculturally developed land is at least 80 percent overall irrigation efficient, based on evapotranspiration requirements, an Annual Efficiency extraction allocation shall be established for one calendar year. An 80 percent overall irrigation efficiency has been determined by the Agency to be reasonable on agricultural lands within the Agency's boundaries.

5.6.1.2.1. An Efficiency Allocation may be used when no historical allocation exists or when the historical allocation is not

sufficient for the crop being grown. A historical allocation shall not be used in conjunction with an efficiency allocation.

5.6.1.2.2. To prove that irrigation efficiency is at least 80 percent, the operator must submit a detailed report covering a minimum period of the immediately preceding calendar year. This report shall be submitted to the Executive Officer no later than February 1st of the following year unless otherwise extended by the Board. The report shall include a complete crop and irrigation history for the extraction facility and actual acreage irrigated. The report shall include the reference evapotranspiration (ETo) rates and crop factors (Kc) for the calendar year period similar to that provided by the California Irrigation Management Information System (CIMIS) as developed and modified by the California Department of Water Resources. The report shall include a summary sheet that compares the water use to the evapotranspiration requirements for each crop and the corresponding acreage covered in the calendar year. The Board may extend the time to apply for an efficiency allocation for any year.

5.6.1.2.3. Irrigation efficiency will include an appropriate amount of water necessary to avoid salt build-up based on the quality of irrigation water used.

5.6.1.2.4. Irrigation Efficiency (I.E.) will be calculated using the following formula:

$$\text{I.E.} = \frac{[\text{ETo} \times \text{Kc}] - \text{ER} \times 100}{\text{Actual Water Applied (inches)}}$$

Where:

ETo is the reference evapotranspiration measured in inches.

Kc is a crop factor, which is a dimensionless number that relates water use by a given plant in comparison to ETo.

ER is the effective rainfall measured in inches as determined by the Executive Officer.

5.6.2. Exceptions - The Board may grant exceptions to Sections 5.6.1.1 and 5.6.1.2 on a case-by-case basis. However, individual exceptions shall not become the norm. Where agricultural efficiency cannot be measured as set forth in Section 5.6.1.2, then the most efficient practices of record for the type of agricultural use shall be the measurement of efficiency utilized by the Board in its deliberations.

5.7. **Credits**

5.7.1. Credits can be obtained by operators, but are not considered as extraction allocations or adjustments to extraction allocations. Credits are not subject to any reductions as set forth in Section 5.4.1. Credits, if available, shall be used to avoid paying extraction surcharges. Credits shall be accounted for through the normal reporting and accounting procedure and are carried forward from year to year. Except as provided below, credits may be transferred between commonly operated extraction facilities and within the basin where the credits were earned.

5.7.2. The Board may transfer credits between facilities that are not commonly operated within a basin or beyond the basin where such credits were earned, provided that there is no net detriment to the aquifers within the Agency. In determining whether there is no net detriment, the Board may, among other things, consider whether the transfer will help bring the aquifers within the Agency into equilibrium or whether the transfer is a part of an Agency or inter-Agency management plan or program to bring the aquifers of the Agency into balance. Also, in making this determination of no net detriment the Board may consider quality of water as well as the quantity. The transfer of credits will be of indefinite duration, approved on a "case-by-case" basis, and the Executive Officer shall determine the rate of extraction and the point or points of extraction.

5.7.2.1. Requests for the transfer of credits shall be submitted jointly by the parties involved and shall include the specific details of their proposal. To ensure that there is no net detriment to the aquifer systems, transfers of credits shall be subject to other conditions as approved by the Board. Under no circumstances shall credits earned as a result of agricultural use be transferred to an M & I Provider, M & I Operator or an M & I User unless the transfer is specifically approved by the Board and no net detriment to the aquifer systems involved can be shown. Credits earned by an M & I facility shall remain with that facility unless transferred by the Board or transferred as part of a program such as an Agency or inter-Agency management plan or program approved by the Board. The types of credits are:

5.7.2.1.1. Conservation credits - An operator can obtain conservation credits by extracting less groundwater than the historical extraction allocation. Annual Efficiency, Baseline, or an allocation assigned to an extraction facility that is not required to have a flowmeter shall not earn credits. Credits shall be determined by the Executive Officer after receipt of annual extraction data. Subsequent to determining the amount of credits earned, a confirmation shall be mailed to the operator indicating the current allocation, the groundwater extracted during the previous calendar year, and the credits or surcharges for the previous year.

5.7.2.1.2. Storage credits - An operator may obtain storage credits for water that has been determined by the Board to qualify for

credits or foreign water stored, injected or spread and percolated or delivered in lieu of pumping in a Board approved injection/storage program used within the Agency Boundary. A written application for approval of a program or an injection/storage facility shall include:

5.7.2.1.2.1. Operator of proposed injection/storage program.

5.7.2.1.2.2. Purpose of proposed injection/storage program.

5.7.2.1.2.3. Location, depth, casing diameter, perforated interval and other information regarding proposed injection/extraction facilities, if applicable.

5.7.2.1.2.4. Method of operation including source, quantity and quality of water, planned scheduling of storage, injection/extraction, delivery or percolation operations and proposed use of extracted water.

5.7.2.1.2.5. Any other information deemed necessary by the Executive Officer.

5.7.3. Following Board approval of the application, successful storage, delivery or injection of water and reporting of results, an operator will obtain credit as determined by the Executive Officer.

5.8. Extraction Surcharges and Late Penalty

5.8.1. Necessity for Surcharges

5.8.1.1. Extraction surcharges are necessary to achieve safe yield from the groundwater basins within the Agency and shall be assessed annually when annual extractions exceed the historical and/or baseline allocation for a given extraction facility or the combined sum of historical allocation and baseline allocation for combined facilities. The extraction surcharge shall be fixed by the Board and shall be based upon (1) the cost to import potable water from the Metropolitan Water District of Southern California, or other equivalent water sources that can or do provide non-native water within the Agency jurisdiction; and (2) the current groundwater conditions within the Agency jurisdiction.

5.8.2. At the discretion of the Board, the extraction surcharge may be structured, tiered, and varied between basins and or aquifers.

5.8.3. The Board shall fix the surcharge by Resolution at a cost sufficiently high to discourage extraction of groundwater in excess of the approved allocation when that extraction will adversely affect achieving safe yield of any basin within the

Agency and may adjust the surcharge by Resolution; provided however, that the then existing extraction surcharge shall remain in effect until adjusted by the Board.

5.8.4. Surcharge for No Allocation - In circumstances where an individual or entity extracts groundwater from a facility(s) having no valid extraction allocation, the extraction surcharge shall be applied to the entire quantity of water extracted. Imposition and acceptance of payment of the surcharge imposed on an individual or entity that extracts water from a facility(s) that holds no extraction allocation shall not be deemed a waiver of the Agency's authority to limit or enjoin the unauthorized extractions.

5.8.5. Efficiency Surcharge Facilities relying on the annual efficiency allocation shall also be subject to surcharge for inefficient use. The extraction allocation for efficiency is the amount of water used at 80% efficiency as defined in 5.6.1.2 of this ordinance. Extraction surcharges will be applied to the difference between the water extracted which correlates with the actual efficiency achieved and the water that would have been extracted to attain the 80% efficiency allocation. For example, an actual efficiency of 70% would be subject to surcharges on the difference between the amount of water used at 70% efficiency and the amount of water that would have been used at 80% efficiency. If an efficiency of less than 60% is achieved, no efficiency allocation will be available, and the operator shall revert to a historical, baseline or to no allocation whichever applies to that facility. Extraction surcharges would then apply to the difference between actual water used and the applicable allocation, if any. For example, a facility operating at an actual efficiency of 59% with no historical or baseline allocation, would be subject to surcharges on all water used.

5.8.6. Payment of Extraction Surcharges

5.8.6.1. Surcharges are assessed annually with respect to the annual allocation and shall become due and payable by the owner/operator on February 1st each year or 30 days after the date shown on the "Semi-Annual Groundwater Extraction Statement." Payments shall be made with credits, if available. The Board may extend the 30-day time allowed to pay surcharges for a period of up to twelve months when circumstances exist that in the opinion of the Board warrant such extension. The Board may also approve the payment of surcharges in installments of up to 24 months with terms suitable to the Board.

5.8.6.2. Late Penalty - The operator shall pay a late penalty for any extraction surcharge not satisfied by the due and payable date. The late penalty shall be 1.5 percent per month, or any portion thereof, of the amount of the unsatisfied extraction surcharge. The late penalty shall not exceed 100% of the original surcharge, provided the penalty is paid within 60 days of billing. If the fee is not paid within the 60 days, the penalty will continue to accrue at 1.5 percent per month with a final maximum of 200% of the original penalty due.

5.8.6.3. Collection of Delinquent Extraction Surcharges and Late Penalties - The Board may order that any given extraction surcharge and/or late penalty shall be a personal obligation of the operator or shall be an assessment against the property on which the extraction facility is located. Such assessment constitutes a lien upon the property, which lien attaches upon recordation in the office of the County Recorder. The assessment may be collected at the same time and in the same manner as ordinary ad valorem taxes are collected, and shall be subject to the same penalties and the same procedure and sale, in case of delinquency as provided for such taxes. All laws applicable to the levy, collection and enforcement of ad valorem taxes shall be applicable to such assessment, except that if any real property to which such lien would attach has been transferred or conveyed to a bona fide purchaser for value, or if a lien of a bona fide encumbrance for value has been created and attaches thereon, prior to the date on which the first installment of such taxes would become delinquent, then the lien which would otherwise be imposed by this section shall not attach to such real property and an assessment relating to such property shall be transferred to the unsecured roll for collection.

5.8.6.4. Use of Extraction Surcharges and Late Penalties - Revenues generated from extraction surcharges and late penalties shall be used exclusively for authorized Agency purposes, including financial assistance to support Board approved water supply, conservation, monitoring programs and water reclamation projects that demonstrate significant reductions in overdraft.

CHAPTER 6.0
Appeals

6.1. Any person aggrieved by a decision or determination made by the Executive Officer may appeal to the Board within forty-five (45) calendar days thereof by filing with the Clerk, or Deputy Clerk, of the Board a written request that the Board review the decision of the Executive Officer. The Board shall equitably act on the appeal within 120 days after all relevant information has been provided by the appellant.

CHAPTER 7.0
Severability

7.1. If any section, part, clause or phrase in this Ordinance Code is for any reason held invalid or unconstitutional, the remaining portion of this Ordinance Code shall not be affected but shall remain in full force and effect.

CHAPTER 8.0
Penalties

8.1. Any operator or other person who violates the provisions of this Ordinance Code is subject to the criminal and civil sanctions set forth in the Agency's enabling act and its Ordinances.

8.2. Any person who intentionally violates any provision of this Ordinance Code shall be guilty of an infraction and may be required to pay a fine to the Agency in an amount not to exceed five hundred dollars ($500).

8.3. Any person who negligently or intentionally violates any provision of this Ordinance Code may also be liable civilly to the Agency for a sum not to exceed one thousand dollars ($1,000) per day for each day of such violation, in addition to any other penalties that may be prescribed by law.

8.4. Upon the failure of any person to comply with any provision of this Ordinance Code, the Agency may petition the Superior Court for a temporary restraining order, preliminary or permanent injunction, or such other equitable relief as may be appropriate. The right to petition for injunctive relief is an additional right to those, which may be provided elsewhere in this Ordinance Code or otherwise allowed by law. The Agency may petition the Superior Court of the County to recover any sums due the Agency.

This Ordinance Code and amendments hereof shall become effective on the thirty-first day after adoption.

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ORDINANCE NO. 8.3

An Ordinance to Amend the Fox Canyon Groundwater Management Agency Code

The Board of Directors of the Fox Canyon Groundwater Management Agency ordains as follows:

SECTION ONE: Section 1.27 of Chapter 1.0, Definitions, is hereby repealed and reenacted as follows:

1.27. "Flowmeter" means a manufactured instrument for accurately measuring and recording the flow of water in a pipeline.

SECTION TWO: Section 1.45 of Chapter 1.0, Definitions, is hereby repealed and reenacted as follows:

1.45. "Well Flushing" means the act of temporarily discharging extracted groundwater through a connection located upstream of the water distribution system at the beginning of an extraction cycle. Well flushing is typically performed until the quality of the extracted water is suitable for beneficial use and/or will not damage the distribution system. In some cases, the flushing flows may be discharged upstream of the distribution system, including the flowmeter. Flushing flows discharged upstream of the flowmeter shall be estimated and reported to the Agency in accordance with the requirements accordance with the requirements in Chapter 2 of the Ordinance Code.

SECTION THREE: Section 1.46 of Chapter 1.0, Definitions, is hereby added to the Ordinance Code as follows:

1.46. "Well Rehabilitation" means the act of restoring a well to its most efficient condition by various treatments, development, or reconstruction methods. In most cases, groundwater extracted during well rehabilitation is not discharged through the extraction facility piping and, consequently, is not flowmetered. In these cases, the volume of water extracted shall be estimated and reported to the Agency in accordance with the requirements accordance in Chapter 2 of the Ordinance Code.

SECTION FOUR: Section 1.47 of Chapter 1.0, Definitions, is hereby added to the Ordinance Code as follows:

1.47. "West Las Posas Basin" is that part of the former North Las Posas Basin that is west of the subsurface anomaly described by significant changes in groundwater levels as described in the Groundwater Management Plan and located for record purposes on maps as provided in Section 1.20.

SECTION FIVE: Section 2.3 of Chapter 2.0, Registration of Wells and Levying of Charges, is hereby repealed and reenacted as follows:

2.3. **Reporting Extractions** - All extractions shall be reported to the Agency. All extractions shall be flowmetered in accordance with the requirements and methods for flowmetering extractions as specified by Chapter 3. In cases where flowmetering is not required, the volume of water extracted shall be estimated and reported to Agency. The Agency shall send a "Semi-Annual Groundwater Extraction Statement" form to each well operator on or about the first week of January and the first week of July each year. Each operator of a registered extraction facility shall enter the necessary information and return the "Semi-Annual Groundwater Extraction Statement" covering all wells they operate on or before the due date. Statements are due on or before February 1st or August 1st annually or thirty days after the date of the letter requesting submittal of the Semi-Annual Statement for the given period. Statements shall contain the following information on forms provided by the Agency:

2.3.1. The information required under Section 2.1.2 above.

2.3.2. The method of measuring or computing groundwater extractions.

2.3.3. The crop types or other uses and the acreage served by the extraction facility.

2.3.4. Total extractions from each extraction facility in acre-feet for the proceeding six (6) month period.

SECTION SIX: Chapter 3.0, Installation of Metering Equipment for Groundwater Extraction Facilities, is hereby repealed and reenacted as follows:

CHAPTER 3.0
Installation and Use of Flowmeters for Groundwater Extraction Facilities

3.1. Installation and Use of Flowmeters

3.1.1. Installation Requirement - Prior to extracting groundwater, the operator shall install a flowmeter. With the exception of connections used for well flushing and extraction facilities used by multiple operators, flowmeters shall be installed upstream of all connections to the main discharge line. Flowmetering is not required during well flushing and well rehabilitation; however, the volume of water extracted shall be estimated and reported to the Agency. Flowmeters are not required on inactive wells as defined in this Ordinance Code, nor are flowmeters required for extraction facilities supplying a single family dwelling on one acre or less, with no income producing operations. If more than one operator uses the same extraction facility, flowmeters shall be installed to record the water use of each operator. Well operators were required to install flowmeters on wells by July 1, 1994.

3.1.2. Flowmeter Failure and Back-up Measurement Requirements - Flowmeters occasionally fail, losing periods of record before the disabled or inaccurate meter is either replaced or repaired. When a flowmeter fails, the operator shall repair or replace the flowmeter within the timeframe specified in a separate Resolution. Flowmeter failures and associated repairs or replacements shall be reported to the another acceptable method of computing extractions during these periods of flowmeter failure to avoid the loss of record on wells that require flowmetering under this Ordinance Code Agency together with any other information required by the Executive Officer on or before the due date of the next Semi-Annual Groundwater Extraction Statement. Well operators shall be prepared to provide.

3.1.3. Back-up Methods - It is the operator's responsibility to maintain the flowmeter. Any allowable or acceptable backup measurement methods will be specified in a separate Resolution and may be changed as technology improves or changes.

3.1.4. Flowmeter Readings - Functional flowmeters shall be read and the readings reported semi-annually on the extraction statements required under Section 2.3 above.

3.1.5. Inspection of Flowmeters - The Agency may inspect flowmeter installations for compliance with this Ordinance Code at any reasonable time.

3.2. **Flowmeter Testing and Calibration** - All flowmeters shall be tested for accuracy at a frequency interval determined by the Board to meet specific measurement standards. Calibration methods and procedures approved by the Board shall be detailed in an adopted Resolution.

3.3. **Altering Flowmeters** - Any person who alters, removes, resets, adjusts, manipulates, obstructs, or in any manner interferes or tampers with any flowmeter affixed to any groundwater extraction facility required by this Ordinance Code, resulting in said flowmeter to improperly or inaccurately measure and record groundwater extractions, is guilty of an intentional violation of this Ordinance Code and will be subject to any and all penalties as described in Chapter 8.

3.4. **Costs of Testing and Calibration** - All costs incurred with flowmeter testing or calibration shall be the personal obligation of the well owner. Non-compliance with any provision of the flowmeter calibration requirements will subject the owner to financial penalties and/or liens as described below or in Chapter 8 of the Ordinance Code.

3.5. **Fees and Enforcement** - If any water production facility within the Agency's boundaries is used to produce water without a flowmeter or with a non-operating flowmeter in excess of the allowable timeframe specified in a separate Resolution, the Agency shall assess a Non-Metered Water Use Fee against the water production facility owner. The amount of the fee shall be calculated as follows:

3.5.1 Groundwater extraction facilities - The fee shall be equal to double the current groundwater extraction charge for all estimated water used. Estimates of water used shall be calculated by the operator and approved by the Executive Officer. Any delinquent extraction charge obligations shall also be charged interest at the rate of 1.5 percent per month on any unpaid balances.

3.6. Upon violation of any flowmeter provision, the Agency may, as allowed by law, petition the Superior Court of the County for a temporary restraining order or preliminary or permanent injunction prohibiting the well owner from operating the facility or for such other injunctive relief as may be appropriate.

SECTION SEVEN: The Ordinance Code is amended so that the terms "Metering Equipment" and "Meter" shall be replaced with "Flowmeter."

This Ordinance shall become effective on the thirty-first day after adoption.

ADOPTED this 28th day of July 2010 by the following vote:

AYES: Directors Maulhardt, Craven, Bennett, Kelley, and Borchard
NOES: None
ABSENT: None

Lynn Maulhardt, Chair, Board of Directors
Fox Canyon Groundwater Management Agency

ATTEST: I hereby certify that the above is a true and correct copy of Ordinance No. 8.3

Tammy Butterworth, Deputy Clerk of the Board

FOX CANYON GROUNDWATER MANAGEMENT AGENCY

BOARD OF DIRECTORS
Lynn E. Maulhardt, Chair
John K. Flynn
Sam McIntyre
James Daniels
Michael Conroy

AGENCY COORDINATOR
Lowell Preston, Ph.D.

July 12, 1994

Eric Berg, Projects Administrator
Calleguas Municipal Water District
2100 Olsen Road
Thousand Oaks, CA 91360-6800

SUBJECT: BOARD APPROVAL OF CMWD APPLICATION FOR INJECTION/STORAGE FACILITIES IN NORTH LAS POSAS GROUNDWATER BASIN

Dear Mr. Berg:

At the Board of Directors meeting on February 23, 1994, the Board approved the CMWD application for injection/storage facilities in the North Las Posas Basin. The approval of this application, as provided for under Ordinance 5.3, was subject to the conditions that follow. These conditions include several changes and additions requested by the Board of Directors.

NORTH LAS POSAS BASIN INJECTION/STORAGE FACILITIES CONDITIONS

1. *The identification, size, depth, well logs and location of wells used for injection/extraction will be registered with the GMA. A maximum of twenty (20) wells all to be permitted by the County of Ventura, Public Works Agency, and registered with the GMA.*

2. *Calleguas will inject/extract on a schedule determined by availability of water to inject and the needs of their customers. The number of acre-feet injected/extracted from each well shall be reported to the GMA monthly. The monthly report shall also include a water quality analysis for the injected water that covers and conforms to the limits listed for the following items:*

a.	*Sodium Adsorption Ratio (SAR) calculated in meq/l as* $SAR=NA/((CA + Mg)/2)^{.5}$	$\geq 1 \leq 4$	
b.	*Total Dissolved Solids (TDS)* *Electrical conductivity (EC)*	$\geq 100 \leq 800$ <1100	*mg/l* *uMHO*
c.	*Chloride (Cl)*	<120	*mg/l*
d.	*Boron* (H_3Bo_3)	<1	*mg/l*
e.	*Nitrates*	<45	*mg/l*

(NOTE: These limits are based on University of California research. Should the University reverse these limits, the recommended changes will be incorporated into these conditions.)

800 South Victoria Avenue, Ventura, CA 93009
(805) 654-2088 FAX:(805) 654-3951

Testing shall be conducted monthly during periods of continuous injection, prior to beginning an injection of more than one hundred (100) acre-feet (but no more frequently than monthly), and as frequently as necessary when a change in water quality is suspected or known to exist.

3. *The total water in storage at any one time shall not exceed three hundred thousand (300,000) acre-feet (AF) unless approved by the GMA Board of Directors.*

4. *The point of extraction shall be the same as the point of injection or in the near vicinity. Extraction from points other than that of injection may be desirable and shall be coordinated with, and approved by the GMA.*

5. *Water stored by the facility shall be used in Ventura County.*

6. *Calleguas shall periodically review the effects of the injection on surrounding basins to ensure no detrimental effects result from the injection alone or in combination with natural recharge. Should negative effects exist, Calleguas shall take action to mitigate those effects caused by the injection program.*

7. *Should the injected water or conditions deviate from these standards, injection will stop, or not be started until the condition has been corrected.*

If you have any questions regarding this Agency's approval of your project facilities, please call Rick Farnsworth at 654-2327 or myself at 648-9204.

Very truly yours,

Lowell Preston, Ph.D.
Agency Coordinator

RF:vg

xGG/berg

Appendix C
Purveyor Projections

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CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

NORMAL YEAR SCENARIO

1 Berylwood Heights Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	-	-	-	-	-	-
i t	1 0	1 00	2 200	2 00	200	00
t t i	1 0	1 00	2 200	2 00	200	00
i						
t	-	-	-	-	-	-
- t b	1	1	2 1	2 2	1 0	
t - t b	1	1	2 1	2 2	1 0	
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	1	1	2 1	2 2	1 0	
E E E	2				10	12

2 Brandeis Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i				0	1	2
i t	-	-	-	-	-	-
t t i				0	1	2
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E				0	1	2

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

NORMAL YEAR SCENARIO

3 Butler Ranch Mutual Water Company ***(No information provided)***

t i t	2010	2015	2020	2025	2030	2035
i i t i	-	-	-	-	-	-
i t	-	-	-	-	-	-
t t i	-	-	-	-	-	-
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E	-	-	-	-	-	-

4 California-American Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	20 0 2	20	20	21 2	21	22 2 0
i t	-	-	-	-	-	-
t t i	20 0 2	20	20	21 2	21	22 2 0
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E	20 0 2	20	20	21 2	21	22 2 0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

NORMAL YEAR SCENARIO

5 California Water Service

t i t	2010	2015	2020	2025	2030	2035
i i t i	10 0	10 112	10 1 0	10 2	10 1	10
i t	-	-	-	-	-	-
t t i	10 0	10 112	10 1 0	10 2	10 1	10
i						
t	2	2			1	
- t b	-	-	-	-	-	-
t - t b	2	2			1	
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	2	2			1	
E E E	20			11		2

6 City of Camarillo

t i t	2010	2015	2020	2025	2030	2035
i i t i	00	10	11 02	11	12 0 0	12
i t	0	00	2 0	2 0	2 0	2 0
t t i	10 2 0	10	11 2	11	12 00	12 1
i						
t	-	00	00	00	00	00
- t b	-	-	-	-	-	-
t - t b	-	00	00	00	00	00
	-	2	2	2	2	2
t b	000	-	-	-	-	-
t t b	000	2	2	2	2	2
t i	000					
E E E	2 0	2	0	022		0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

NORMAL YEAR SCENARIO

7 Camrosa Water District

t i t	2010	2015	2020	2025	2030	2035
i i t i	02	10 0	12 02	12 0	1 0	1 0
i t	00	00	00	00	00	00
t t i	1 2	1 0 0	1 2	20 0	21 0	21 0
i						
t	2	110	0	1 0	00	0
- t b	1 000	1 000	1 000	1 000	1 000	1 000
t - t b	2	110	0	1 0	00	0
	-	2	0	0	0	0
t b	00	00	00	00	00	00
t t b	00	02	0	0	0	0
t i	2	11 1	12 0	1 20	1 0	1 0
E E E	101		0	0	220	1 0

8 Crestview Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	1 12	1 1 0	1 1	1 200	1 200	1 200
i t	-	-	-	-	-	-
t t i	1 12	1 1 0	1 1	1 200	1 200	1 200
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	2	0	0	0	0	0
t t b	2	0	0	0	0	0
t i	2	0	0	0	0	0
E E E		0	0	0	0	0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

NORMAL YEAR SCENARIO

9 Golden State Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	0 2		2	10 1	11 0	11
i t	-	-	-	-	-	-
t t i	0 2		2	10 1	11 0	11
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	1 000	1 000	1 000	1 000	1 000	1 000
t t b	1 000	1 000	1 000	1 000	1 000	1 000
t i	1 000	1 000	1 000	1 000	1 000	1 000
E E E	0 2		2	1	10 0	10

10 Lake Sherwood CSD

t i t	2010	2015	2020	2025	2030	2035
i i t i	1 0	1	1 0	1 0	1 0	1 0
i t	-	-	-	-	-	-
t t i	1 0	1	1 0	1 0	1 0	1 0
i						
t	00	00	00	00	00	00
- t b	-	-	-	-	-	-
t - t b	00	00	00	00	00	00
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	00	00	00	00	00	00
E E E	1 20	1	1 0	1 0	1 0	1 0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

NORMAL YEAR SCENARIO

11 Oak Park Water Service

t i t	2010	2015	2020	2025	2030	2035
i i t i	0	0	0	0	0	0
i t	-	-	-	-	-	-
t t i	0	0	0	0	0	0
i						
t	0	0	0	0	0	0
- t b	-	-	-	-	-	-
t - t b	0	0	0	0	0	0
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	0	0	0	0	0	0
E E E	100	100	100	100	100	100

12 City of Oxnard

t i t	2010	2015	2020	2025	2030	2035
i i t i	00	0	0 0	0	0 0	0 0
i t	-	-	-	-	-	-
t t i	00	0	0 0	0	0 0	0 0
i						
t	-	2 00	0 0	0 0	0 0	0 0
- t b	-	-	-	-	-	-
t - t b	-	2 00	0 0	0 0	0 0	0 0
	-	-	-	-	-	-
t b	2 2	22 2	20 1	1 1	20 2	20 2
t t b	2 2	22 2	20 1	1 1	20 2	20 2
t i	2 2	2 12	2 2	2 20	2	2
E E E	11	1	1	1	1	1

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

NORMAL YEAR SCENARIO

13 Pleasant Valley Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	1 020	1 0	1 12	1 1	1 20	1 2 0
i t	-	-	-	-	-	-
t t i	1 020	1 0	1 12	1 1	1 20	1 2 0
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	20	0	0	0	0	0
t t b	20	0	0	0	0	0
t i	20	0	0	0	0	0
E E E	00			0		0

14 City of Simi Valley

t i t	2010	2015	2020	2025	2030	2035
i i t i	2 1	2 0	2	2 1	2 1	2 21
i t	100	101	102	10	10	10
t t i	2 1	2 0	2	2 2	2 0	2 2
i						
t	0	0	110	110	110	110
- t b	-	-	-	-	-	-
t - t b	0	0	110	110	110	110
	00	0	1	2	2	1
t b	-	-	-	-	-	-
t t b	00	0	1	2	2	1
t i	0		2		2	1
E E E	2 101	2 20	2 1	2	2 1	2

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

NORMAL YEAR SCENARIO

15 Solano Verde Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	0		0	0	0	0
i t	2 0	2	2	2	2	2
t t i	10	0				
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E	10	0				

16 City of Thousand Oaks

t i t	2010	2015	2020	2025	2030	2035
i i t i	12 00	1 000	1 00	1 00	1 00	1 00
i t	-	-	-	-	-	-
t t i	12 00	1 000	1 00	1 00	1 00	1 00
i						
t	-	-	-	-	-	-
- t b	20		0	0	0	0
t - t b	20		0	0	0	0
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	20		0	0	0	0
E E E	12 0	1	1 0	1 0	1 0	1 0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

NORMAL YEAR SCENARIO

17 VCWWD No. 1

t i t	2010	2015	2020	2025	2030	2035
i i t i	10 00	11 01	11	12	1 2	1 1
i t	1	1	1	1	1	1
t t i	1	1 1 2	1	1	1 2	1 2 1
i						
t		1 100	1 100	1 100	1 100	1 100
- t b	-	-	-	-	-	-
t - t b		1 100	1 100	1 100	1 100	1 100
	-	000	000	000	000	000
t b	2	2	2	2	2	2
t t b	2					
t i	2					
E E E	10 2	1	2			

18 VCWWD No. 19

t i t	2010	2015	2020	2025	2030	2035
i i t i	1 0	1 0 1	1 0 0	1 120	1 1 2	1 1
i t	2 2	2 2	2 2	2 2	2 2	2 2
t t i	2			1		1
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	2 2	2 2	2 2	2 2	2 2	2 2
t t b	2 2	2 2	2 2	2 2	2 2	2 2
t i	2 2	2 2	2 2	2 2	2 2	2 2
E E E	0				1	

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

NORMAL YEAR SCENARIO

19 Zone Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	-	-	-	-	-	-
i t	000	000	000	000	000	000
t t i	000	000	000	000	000	000
i						
t	-	-	-	-	-	-
- t b	00	00	00	00	00	00
t - t b	00	00	00	00	00	00
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	00	00	00	00	00	00
E E E	00	00	00	00	00	00

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

DRY YEAR SCENARIO

1 Berylwood Heights Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	-	-	-	-	-	-
i t	1 00	1 00	2 00	2 00	00	200
t t i	1 00	1 00	2 00	2 00	00	200
i						
t	-	-	-	-	-	-
- t b	1	1	2 0	2	0	1
t - t b	1	1	2 0	2	0	1
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	1	1	2 0	2	0	1
E E E			10	1	20	2

2 Brandeis Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i				0	1	2
i t	-	-	-	-	-	-
t t i				0	1	2
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E				0	1	2

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

DRY YEAR SCENARIO

3 Butler Ranch Mutual Water Company ***(No information provided)***

t i t	2010	2015	2020	2025	2030	2035
i i t i	-	-	-	-	-	-
i t	-	-	-	-	-	-
t t i	-	-	-	-	-	-
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E	-	-	-	-	-	-

4 California-American Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	20 0 2	20	20	21 2	21	22 2 0
i t	-	-	-	-	-	-
t t i	20 0 2	20	20	21 2	21	22 2 0
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E	20 0 2	20	20	21 2	21	22 2 0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

DRY YEAR SCENARIO

5 California Water Service

t i t	2010	2015	2020	2025	2030	2035
i i t i	10 000	10	11 1	11	12 1 0	12
i t	-	-	-	-	-	-
t t i	10 000	10	11 1	11	12 1 0	12
i						
t	0		1		1	
- t b	-	-	-	-	-	-
t - t b	0		1		1	
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	0		1		1	
E E E	0	10 00	10	11 0	11	12 101

6 City of Camarillo

t i t	2010	2015	2020	2025	2030	2035
i i t i	0	10 10	10	11 2	11 2	11 1
i t	0	00	2 0	2 0	2 0	2 0
t t i	0	10 0	11 01	11	11	12 0
i						
t	-	00	00	00	00	00
- t b	-	-	-	-	-	-
t - t b	-	00	00	00	00	00
	-	2	2	2	2	2
t b	000	-	-	-	-	-
t t b	000	2	2	2	2	2
t i	000					
E E E	0	2 1	2	2	01	01

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

DRY YEAR SCENARIO

7 Camrosa Water District

t i t	2010	2015	2020	2025	2030	2035
i i t i	00	11 020	12 0	1 0	1 00	1 00
i t	000	000	000	000	000	000
t t i	1 00	1 020	20 0	21 0	22 00	22 00
i						
t	2	110	0	1 0	00	0
- t b	1 000	1 000	1 000	1 000	1 000	1 000
t - t b	2	110	0	1 0	00	0
	-	2	0	0	0	0
t b	00	00	00	00	00	00
t t b	00	02	0	0	0	0
t i	2	11 1	12 0	1 20	1 0	1 0
E E E			120	10	0	2 0

8 Crestview Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	1 12	1 1 0	1 1	1 200	1 200	1 200
i t	-	-	-	-	-	-
t t i	1 12	1 1 0	1 1	1 200	1 200	1 200
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	2	00	00	00	00	00
t t b	2	00	00	00	00	00
t i	2	00	00	00	00	00
E E E		0		00	00	00

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

DRY YEAR SCENARIO

9 Golden State Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	0 2		2	10 1	11 0	11
i t	-	-	-	-	-	-
t t i	0 2		2	10 1	11 0	11
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	1 000	1 000	1 000	1 000	1 000	1 000
t t b	1 000	1 000	1 000	1 000	1 000	1 000
t i	1 000	1 000	1 000	1 000	1 000	1 000
E E E	0 2		2	1	10 0	10

10 Lake Sherwood CSD

t i t	2010	2015	2020	2025	2030	2035
i i t i	1	1 0	2 111	2 111	2 111	2 111
i t	-	-	-	-	-	-
t t i	1	1 0	2 111	2 111	2 111	2 111
i						
t	0	0	0	0	0	0
- t b	-	-	-	-	-	-
t - t b	0	0	0	0	0	0
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	0	0	0	0	0	0
E E E	1	1	1 1	1 1	1 1	1 1

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

DRY YEAR SCENARIO

11 Oak Park Water Service

t i t	2010	2015	2020	2025	2030	2035
i i t i	0 0	0 0	0 0	0 0	0 0	0 0
i t	-	-	-	-	-	-
t t i	0 0	0 0	0 0	0 0	0 0	0 0
i						
t	0	0	0	0	0	0
- t b	-	-	-	-	-	-
t - t b	0	0	0	0	0	0
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	0	0	0	0	0	0
E E E	200	200	200	200	200	200

12 City of Oxnard

t i t	2010	2015	2020	2025	2030	2035
i i t i	00	0	0 0	0	0 0	0 0
i t	-	-	-	-	-	-
t t i	00	0	0 0	0	0 0	0 0
i						
t	-	2 00	0 0	0 0	0 0	0 0
- t b	-	-	-	-	-	-
t - t b	-	2 00	0 0	0 0	0 0	0 0
	-	-	-	-	-	-
t b	2 2	22 2	20 1	1 1	20 2	20 2
t t b	2 2	22 2	20 1	1 1	20 2	20 2
t i	2 2	2 12	2 2	2 20	2	2
E E E	11	1	1	1	1	1

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

DRY YEAR SCENARIO

13 Pleasant Valley Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i		1 020	1 0	1 12	1 1 0	1 20
i t	-	-	-	-	-	-
t t i		1 020	1 0	1 12	1 1 0	1 20
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	10	20	0	0	0	0
t t b	10	20	0	0	0	0
t i	10	20	0	0	0	0
E E E	2	00			20	

14 City of Simi Valley

t i t	2010	2015	2020	2025	2030	2035
i i t i	2 1	2 10	2 0	2 0	0 21	1 0
i t	100	101	102	10	10	10
t t i	2 1	2 20	2 11	2	0 2	1
i						
t	0	0	110	110	110	110
- t b	-	-	-	-	-	-
t - t b	0	0	110	110	110	110
	00	2			00	2
t b	-	-	-	-	-	-
t t b	00	2			00	2
t i	0	1			1 010	1 0
E E E	2 0 1	2 2 1	2 2	2	2 1	0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

DRY YEAR SCENARIO

15 Solano Verde Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	0		0	0	0	0
i t	2 0	2	2	2	2	2
t t i	10	20	2			
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E	10	20	2			

16 City of Thousand Oaks

t i t	2010	2015	2020	2025	2030	2035
i i t i	1 100	1 00	1 00	1 00	1 00	1 00
i t	-	-	-	-	-	-
t t i	1 100	1 00	1 00	1 00	1 00	1 00
i						
t	-	-	-	-	-	-
- t b	20		0	0	0	0
t - t b	20		0	0	0	0
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	20		0	0	0	0
E E E	1 0 0	1 2	1 2 0	1 2 0	1 2 0	1 2 0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

DRY YEAR SCENARIO

17 VCWWD No. 1

t i t	2010	2015	2020	2025	2030	2035
i i t i	12 0	12	1	1 2	1 1	1
i t	1	1	1	1	1	1
t t i	1 212	1 112	1 1	1 0	1	1 10
i						
t		1 100	1 100	1 100	1 100	1 100
- t b	-	-	-	-	-	-
t - t b		1 100	1 100	1 100	1 100	1 100
	-	000	000	000	000	000
t b	2	2	2	2	2	2
t t b	2					
t i	2					
E E E	12 21		0	2	1	10

18 VCWWD No. 19

t i t	2010	2015	2020	2025	2030	2035
i i t i	1 2	1	1 2	1 1	1	1
i t	2 2	2 2	2 2	2 2	2 2	2 2
t t i		0	2		2	0
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	2 2	2 2	2 2	2 2	2 2	2 2
t t b	2 2	2 2	2 2	2 2	2 2	2 2
t i	2 2	2 2	2 2	2 2	2 2	2 2
E E E	1 2	1 2	1 00	1	1	1 0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

DRY YEAR SCENARIO

19 Zone Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	-	-	-	-	-	-
i t	00	00	00	00	00	00
t t i	00	00	00	00	00	00
i						
t	-	-	-	-	-	-
- t b	000	000	000	000	000	000
t - t b	000	000	000	000	000	000
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	000	000	000	000	000	000
E E E	00	00	00	00	00	00

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

MULTIPLE DRY YEAR SCENARIO

1 Berylwood Heights Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	-	-	-	-	-	-
i t	1 0	1 0	2 0	2 0	0	2 0
t t i	1 0	1 0	2 0	2 0	0	2 0
i						
t	-	-	-	-	-	-
- t b	1 0	1	2 0	2 2	1	210
t - t b	1 0	1	2 0	2 2	1	210
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	1 0	1	2 0	2 2	1	210
E E E	10	1	20	2		0

2 Brandeis Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i				0	1	2
i t	-	-	-	-	-	-
t t i				0	1	2
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E				0	1	2

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

MULTIPLE DRY YEAR SCENARIO

3 Butler Ranch Mutual Water Company ***(No information provided)***

t i t	2010	2015	2020	2025	2030	2035
i i t i	-	-	-	-	-	-
i t	-	-	-	-	-	-
t t i	-	-	-	-	-	-
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E	-	-	-	-	-	-

4 California-American Water Company

t i t i i t i	2010	2015	2020	2025	2030	2035
	20 0 2	20	20	21 2	21	22 2 0
i t	-	-	-	-	-	-
t t i	20 0 2	20	20	21 2	21	22 2 0
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E	20 0 2	20	20	21 2	21	22 2 0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

MULTIPLE DRY YEAR SCENARIO

5 California Water Service

	2010	2015	2020	2025	2030	2035
t i t i i t i				1		0
i t	-	-	-	-	-	-
t t i				1		0
i						
t	0		1		1	
- t b	-	-	-	-	-	-
t - t b	0		1		1	
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	0		1		1	
E E E	1	2 1	2			1

6 City of Camarillo

	2010	2015	2020	2025	2030	2035
t i t i i t i	2				10 20	10 0
i t	0	00	2 0	2 0	2 0	2 0
t t i	12	1		10 01	10	10 0
i						
t	-	00	00	00	00	00
- t b	-	-	-	-	-	-
t - t b	-	00	00	00	00	00
	-	2	2	2	2	2
t b	000	-	-	-	-	-
t t b	000	2	2	2	2	2
t i	000					
E E E	12	1 2	1 1	2 2	2	12

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

MULTIPLE DRY YEAR SCENARIO

7 Camrosa Water District

t i t	2010	2015	2020	2025	2030	2035
i i t i	11 210	1 000	1 000	1 000	1 0	1 0
i t	0	0	0	0	0	0
t t i	20 0	22 0	2 0	2 0	2 0	2 0
i						
t	2	110	1 0	0	0	20
- t b	00	00	00	00	00	00
t - t b	2	10	0	0	0	20
	-	00	0	0	0	0
t b	2 00	2 00	2 00	2 00	2 00	2 00
t t b	2 00	2 00	0	0	0	0
t i	12	10	10 10	10 10	10 0	11 0 0
E E E	12 2	12 0	1 1 0	1 0	1 00	1 20

8 Crestview Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	1 12	1 1 0	1 1	1 200	1 200	1 200
i t	-	-	-	-	-	-
t t i	1 12	1 1 0	1 1	1 200	1 200	1 200
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	2	00	00	00	00	00
t t b	2	00	00	00	00	00
t i	2	00	00	00	00	00
E E E		2 0	2	00	00	00

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

MULTIPLE DRY YEAR SCENARIO

9 Golden State Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	1				0	10 00
i t	-	-	-	-	-	-
t t i	1				0	10 00
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	1 000	1 000	1 000	1 000	1 000	1 000
t t b	1 000	1 000	1 000	1 000	1 000	1 000
t i	1 000	1 000	1 000	1 000	1 000	1 000
E E E	1				0	00

10 Lake Sherwood CSD

t i t	2010	2015	2020	2025	2030	2035
i i t i	1 2	1	2 1	2 1	2 1	2 1
i t	-	-	-	-	-	-
t t i	1 2	1	2 1	2 1	2 1	2 1
i						
t	0	0	0	0	0	0
- t b	-	-	-	-	-	-
t - t b	0	0	0	0	0	0
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	0	0	0	0	0	0
E E E	1	1	1	1	1	1

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

MULTIPLE DRY YEAR SCENARIO

11 Oak Park Water Service

t i t	2010	2015	2020	2025	2030	2035
i i t i	0	0	0	0	0	0
i t	-	-	-	-	-	-
t t i	0	0	0	0	0	0
i						
t	0	0	0	0	0	0
- t b	-	-	-	-	-	-
t - t b	0	0	0	0	0	0
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	0	0	0	0	0	0
E E E	100	100	100	100	100	100

12 City of Oxnard

t i t	2010	2015	2020	2025	2030	2035
i i t i	00	0	0 20	20	1 0 0	1 0 0
i t	-	-	-	-	-	-
t t i	00	0	0 20	20	1 0 0	1 0 0
i						
t	-	2 00	0 0	0 0	0 0	0 0
- t b	-	-	-	-	-	-
t - t b	-	2 00	0 0	0 0	0 0	0 0
	-	-	-	-	-	-
t b	2 2	1 0	1 210	1 0	1 0	1 0
t t b	2 2	1 0	1 210	1 0	1 0	1 0
t i	2 2	1 0	22 2 0	22 10	22 20	22 20
E E E	11	1 0	1 0	1 10	1 0	1 0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

MULTIPLE DRY YEAR SCENARIO

13 Pleasant Valley Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i	2		1 0	1 102	1 1	1 1 2
i t	-	-	-	-	-	-
t t i	2		1 0	1 102	1 1	1 1 2
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	00	10	20	0	0	0
t t b	00	10	20	0	0	0
t i	00	10	20	0	0	0
E E E	2 2	2	2	2	0	2

14 City of Simi Valley

t i t	2010	2015	2020	2025	2030	2035
i i t i	2 1	2 10	2 0	2 0	0 21	1 0
i t	100	100	100	100	100	100
t t i	2 1	2 20	2 0	2 0	0 1	1 0
i						
t	0	100	110	110	110	110
- t b	-	-	-	-	-	-
t - t b	0	100	110	110	110	110
	00	0	2	2	2	1 021
t b	-	-	-	-	-	-
t t b	00	0	2	2	2	1 021
t i	0	0	2	1 0	1 0 2	1 1 1
E E E	2 0 1	2 2	2 1	2	2 2	0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

MULTIPLE DRY YEAR SCENARIO

15 Solano Verde Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
i i t i		0				
i t	2 0	20	0	0	0	0
t t i		0	2	2	2	2
i						
t	-	-	-	-	-	-
- t b	-	-	-	-	-	-
t - t b	-	-	-	-	-	-
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	-	-	-	-	-	-
E E E		0	2	2	2	2

16 City of Thousand Oaks

t i t	2010	2015	2020	2025	2030	2035
i i t i	1 100	1 00	1 00	1 00	1 00	1 00
i t	-	-	-	-	-	-
t t i	1 100	1 00	1 00	1 00	1 00	1 00
i						
t	-	-	-	-	-	-
- t b	20		0	0	0	0
t - t b	20		0	0	0	0
	-	-	-	-	-	-
t b	-	-	-	-	-	-
t t b	-	-	-	-	-	-
t i	20		0	0	0	0
E E E	1 0 0	1 2	1 2 0	1 2 0	1 2 0	1 2 0

CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

MULTIPLE DRY YEAR SCENARIO

17 VCWWD No. 1

t i t	2010	2015	2020	2025	2030	2035
i i t i	12 21	1 111	1 1	1 12	1 2	1 2
i t	1	1	1	1	1	1
t t i	1	1 2	1 11	1	1 02	1
i						
t		1 100	1 100	1 100	1 100	1 100
- t b	-	-	-	-	-	-
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CMWD 2010 UWMP - PURVEYOR FORECAST SUMMARY (AC-FT)

MULTIPLE DRY YEAR SCENARIO

19 Zone Mutual Water Company

t i t	2010	2015	2020	2025	2030	2035
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Appendix D
CUWCC Annual Reports

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BMP 03: System Water Audits, Leak Detection and Repair

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Calleguas Municipal Water District **100% Complete** **2005**

A. Implementation

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B. Survey Data

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C. "At Least As Effective As"

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D. Comments

Voluntary Questions (Not used to calculate compliance)

E. Volumes

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F. Infrastructure and Hydraulics

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G. Maintenance Questions

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BMP 07: Public Information Programs

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Calleguas Municipal Water District t t **100% Complete** **2005**

A. Implementation

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B. Conservation Information Program Expenditures

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C. "At Least As Effective As"

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BMP 08: School Education Programs

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Calleguas Municipal Water District | t t **100% Complete** | **2005**

A. Implementation

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B. School Education Program Expenditures

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C. "At Least As Effective As"

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D. Comments

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BMP 10: Wholesale Agency Assistance Programs

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Calleguas Municipal Water District | t t **100% Complete** | **2005**

A. Implementation

1. Financial Support by BMP

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3. Staff Resources by BMP

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4. Regional Programs by BMP

	Implementation/ Management Program?		Implementation/ Management Program?
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B. "At Least As Effective As"

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BMP 12: Conservation Coordinator

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Calleguas Municipal Water District **100% Complete** **2005**

A. Implementation

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B. Conservation Staff Program Expenditures

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C. "At Least As Effective As"

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BMP 03: System Water Audits, Leak Detection and Repair

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Calleguas Municipal Water District **100% Complete** **2006**

A. Implementation

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C. "At Least As Effective As"

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Voluntary Questions (Not used to calculate compliance)

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BMP 07: Public Information Programs

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Calleguas Municipal Water District t t **100% Complete** **2006**

A. Implementation

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B. Conservation Information Program Expenditures

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C. "At Least As Effective As"

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D. Comments

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BMP 08: School Education Programs

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Calleguas Municipal Water District | t t **100% Complete** | **2006**

A. Implementation

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Grade	Are grade-appropriate materials distributed?	No. of class presentations	No. of students reached	No. of teachers' workshops
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B. School Education Program Expenditures

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C. "At Least As Effective As"

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BMP 10: Wholesale Agency Assistance Programs

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Calleguas Municipal Water District | t t **100% Complete** | **2006**

A. Implementation

1. Financial Support by BMP

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4. Regional Programs by BMP

	Implementation/ Management Program?		Implementation/ Management Program?
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BMP 12: Conservation Coordinator

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Calleguas Municipal Water District **100% Complete** **2006**

A. Implementation

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C. "At Least As Effective As"

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BMP 03: System Water Audits, Leak Detection and Repair

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Calleguas Municipal Water District **100% Complete** **2007**

A. Implementation

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C. "At Least As Effective As"

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Voluntary Questions (Not used to calculate compliance)

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F. Infrastructure and Hydraulics

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G. Maintenance Questions

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BMP 07: Public Information Programs

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Calleguas Municipal Water District **100% Complete** **2007**

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B. Conservation Information Program Expenditures

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C. "At Least As Effective As"

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BMP 08: School Education Programs

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Calleguas Municipal Water District | t t **100% Complete** | **2007**

A. Implementation

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B. School Education Program Expenditures

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C. "At Least As Effective As"

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BMP 10: Wholesale Agency Assistance Programs

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Calleguas Municipal Water District | t t **100% Complete** | **2007**

A. Implementation

1. Financial Support by BMP

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2. Technical Support

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6	1	**13**	1
7	1	**14**	1

4. Regional Programs by BMP

	Implementation/ Management Program?		Implementation/ Management Program?
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B. "At Least As Effective As"

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BMP 12: Conservation Coordinator

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Calleguas Municipal Water District **100% Complete** **2007**

A. Implementation

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B. Conservation Staff Program Expenditures

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C. "At Least As Effective As"

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BMP 03: System Water Audits, Leak Detection and Repair

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Calleguas Municipal Water District | t t **100% Complete** | **2008**

A. Implementation

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C. "At Least As Effective As"

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F. Infrastructure and Hydraulics

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BMP 07: Public Information Programs

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Calleguas Municipal Water District | t t **100% Complete** | **2008**

A. Implementation

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B. Conservation Information Program Expenditures

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BMP 08: School Education Programs

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Calleguas Municipal Water District | t t **100% Complete** | **2008**

A. Implementation

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B. School Education Program Expenditures

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C. "At Least As Effective As"

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D. Comments

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BMP 10: Wholesale Agency Assistance Programs

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Calleguas Municipal Water District | t t **100% Complete** | **2008**

A. Implementation

1. Financial Support by BMP

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2. Technical Support

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3. Staff Resources by BMP

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4	1	**11**	1

5	1	**12**	1
6	1	**13**	1
7	1	**14**	1

4. Regional Programs by BMP

	Implementation/ Management Program?		Implementation/ Management Program?
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B. "At Least As Effective As"

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C. Comments

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BMP 12: Conservation Coordinator

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Calleguas Municipal Water District **100% Complete** **2008**

A. Implementation

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B. Conservation Staff Program Expenditures

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C. "At Least As Effective As"

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D. Comments

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Appendix E
CMWD Adoption Letters

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RESOLUTION NO. 1636

RESOLUTION OF THE BOARD OF DIRECTORS
OF CALLEGUAS MUNICIPAL WATER DISTRICT
IMPLEMENTING A WATER SUPPLY
ALLOCATION PROGRAM

WHEREAS, the Board of Directors Calleguas Municipal Water District (District) adopted an Urban Water Management Plan (the Plan) in 1995 in accordance with the requirements of the California Urban Water Management Planning Act (Water Code Sections 10610 et seq; the Act); and the plan was updated in accordance with applicable law and adopted by the Board in 2000; and further updated and adopted on October 5th, 2005;

WHEREAS, the Plan describes actions the District may follow to manage demand and, if necessary, allocate water in response to reductions in available water supplies;

WHEREAS, the State of California is now in its third consecutive year of drought and in each year of the current drought, annual rainfall and the water content in the Sierra snowpack have been significantly below the amounts needed to fill California's reservoir system;

WHEREAS, on February 27th, 2009, Governor Schwarzenegger declared a state of emergency regarding ongoing drought conditions and ordered immediate action to manage the State's dwindling supplies;

WHEREAS, on April 14th, 2009, the Metropolitan Water District of Southern California (Metropolitan) declared that a regional water shortage exists and implemented its Water Supply Allocation Plan (WSAP) at a Regional Shortage Level 2, effective July 1st, 2009, including penalty rates for water use in excess of a member agency's annual allocation; and

WHEREAS, Ordinance No. 12 authorizes the Board of Directors to pass through to member agencies of the District any allocations or penalties for use exceeding allocations the Metropolitan Water District of Southern California may impose or that the Board of Directors might independently judge to be necessary.

NOW, THEREFORE, THE BOARD OF DIRECTORS OF CALLEGUAS MUNICIPAL WATER DISTRICT RESOLVES AS FOLLOWS:

1. The General Manager is directed to develop and apply supply allocations for each District purveyor consistent with Metropolitan's WSAP; and

2. While the WSAP is in effect, the General Manager shall monitor implementation of WSAP requirements and provide monthly reports to the Board which compare actual purveyor demand with monthly allocation targets.

ADOPTED, SIGNED AND APPROVED this 27th day of May, 2009.

Ted Grandsen

Ted Grandsen, President
Board of Directors

ATTEST:

Donald G. Hauser

Donald G. Hauser, Secretary
Board of Directors

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Appendix F
Public Notices and Return Receipts

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CALLEGUAS

MUNICIPAL WATER DISTRICT

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Notice of Availability of the
Calleguas Municipal Water District

Draft 2010 Urban Water Management Plan
for
Public Review

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Distribution List
Draft 2010 Urban Water Management Plan
Calleguas Municipal Water District

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Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To BOB BUTLER
Street, Apt. No.; or PO Box No. BUTLER RANCH
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
BOB BUTLER
BUTLER RANCH
24756 AVE MONTA
VALENCIA, CA. 91355

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X Cavanaugh ☐ Agent ☐ Addressee

B. Received by (Printed Name) Cavanaugh C. Date of Delivery 2-14-11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6798

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 6804

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Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To NORMA CAMACHO
Street, Apt. No.; or PO Box No. VENTURA COUNTY WATERSHED
City, State, ZIP+4 PROTECTION DISTRICT

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
NORMA CAMACHO
DIRECTOR
VENTURA COUNTY WATERSHED
PROTECTION DISTRICT
800 S. VICTORIA AVE.
VENTURA CA 93009-1610

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X ☐ Agent ☐ Addressee

B. Received by (Printed Name) ROGER BOULEY C. Date of Delivery FEB 14 2011

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6804

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7030

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Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To CAMARILLO LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
CAMARILLO LIBRARY
4101 LOS POSAS ROAD
CAMARILLO CA
93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature
x S Wenger
☐ Agent
☐ Addressee

B. Received by (Printed Name) Sherry Wenger
C. Date of Delivery 2/12/11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7030

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 6910

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Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To DIRECTOR OF PUBLIC WORKS CITY OF MOORPARK
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
DIRECTOR OF PUBLIC WORKS CITY OF MOORPARK
799 MOORPARK AVE
MOORPARK CA 93021

COMPLETE THIS SECTION ON DELIVERY

A. Signature
x
☒ Agent
☐ Addressee

B. Received by (Printed Name)
C. Date of Delivery 2/14/11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6910

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Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To: ANN DEMARTINI
Street, Apt. No.; or PO Box No.: GEN MGR MANAGER
City, State, ZIP+4

7010 1060 0000 1514 6811

PS Form 3800, August 2006 See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

ANN DEMARTINI
GENERAL MANAGER
SOLANO VERDE MUTUAL
WATER CO.
P.O. BOX 1248
LOMIS CA 93668

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☒ Addressee

B. Received by (Printed Name) C. Date of Delivery 2/14/11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6811

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

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Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To: JERRY DORAN
Street, Apt. No.; or PO Box No.: WATER SUPERINTENDENT
City, State, ZIP+4

7010 1060 0000 1514 6828

PS Form 3800, August 2006 See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

JERRY DORAN
WATER SUPERINTENDENT
PLEASANT VALLEY
MUTUAL WATER CO.
1863 LAS POSAS RD
CAMARILLO CA 93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) C. Date of Delivery 2/14

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6828

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 6835

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Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To ANTHONY EMMERT
Street, Apt. No.; or PO Box No. CITY OF OXNARD
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
ANTHONY EMMERT
CITY OF OXNARD
251 HAYES
OXNARD CA 93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) SANDRA VAES
C. Date of Delivery 2/14/2011

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☒ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6835

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 6842

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Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To ROBERT ERANO
Street, Apt. No.; or PO Box No. GENERAL MANAGER
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
ROBERT ERANO
GENERAL MANAGER
CREST VIEW MUTUAL
WATER CO.
328 VALLEY VISTA DR.
CAMARILLO CA 93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) LAURI MARINO
C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6842

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

USPS CAMARILLO CA 93010 FEB 17 2011

7010 1060 0000 1514 6859

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Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To SKIP FANIA
Street, Apt. No.; or PO Box No. DISTRICT SUPERINTENDENT
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
SKIP FANIA
DISTRICT SUPERINTENDENT
SOUTHERN CALIFORNIA
WATER CO.
4680 LOS ANGELES AVE
UNIT H SIMI VALLEY CA
93065

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

RECEIVED FEB 14 CALIFORNIA

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6859

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 6866

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Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To RON FUCHIWAKI
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
RON FUCHIWAKI
DIRECTOR OF PUBLIC WORKS
CITY OF SIMI VALLEY
2929 TAPO CANYON RD
SIMI VALLEY CA 93063

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X Joe Collis ☐ Agent ☒ Addressee

B. Received by (Printed Name) C. Date of Delivery
JOE COLLIS 2/14/11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☒ No

RECEIVED FEB 14 2011

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6866

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 6880

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Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To DON JENSEN
Street, Apt. No.; or PO Box No. GENERAL MANAGER
City, State, ZIP+4

PS Form 3800, August 2006 See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
DON JENSEN
GENERAL MANAGER
CALIFORNIA WATER
SERVICE 2524
TOWNSGATE SUITE
WESTLAKE VILLAGE
CA 91361

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name) C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

FEB 14 2011

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6880

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 6897

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To SUSAN KIRKPATRICK
Street, Apt. No.; or PO Box No. BERNWOOD HEIGHTS
City, State, ZIP+4

PS Form 3800, August 2006 See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
SUSAN KIRKPATRICK
BERNWOOD HEIGHTS
MUTUAL WATER CO.
P.O. BOX 3555
CAMARILLO, CA
93011

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name) C. Date of Delivery
SUSAN KIRKPATRICK

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

FEB

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6897

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com.

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To JOHN KRIST
Street, Apt. No.; or PO Box No. CHIEF EXECUTIVE
City, State, ZIP+4

7010 1060 0000 1514 6903

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
JOHN KRIST
CHIEF EXECUTIVE
OFFICER FARM
BUREAU OF VENTURA
COUNTY 5166 MCGRATH
STREET VENTURA CA.
93001

COMPLETE THIS SECTION ON DELIVERY

A. Signature X ☐ Agent ☐ Addressee
B. Received by (Printed Name) RAFAEL M. WOODPECK C. Date of Delivery
D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☐ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6903

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com.

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To LUCIE MCGOVERN
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

7010 1060 0000 1514 6934

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
LUCIE MCGOVERN
DEPUTY DIRECTOR OF
PUBLIC WORKS
CITY OF CAMARILLO
601 CARMEN DRIVE
CAMARILLO CA 93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature X ☐ Agent ☐ Addressee
B. Received by (Printed Name) J Starr C. Date of Delivery 3-14-11
D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☐ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6934

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

U.S. Postal Service
CERTIFIED MAIL™ RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com®

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To: MARK LAWLER
Street, Apt. No.; or PO Box No.: GENERAL MANAGER
City, State, ZIP+4

7010 1060 0000 1514 6927

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

MARK LAWLER
GENERAL MANAGER
VENTURA COUNTY REG.
SANITATION DISTRICT
1001 PARTRIDGE DR
SUITE 150 VENTURA CA 93003

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6927

PS Form 3811, February 2004 Domestic Return Receipt

COMPLETE THIS SECTION ON DELIVERY

A. Signature: Rio Rodriguez ☐ Agent ☐ Addressee
B. Received by (Printed Name): D. Rodriguez C. Date of Delivery: FEB 14 2005
D. Is delivery address different from item 1? ☐ Yes If YES, enter delivery address below: ☐ No

3. Service Type: ☒ Certified Mail ☐ Express Mail ☐ Registered ☐ Return Receipt for Merchandise ☐ Insured Mail ☐ C.O.D.
4. Restricted Delivery? (Extra Fee) ☐ Yes

U.S. Postal Service
CERTIFIED MAIL™ RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com®

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To: MOORPARK LIBRARY
Street, Apt. No.; or PO Box No.:
City, State, ZIP+4

7010 1060 0000 1514 7047

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

MOORPARK LIBRARY
699 MOORPARK AVE
MOORPARK CA 93021

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7047

PS Form 3811, February 2004 Domestic Return Receipt

COMPLETE THIS SECTION ON DELIVERY

A. Signature: X Thank ☐ Agent ☐ Addressee
B. Received by (Printed Name): C. Date of Delivery: 2/2
D. Is delivery address different from item 1? ☐ Yes If YES, enter delivery address below: ☐ No

3. Service Type: ☒ Certified Mail ☐ Express Mail ☐ Registered ☐ Return Receipt for Merchandise ☐ Insured Mail ☐ C.O.D.
4. Restricted Delivery? (Extra Fee) ☐ Yes

7010 1060 0000 1514 7054

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To OXNARD LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
OXNARD LIBRARY
251 SOUTH A STREET
OXNARD CA 93030

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X DL
☐ Agent
☐ Addressee

B. Received by (Printed Name)
C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7054

PS Form 3811, February 2004 Domestic Return Receipt

7010 1060 0000 1514 6941

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To Reddy PAKALA
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
Reddy PAKALA
GENERAL MANAGER
VENTURA COUNTY WATER
WORKS 67607 Spring
Rd. MOORPARK CA
93020

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name) Mom Pakala
C. Date of Delivery 7/4

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6941

PS Form 3811, February 2004 Domestic Return Receipt

7010 1060 0000 1514 7061

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To PORT HUENEME LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
PORT HUENEME LIBRARY
510 PARK AVE
PORT HUENEME
CA 93041

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name) C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☑ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7061

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 6972

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To CAROL SCHOEN
Street, Apt. No.; or PO Box No.
City, State, ZIP+4 GENERAL MANAGER

PS Form 3800, August 2006 See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
CAROL SCHOEN
GENERAL MANAGER
ZONE MUTUAL
WATER CO.
P.O. BOX 239
SOMIS CA
93066

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name) C. Date of Delivery
Carol Schoen 2-17-4

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☑ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6972

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 6989

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To PETER SHAW
Street, Apt. No. or PO Box No. PROJECT MANAGER
City, State, ZIP+4

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

PETER SHAW
SR PROJECT MANAGER
CAL-AMER. CAL
WATER CO.
1033B AVE. STE #200
MORRO BAY CA 93442

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☒ Agent
☐ Addressee

B. Received by (Printed Name)
C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

RECEIVED
FEB 1 2011

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 6989

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7078

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To SIMI VALLEY LIBRARY
Street, Apt. No. or PO Box No.
City, State, ZIP+4

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

SIMI VALLEY LIBRARY
2969 TAPO CANYON RD
SIMI VALLEY CA
93063

RECEIVED
FEB 1 2011

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name)
C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

FEB 14 2011
1107

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7078

PS Form 3811, February 2004 Domestic Return Receipt

7010 1060 0000 1514 6965

U.S. Postal Service™
CERTIFIED MAIL™ RECEIPT
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For delivery information visit our website at www.usps.com®

OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: MARTY ROBINSON

Street, Apt. No.; or PO Box No.

City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

MARTY ROBINSON
COUNTY EXECUTIVE
OFFICER COUNTY
OF VENTURA
800 S. VICTORIA AVE
VENTURA CA 93009

COMPLETE THIS SECTION ON DELIVERY

A. Signature: X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name): ROGER BOULEY C. Date of Delivery: FEB 1 4 2011

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label): 7010 1060 0000 1514 6965

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 6996

U.S. Postal Service™
CERTIFIED MAIL™ RECEIPT
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For delivery information visit our website at www.usps.com®

OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: E. MICHAEL SOLOMON

Street, Apt. No.; or PO Box No.: GENERAL MANAGER

City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

E. MICHAEL SOLOMON
GENERAL MANAGER
UNITED WATER CONSERVATION
DISTRICT 1020 N. 5TH
ST. SANTA PAULA
CA. 93060

COMPLETE THIS SECTION ON DELIVERY

A. Signature: X [signature] ☒ Agent ☐ Addressee

B. Received by (Printed Name): Michael K Cochran C. Date of Delivery: 2-17-11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

RECEIVED FEB 22 2011 CA 93060

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label): 7010 1060 0000 1514 6996

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7085

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $ 6

Postmark Here

Sent To THOUSAND OAKS LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
THOUSAND OAKS LIBRARY
1401 E. JANSS Rd.
THOUSAND OAKS CA.
91362

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name) SUSAN ELIAS
C. Date of Delivery 2-14-11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

FEB 14 2011

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7085

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7016

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To MARK WATKINS
Street, Apt. No.; or PO Box No. PUBLIC WORKS
City, State, ZIP+4 DIRECTOR

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
MARK WATKINS
PUBLIC WORKS DIRECTOR
CITY OF THOUSAND OAKS
2100 THOUSAND OAKS
BLVD. THOUSAND OAKS, CA
91362

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name)
C. Date of Delivery 02-14-11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7016

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7092

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To DOUGLAS WILLFORD
Street, Apt. No.; or PO Box No. DEPUTY EXECUTIVE
City, State, ZIP+4

PS Form 3800, August 2006 See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
DOUGLAS WILLFORD
DEPUTY EXECUTIVE
DIRECTOR SOUTHERN
CAL. ASSOC. OF GOV.
950 COUNTY SQUARE
VENTURA CA 93009

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name)
C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number
(Transfer from service label) 7010 1060 0000 1514 7092

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7023

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To ALFRED VAREZ
Street, Apt. No.; or PO Box No. CAL-AMERICAN WATER
City, State, ZIP+4

PS Form 3800, August 2006 See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
ALFRED VAREZ
CAL AMERICAN WATER CO
VILLAGE DISTRICT
2439 W. HILLCREST DR
NEWBURY PARK CA 91320

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name)
C. Date of Delivery 2-14-11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number
(Transfer from service label) 7010 1060 0000 1514 7023

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

UNITED STATES POSTAL SERVICE

Track & Confirm

Search Results

Label/Receipt Number: **7010 1060 0000 1514 6958**
Service(s): **Certified Mail™**
Status: **Delivered**

Your item was delivered at 12:24 pm on February 14, 2011 in CAMARILLO, CA 93012

Track & Confirm
Enter Label/Receipt Number
Go >

Detailed Results

- **Delivered, February 14, 2011, 12:24 pm, CAMARILLO, CA 93012**
- **Notice Left, February 12, 2011, 9:39 am, CAMARILLO, CA 93010**
- **Arrival at Unit, February 12, 2011, 8:03 am, CAMARILLO, CA 93010**

Notification Options

Track & Confirm by email

Get current event information or updates for your item sent to you or others by email. Go >

7010 1060 0000 1514 6958

U.S. Postal Service™
CERTIFIED MAIL™ RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)
For delivery information visit our website at www.usps.com®

OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: Frank Lower
Street, Apt. No.; or PO Box No.: 6 Arcadia Market
City, State, ZIP+4:

PS Form 3800, August 2006 See Reverse for Instructions

UNITED STATES POSTAL SERVICE

Home | Help | Sign In

Track & Confirm FAQs

Track & Confirm

Search Results

Label/Receipt Number: **7010 1060 0000 1514 7009**
Service(s): **Certified Mail™**
Status: **Delivered**

Your item was delivered at 8:33 am on February 15, 2011 in BRANDEIS, CA 93064

Track & Confirm
Enter Label/Receipt Number
Go >

Detailed Results

- **Delivered, February 15, 2011, 8:33 am, BRANDEIS, CA 93064**
- **Arrival at Unit, February 12, 2011, 4:29 am, SIMI VALLEY, CA 93063**

Notification Options

Track & Confirm by email

Get current event information or updates for your item sent to you or others by email Go >

7010 1060 0000 1514 7009

U.S. Postal Service™
CERTIFIED MAIL™ RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com®

OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: JOHN WALSH
Street, Apt. No.; or PO Box No. 2 HAYES PLACE
City, State, ZIP+4 SIMI VALLEY

PS Form 3800, August 2006 See Reverse for Instructions

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For Double Sided Printing

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Notice of Adoption of the
Calleguas Municipal Water District

2010 Urban Water Management Plan

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For Double Sided Printing

Distribution List
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Calleguas Municipal Water District

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7010 1060 0000 1514 7221

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To BOB BUTLER
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, January 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
BOB BUTLER
27756 AVE. MONTRY
VALENCIA CA. 91355

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) [illegible] C. Date of Delivery 5/26/11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7221

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7247

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To CALIFORNIA STATE LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
CALIFORNIA STATE LIBRARY P.O. BOX 942837 SACRAMENTO CA. 94237-0001

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) CARL MONTILLA C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☐ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article N
(Transfer

PS Form 3

7010 1060 0000 1514 7214

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com.

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To NORMA CAMACHO
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
NORMA CAMACHO
DIRECTOR VENTURA
COUNTY WATERSHED
PROTECTION DISTRICT
800 S. VICTORIA AVE.
VENTURA CA. 93009-
1610

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) ROGER ROULEY
C. Date of Delivery MAY 26 2011

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7214

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7504

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com.

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To CAMARILLO LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
CAMARILLO LIBRARY
4101 LAS POSAS
RD. CAMARILLO
CA. 93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☒ Addressee

B. Received by (Printed Name)
C. Date of Delivery 5/26

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7504

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To: ANN DEMARTINI
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

7010 1060 0000 1514 7238

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
ANN DeMARTINI
GENERAL MANAGER
SOLANO VERDE MUTUAL
WATER CO.
P.O. BOX 1248
SOMIS CA. 93060

COMPLETE THIS SECTION ON DELIVERY

A. Signature: X [signature] ☐ Agent ☐ Addressee
B. Received by (Printed Name): ANN DEMARTINI
C. Date of Delivery: 5-26-11
D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7238

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

LEFT NOTICE 6/10
LEFT NOTICE 6/4
BUSINESS CLOSED

Sent To: JERRY DORAN
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

7010 1060 0000 1514 7245

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
JERRY DORAN
WATER SUPERINTENDENT
PLEASANT VALLEY
MUTUAL WATER CO
1863 LAS POSAS RD.
CAMARILLO, CA. 93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature: X Beth Ward ☐ Agent ☐ Addressee
B. Received by (Printed Name): Beth Ward
C. Date of Delivery: 6-7-11
D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No
JUN 03 2011

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7245

[redacted] Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7252

U.S. Postal Service
CERTIFIED MAIL™ RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com.

OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: ANTHONY EMMERT

Street, Apt. No.; or PO Box No.

City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

ANTHONY EMMERT
WATER RESOURCES
MANAGER CITY OF OXNARD
251 HAYES
OXNARD CA. 93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature: X Rebecca Cook — ☐ Agent ☐ Addressee

B. Received by (Printed Name): Rebecca Cook — C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

MAR 21 2011 USPS-ACCTG

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label): 7010 1060 0000 1514 7252

PS Form 3811, February 2004 — Domestic Return Receipt — 102595-02-M-1540

7010 1060 0000 1514 7269

U.S. Postal Service
CERTIFIED MAIL™ RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com.

OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: ROBERT ERANIO

Street, Apt. No.; or PO Box No.

City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

ROBERT ERANIO
GENERAL MANAGER
CREST VIEW MUTUAL
WATER CO.
378 VALLEY VISTA
DR. CAMARILLO CA
93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature: X Robert Eranio — ☐ Agent ☐ Addressee

B. Received by (Printed Name): ERANIO — C. Date of Delivery: 3-JAN-11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label): 7010 1060 0000 1514 7269

PS Form 3811, February 2004 — Domestic Return Receipt — 102595-02-M-1540

7010 1060 0000 1514 7436

U.S. Postal Service™
CERTIFIED MAIL™ RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com®

OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: EDGAR FANDALIAN
Street, Apt. No.; or PO Box No.: MET RO WATER
City, State, ZIP+4:

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
EDGAR FANDALIAN
METROPOLITAN
WATER DISTRICT
OFS.C
P.O. BOX 54153
L.A. CA. 90054-
0153

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) JUN
C. Date of Delivery 0 1 2011

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7436

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7276

U.S. Postal Service™
CERTIFIED MAIL™ RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com®

OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: SKIP FARIA
Street, Apt. No.; or PO Box No.:
City, State, ZIP+4:

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
SKIP FARIA
DISTRICT SUPERINTENDENT
SOUTHERN CALIFORNIA
WATER CO.
4680 LOS ANGELES AVE.
UNIT H SIMI VALLEY CA
93065

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name)
C. Date of Delivery 5/27

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

MAY 27 2011

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7276

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7306

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To SUSAN KIRKPATRICK

Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
Print your name and address on the reverse so that we can return the card to you.
Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

SUSAN KIRKPATRICK
BEVERLYWOOD HEIGHTS
MUTUAL WATER CO.
1852 HARVEST LANE
CAMARILLO CA. 93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X
☐ Agent
☐ Addressee

B. Received by (Printed Name)
C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☑ Certified Mail ☐ Express Mail
☑ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7306

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7283

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To RON FUCHIWAKI

Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:

RON FUCHIWAKI,
DIRECTOR OF PUBLIC
WORKS CITY OF SIMI
VALLEY 2929 TAPO
CANYON ROAD SIMI VALLEY
CA. 93063

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X Joe Corrillo
☐ Agent
☑ Addressee

B. Received by (Printed Name) JOE CORRILLO
C. Date of Delivery 5-26-11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

MAY 27 2011

3. Service Type
☑ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7283

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7320

U.S. Postal Service™
CERTIFIED MAIL™ RECEIPT
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For delivery information visit our website at www.usps.com®

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To DAVE KLOTZLE
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
DAVE KLOTZLE
DIRECTOR OF PUBLIC
WORKS CITY OF
MOORPARK 799
MOORPARK AVE.
MOORPARK CA. 93021

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) C. Date of Delivery
5/26

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7320

PS Form 3811, February 2004 Domestic Return Receipt

7010 1060 0000 1514 7313

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OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To JOHN KRIST
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
JOHN KRIST
CHIEF EXECUTIVE
OFFICER FARM
BUREAU OF VENTURA
COUNTY 566 MORATH ST.
VENTURA CA 93003

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7313

PS Form 3811, February 2004 Domestic Return Receipt

7008 1830 0003 5700 4547

U.S. Postal Service™
CERTIFIED MAIL™ RECEIPT
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OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To MARK LAWLER
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
MARK LAWLER
GENERAL MANAGER
VENTURA COUNTY
REGIONAL SANITATION
DISTRICT 1001 PARTRIDGE
DR. STE. #150 VENTURA
CA. 93003

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X Eli Rodriguez ☐ Agent ☐ Addressee

B. Received by (Printed Name) D. Rodriguez
C. Date of Delivery MAY 26 2011

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7008 1830 0003 5700 4547

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7139

U.S. Postal Service™
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OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Delivered 6/6 9:23 AM 2011 LEFT NOTICE 6/4

Sent To LUCIE MCGOVERN
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
LUCIE MCGOVERN
DEPUTY DIRECTOR
OF PUBLIC WORKS
CITY OF CAMARILLO
601 CARMEN DRIVE
CAMARILLO CA
93010

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X J. Starr ☐ Agent ☐ Addressee

B. Received by (Printed Name) J. STARR
C. Date of Delivery 6-6-11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7139

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

U.S. Postal Service
CERTIFIED MAIL RECEIPT
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For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To
MOORPARK LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

7010 1060 0000 1514 7481

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
MOORPARK LIBRARY 699 MOORPARK AVE MOORPARK CA 93021

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) C. Date of Delivery
5/26

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☐ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7481

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

U.S. Postal Service
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For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To
OXNARD LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

7010 1060 0000 1514 7474

PS Form 3800, August 2006

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
OXNARD LIBRARY 251 SOUTH A STREET OXNARD CA 93030

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

MAY 26 2010

3. Service Type
☐ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

3. Article Number (Transfer from service label) 7010 1060 0000 1514 7474

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

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OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To PORT HUENEME LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

7010 1060 0000 1514 7447

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
PORT HUENEME LIBRARY 510 PARK AVE. PORT HUENEME CA. 93041

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) | C. Date of Delivery 5-26

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☐ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7447

PS Form 3811, February 2004 Domestic Return Receipt

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OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To Reddy PAKALA
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

7010 1060 0000 1514 7454

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
Reddy PAKALA GENERAL MANAGER VENTURA COUNTY WATER WORK DISTRICT 1 & LCCSD 6767 Spring Rd MOORPARK CA. 93020

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) Kevin Rickard | C. Date of Delivery 5/20/1

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7454

PS Form 3811, February 2004 Domestic Return Receipt

7010 1060 0000 1514 7153

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OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To MICHAEL POWERS
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
MICHAEL POWERS
COUNTY OF VENTURA
800 S. VICTORIA
AVE. VENTURA
CA. 93009

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name) ROGER BOULEY
C. Date of Delivery MAY 25 2011

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7153

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7160

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OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Delivered June 6th 2011 1:18 PM

Sent To FRANK ROYER
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
FRANK ROYER
GENERAL MANAGER
CAMROSA WATER
DISTRICT 7385
SANTA ROSA ROAD
CAMARILLO CA. 93012-
8998

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X [signature] ☐ Agent ☐ Addressee

B. Received by (Printed Name)
C. Date of Delivery 6-10-11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7160

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7177

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OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: CAROL SCHOEN

Street, Apt. No.; or PO Box No.

City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
CAROL SCHOEN
GENERAL MANAGER
ZONE MUTUAL
WATER CO.
P.O. BOX 739
SOMIS, CA. 93066

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X Carol Schoen — ☐ Agent ☒ Addressee

B. Received by (Printed Name): Carol Schoen — C. Date of Delivery: 5/26/11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label): 7010 1060 0000 1514 7177

PS Form 3811, February 2004 — Domestic Return Receipt — 102595-02-M-1540

7010 1060 0000 1514 7184

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OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: Peter Sher

Street, Apt. No.; or PO Box No.

City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
Peter Sher
Sr. PROJECT MANAGER
CALIFORNIA -
AMERICAN WATER
CO 1033 B AVE. STE. #200
CORONADO CA. 92118

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X Matthew W. — ☒ Agent ☐ Addressee

B. Received by (Printed Name): Matthew Warren — C. Date of Delivery: 5/27/11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label): 7010 1060 0000 1514 7184

PS Form 3811, February 2004 — Domestic Return Receipt — 102595-02-M-1540

7010 1060 0000 1514 7450

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

For delivery information visit our website at www.usps.com

OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To SIMI VALLEY LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
SIMI VALLEY LIBRARY 2969 TAPO CANYON RD. SIMI VALLEY CA 93063

COMPLETE THIS SECTION ON DELIVERY

A. Signature
X Hazel Dunlap ☐ Agent ☐ Addressee

B. Received by (Printed Name) HAZEL DUNLAPSTER
C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7450

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7191

U.S. Postal Service
CERTIFIED MAIL RECEIPT
(Domestic Mail Only; No Insurance Coverage Provided)

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OFFICIAL USE

Postage $
Certified Fee
Return Receipt Fee (Endorsement Required)
Restricted Delivery Fee (Endorsement Required)
Total Postage & Fees $

Postmark Here

Sent To MICHAEL SOLOMAN
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
E. MICHAEL SOLOMON
GENERAL MANAGER
UNITED WATER CONSERVATION DISTRICT
106 NORTH 8TH ST
SANTA PAULA, CA 93060

COMPLETE THIS SECTION ON DELIVERY

A. Signature
x M. Kinnun ☐ Agent ☐ Addressee

B. Received by (Printed Name) M Kinnun
C. Date of Delivery 5-26-11

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☒ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7191

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

7010 1060 0000 1514 7290

U.S. Postal Service™
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OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: CARMELO SORCE
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
CARMELO SORCE
DISTRICT MANAGER
CALIFORNIA WATER SERVICE
2524 TOWNSGATE STE A
WESTLAKE VILLAGE CA
91361

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7290

COMPLETE THIS SECTION ON DELIVERY

A. Signature X — ☐ Agent ☐ Addressee

B. Received by (Printed Name) — C. Date of Delivery 5/26

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☐ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

PS Form 3811, February 2004 — Domestic Return Receipt — 102595-02-M-1540

7010 1060 0000 1514 7368

U.S. Postal Service™
CERTIFIED MAIL™ RECEIPT
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OFFICIAL USE

Postage	$
Certified Fee	
Return Receipt Fee (Endorsement Required)	
Restricted Delivery Fee (Endorsement Required)	
Total Postage & Fees	$

Postmark Here

Sent To: THOUSAND OAKS LIBRARY
Street, Apt. No.; or PO Box No.
City, State, ZIP+4

PS Form 3800, August 2006 — See Reverse for Instructions

SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
THOUSAND OAKS
LIBRARY
1401 E. JANSS RD
THOUSAND OAKS
CA 91362

2. Article Number (Transfer from service label) 7010 1060 0000 1514 7368

COMPLETE THIS SECTION ON DELIVERY

A. Signature X — ☐ Agent ☐ Addressee

B. Received by (Printed Name) — C. Date of Delivery 5/26

D. Is delivery address different from item 1? ☑ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☑ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

PS Form 3811, February 2004 — Domestic Return Receipt — 102595-02-M-1540

7010 1060 0000 1514 7337

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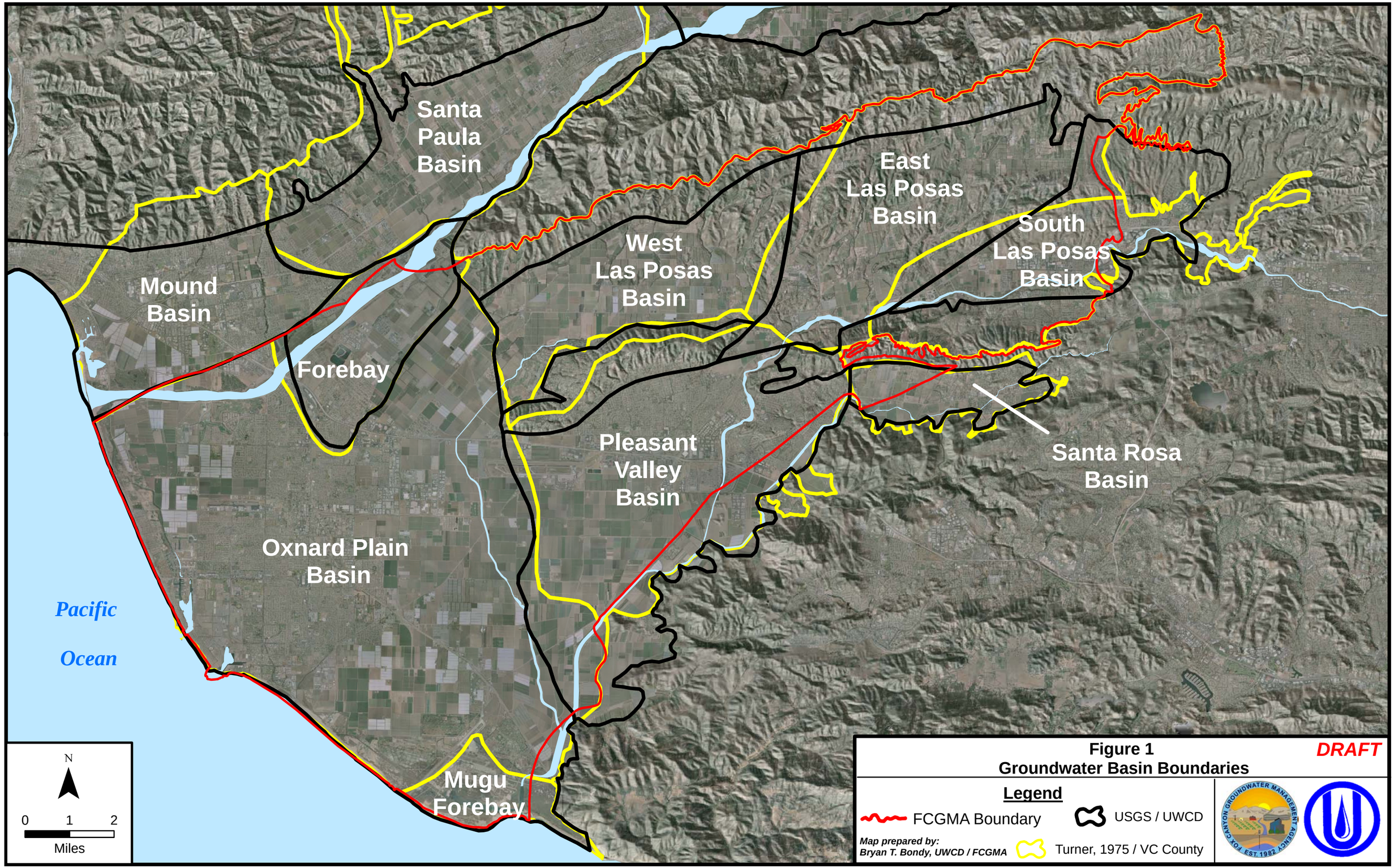

Figure 1
Groundwater Basin Boundaries

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Factors Influencing Invasion of Giant Reed (*Arundo donax*) in Riparian Ecosystems of Mediterranean-type Climate Regions

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Environmental Health Sciences

by

Gretchen Christina Coffman

2007

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The dissertation of Gretchen Christina Coffman is approved.

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University of California, Los Angeles

2007

DEDICATION

I dedicate this dissertation to my parents

Mary Lou Coffman

and

Glenn Norman Coffman

Without their constant love and support over the years

this dissertation would not have been possible.

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ABSTRACT OF THE DISSERTATION

Factors Influencing Invasion of Giant Reed (*Arundo donax*)

in Riparian Ecosystems of Mediterranean-type Climate Regions

by

Gretchen Christina Coffman

Doctor of Philosophy in Environmental Health Sciences

University of California, Los Angeles, 2007

Professor Richard F. Ambrose, Chair

Giant reed, *Arundo donax* L., is one of the greatest threats to riparian ecosystems of Mediterranean-type climate regions, including California. Forming extensive monotypic stands, *A. donax* increases the risks of flooding and fire, uses prodigious amounts of water, and reduces habitat value for wildlife. Urban and agricultural development adjacent to riparian ecosystems may contribute to its invasion success. The main hypothesis of my dissertation is that the current abundance of nutrients, water, light, and fire in riparian ecosystems of Mediterranean-type climate promotes *A. donax* invasion. A two-year field experiment in a riparian ecosystem on the Santa Clara River

in California showed that *A. donax* produced greater biomass than native species under high soil moisture, light, and nutrient levels, and its biomas-s in monoculture was much greater than most species and treatment levels. However, results suggest that high resource levels and this new plant functional group in these riparian ecosystems, rather than superior resource competition, promote *A. donax*'s competitive exclusion of native riparian species. Analysis of the influence of nutrient enrichment from residential and agricultural land use types on *A. donax* infestation throughout several coastal watersheds in Southern California revealed that floodplains with enriched soil NO_3-N supported *A. donax* infestations whereas sites with lower N levels did not. Unlike the native red willow (*Salix laevigata* Bebb.), *A. donax* may take advantage of anthropogenically enriched N (and K) levels in riparian ecosystems. Regarding fire, *A. donax* began regrowth from rhizomes immediately after being burned in October 2003 along the Santa Clara River whereas native riparian plants remained dormant for several months, and *A. donax* grew 3–4 times faster than native riparian plants. A year after the fire, *A. donax* dominated these burned areas (99% relative cover and a 24% increase in relative cover compared to pre-fire conditions). *Arundo donax* infestations appear to create an invasive plant-fire regime. These results help elucidate the optimal conditions for *A. donax* invasion of riparian ecosystems, which in turn can help prioritize control strategies and revegetation of riparian ecosystems.

CHAPTER 1 -

INTRODUCTION

Invasion of riparian ecosystems by the alien plant giant reed, *Arundo donax* L., is one of the most serious threats to rivers in Mediterranean-type climate regions worldwide. *Arundo donax* has successfully invaded many rivers in these regions, forming extensive monocultures and altering physical and biological processes. In California, infestations of *A. donax* are known to increase risks of flooding, create unnatural fire hazards, outcompeting indigenous riparian species for scarce water resources, and reduce the value of riparian habitat for most wildlife (Dudley and Collins 1995, Bell 1997, DiTomaso 1998, Dudley 2000). Although introduced several hundred years ago to southern California, rapid expansion of *A. donax* in natural riparian ecosystems appears to have occurred in the last 35 years (Bell 1997).

Researchers have suggested that natural and human disturbances, which are prevalent in Mediterranean-type climate regions such as California, are primary factors contributing to the extensive distribution of *A. donax* along rivers in these areas (Rieger and Kreager 1989, Bell 1997). Large winter floods occur naturally every few years and remove riparian plants from floodplains, thereby creating open substrates for recolonization. Pieces of *A. donax* (rhizomes and culms) are dispersed downstream during flooding and establish vegetatively wherever they are deposited (Else 1996, Else and Zedler 1996). However, natural disturbance along rivers is not a new phenomenon in Mediterranean-type climates; river systems have long been dynamic components of the

landscape in these regions (Mount 1995). Most physical human disturbance of rivers and their watersheds dates back to human settlement of these regions (Mount 1995, Rundel et al. 1998), which occurred much earlier than the onset of *A. donax* invasion. Therefore, other factors must contribute to the relatively recent success of this plant's invasion.

More recently, humans have altered riparian ecosystem processes by increasing nutrient delivery from adjacent land use practices, importing water for the ever-growing population, exporting water for agriculture, removing mature riparian vegetation for development, and increasing fire frequency in adjacent shrubland communities. I investigated the influence of these factors on invasion of rivers by *A. donax* in southern California. I hypothesized that increased nutrient, water, and light availability, as well as the introduction of fire into riparian ecosystems, has contributed to successful *A. donax* invasion in Mediterranean-type climate regions.

BACKGROUND

Throughout history, man has embraced the idea of cultivating exotic plants and animals worldwide for agricultural, aesthetic, and other purposes. However, moving biological organisms has created a human-induced breakdown of biogeographical barriers to species dispersal and many species that evolved separately are now living together (D'Antonio and Vitousek 1992, Richardson et al. 2000). As far back as 1958, Charles Elton wrote of the terrific dislocations in nature that mixing different organisms from various parts of the world would cause (Elton 1958). Despite his warning, consequences of these introductions of plants and animals had not been fully recognized until recently.

The problem of plant introductions[1] and resulting invasions[2] in Mediterranean-type climate regions has received considerable attention because these regions provide ideal climactic conditions for plant growth (Drake et al. 1989, D'Antonio and Dudley 1993). In California, plant invasions have occurred in many natural ecosystems, including grasslands, woodlands, wetlands, coastal dunes, salt marshes, and riparian areas (Kruger et al. 1989, Rejmanek 1989, Rejmanek et al. 1991). Aquatic ecosystems such as rivers and wetlands are among the world's most heavily invaded systems (Mooney et al. 1986, Kruger et al. 1989, Pysek and Prach 1994, Alpert et al. 2000, Rundel 2000). Natural and altered disturbance regimes and anthropogenic enhancement of nutrients are thought to contribute to success of plant invasion in rivers (Crawley 1986, Ashton and Mitchell 1989, Drake et al. 1989, Hobbs 1989, Hobbs and Huenneke 1992, Alpert et al. 2000).

Riparian ecosystems occupy a unique area in the landscape; as ecotones between aquatic and terrestrial ecosystems, they have naturally high species diversity, a diverse array of biological and physical processes, and a mosaic of vegetation types and structural components due to natural disturbance regimes (Gregory et al. 1991, Malanson 1993, Naiman and Decamps 1997). Natural dynamic disturbance regimes of river and stream systems in Mediterranean-type climates likely promote the spread of invasive plant species through these systems. For example, intense but infrequent winter flooding

---

[1] Introduction implies human transport of a plant across a major geographic barrier.
[2] Invasion refers to an introduced plant that produces reproductive offspring in areas distant from the origin of its introduction (>100m in <50 years). Richardson et al. (2000) suggested several barriers to plant introduction, naturalization, and invasion by including geographic, environmental (local), reproductive, dispersal, environmental (disturbed habitats), and environmental (natural habitats).

scours stream corridors and exposes vast areas of sandy floodplain, channels, and terraces (Gasith and Resh 1999), rendering them vulnerable to disturbance colonizers, which are primarily invasive, weedy plants. Weedy plants are able to establish and grow quickly in these open disturbed areas, often out-competing the indigenous riparian plant species for light, water, and nutrients (Baker 1974).

Historically, riparian plant communities in Mediterranean-type climates have been particularly impacted by human perturbations due to the ephemeral and braided nature of the river systems in which they are found (Mount 1995). Since early human settlement of these areas, humans have dammed, channelized, mined, rerouted, diverted, and developed floodplains of rivers, resulting in great losses and degradation of associated riparian plant communities (Palmer 1993, Mount 1995). These alterations to river systems have left riparian plant communities susceptible to plant invasions by weedy species. Rapid expansion of urban and agricultural development into these regions in the last century has resulted in habitat fragmentation, reduction in biological diversity, and altered distribution of resources in these areas (i.e., water and nutrients) (Aschmann 1991, Palmer 1993). These anthropogenic land-use changes have created conditions that allow for large-scale plant invasion of remaining natural ecosystems (D'Antonio and Dudley 1993).

Arundo donax *Invasion*

Currently, one of the greatest invasive threats to the highly modified river ecosystems of Mediterranean-type climate regions is a tall bamboo-like member of the grass family (Poaceae), giant reed (*Arundo donax* L.). *Arundo donax* appears to be of a

broad southern Eurasian origin, extending from Southeast Asia to the Mediterranean Basin, although the precise extent of its native distribution is unclear (Perdue 1958, Zohary 1962, Hickman 1993). The relatively high diversity of herbivores associated with *A. donax* in the Mediterranean Basin compared to other areas where it grows suggests plant-animal co-evolution in that region (Kirk et al. 2003), but *A. donax* might have a broader indigenous range. Introduced to other areas primarily for building materials, erosion control, and windbreaks, it is now successfully established in freshwater systems in tropical to temperate climates worldwide (Polunin and Huxley 1987). In the U.S., *A. donax* has become especially widespread in riparian ecosystems in California's Mediterranean-type climate (Fischer et al. 1978). Although *A. donax* is thought to have been introduced to southern California for building materials and erosion control as early as the 1700s, and it was abundant along the Los Angeles River in the 1820s (Robbins et al. 1951), its widespread expansion in riparian ecosystems appears to be recent (Bell 1997). Currently, *A. donax* infests almost every stream and river system in coastal southern California (Gaffney 2002) (Figure 1). Based on spatial data analyses, researchers estimate more than 1,500 acres of *A. donax* infestations occur throughout rivers in southern California, although only approximately one-third of the riparian areas in coastal southern California have been surveyed (Casanova et al. unpublished data). A comprehensive survey is in progress to verify coverage of *A. donax* infestations in the field throughout all streams and rivers in southern California (Giessow pers. comm.).

Although *A. donax* produces a long plume-like inflorescence with no viable seeds in California (Johnson et al. 2006), *A. donax* spreads rapidly downstream when small

pieces of the plant break off, land on bare, moist substrates, and begin to grow (Else 1996, Else and Zedler 1996, Bell 1997, Boose and Holt 1999, Decruyenaere and Holt 2005). Growing at an extremely high rate (4–10 cm per day under optimal conditions) and during all times of the year, *A. donax* quickly establishes on unvegetated or sparsely vegetated soil and grows taller than 2-4 m after only a few months and may eventually reach up to 8 m (Perdue 1958). Singh et al. (1997) suggested that *A. donax* thrives in a variety of soil types in its indigenous range in India. Under greenhouse conditions, rhizomes of *A. donax* rooted successfully during all months of the year and both rhizomes and stem fragments established under various temperatures, moisture conditions, and soil types (Boose and Holt 1999, Decruyenaere and Holt 2001). It then expands outward in area via its large rhizome or via layering (adventitious sprouting of stem tips in contact with the ground), crowding and even displacing indigenous shrubs, herbs, grasses, and eventually even trees, under elevated light, soil moisture, and nutrient conditions, (Boland 2006, Decruyenaere pers. comm.). Wang (1998) suggested that nutrient loading contributes to *A. donax* invasion, and several authors have proposed that fire might promote *A. donax* invasion because this species can respond more quickly to fire than natives (Bell 1994, DiTomaso 1998). In this manner, *A. donax* forms extensive stands or monocultures in riparian ecosystems along the floodplains and terraces of southern California's river and stream systems.

Impacts of Invasion

Infestations of *A. donax* have created serious physical and biological problems along rivers in southern California. Where it grows extensively along floodplains, *A.*

donax acts as a transformer species; it causes physical obstructions to natural water flow, thereby increasing the risk of flooding to adjacent lands. During large floods *A. donax* increases stream roughness, creates debris dams at bridge crossings, and causes bank erosion and instability (DiTomaso 1998). As the aboveground biomass dries in the hot, dry summer months that characterize Mediterranean-type climates, *A. donax* creates an unnatural fire hazard where moisture-rich riparian corridors used to form natural barriers to fire (Scott 1994, Rundel and Gustafson 2005). Water loss due to high evapotranspiration (ET) of *A. donax* reduces already scarce water resources in Mediterranean-type climate regions. Based on transpiration rates of rice (another C3 species thought to have similar transpiration rates), Iverson (1994) estimated that *A. donax* uses three times more water than native riparian species. Studies using a variety of methods indicate that ET of *A. donax* (1.2–7.5 m/year) may be much higher than that of native riparian vegetation such as *Salix* spp., *Populus* spp. (1.0–3.3 m/year) and mixed riparian communities of arid and Mediterranean-type climates (0.11–1.6 m/year) (Zimmerman 1999, Hendrickson and McGaugh 2005, Shafroth et al. 2005, Abichandani 2007, Coffman in press). Abichandani (2007) showed that *A. donax* infestations may transpire 6 to 110 times more (up to 18,206 kg m^{-2} $year^{-1}$) than native vegetation.

Arundo donax has very little known value as a wildlife habitat in California (Bell 1997, Kisner 2004) compared to the dominant native vegetation (Bell 1994, Herrera and Dudley 2003). Its stems and leaves contain an array of inorganic noxious chemicals (Jackson and Nunez 1964) that reduce herbivory by most native insects and grazers. Due to its dense clonal growth form, it physically restricts indigenous wildlife passage, yet

many animals depend on the riparian corridor and river floodplain for foraging, nesting, and cover (Kisner 2004). Like other invasive plants, *A. donax* appears to have negative impacts on indigenous plant and animal biodiversity through the loss of suitable habitat and competition with indigenous species (Czech and Krausman 1997). In addition, *A. donax* threatens river ecosystem sustainability via its impacts on natural river processes, such as lowering of the groundwater table, decreased surface water levels in streams, creating the potential for unnatural and extremely hot fires, and loss of plant and animal biodiversity.

Control of* Arundo donax *in California

Because of the numerous impacts of *A. donax* infestations on rivers, streams, and adjacent property, large-scale *A. donax* control efforts have been initiated throughout California since 1990 by several multi-agency organizations. For example, Team Arundo, a forum of local, state, federal, and private organizations dedicated to the control of *A. donax*, was formed in 1992 and leads control efforts along the Santa Ana River in southern California, where invasion has been a problem since 1969 (SAWPA 2007). In 2001, the Santa Ana River contained approximately 10,000 acres of *A. donax*-infested riparian habitat; Team Arundo is currently removing *A. donax* along this river on a watershed-scale. Formed in 1996, the Team Arundo del Norte partnership was modeled after the original Team Arundo and leads control and eradication efforts in Central and Northern California, where *A. donax* has more recently invaded (Team Arundo del Norte 2007).

Many local organizations also work on *A. donax* control at the county and watershed levels. For example, the Ventura County Arundo Task Force, led by the Ventura County Resource Conservation District, conducted a pilot removal project on the Ventura River in 2003 and plans to continue long-term watershed-wide eradication of *A. donax* in all major watersheds in Ventura County starting with the Santa Clara River. In the Malibu Creek watershed, the Resource Conservation District of the Santa Monica Mountains and Mountain Conservation Trust conducted an *A. donax* eradication project on 5.2 miles of the stream. Also, *A. donax* eradication is being used for compensatory riparian and wetland mitigation in California (Stein 1998). However, controversy continues over *A. donax* removal and herbicide use associated with its removal in the Topanga Canyon watershed (Topanga Online 2007).

Eradication of *A. donax* from watersheds in Mediterranean-type climates is an important initial step in restoration and long-term sustainability of riparian ecosystems. Various mechanical and hand-clearing techniques have been successful in removing small areas of *A. donax* infestations throughout California. Several researchers are investigating the ecophysiology of *A. donax* (e.g., relative growth rates and critical nitrogen content) to determine the most effective time to apply glyphosate-containing herbicides to kill the rhizomes of these plants (Spencer et al. 2005, Wijte et al. 2005). Research on biocontrol agents is underway; however, the U.S. Food and Drug Administration (USFDA) has not approved any yet. Based on the mechanisms by which it spreads and colonizes, *A. donax* removal efforts are primarily concentrated along higher riparian terraces, locations where it is less likely to reinvade (Coffman et al. 2004).

Removal from floodplain locations requires development of watershed-scale removal plans and permits that specify removal from the upstream most infestation working downstream. However, Boland (2006) proposed an inside-out approach for *A. donax* removal (i.e., conduct treatments first inside and then outside the flood zone) due to his documentation of the importance of layering. Researchers believe that revegetation of riparian areas with native plant species after *A. donax* removal is essential in preventing infestations of other weedy species. However, long-term eradication of *A. donax* from rivers and streams in Mediterranean-type climate regions may not be completely successful without knowledge of understanding how to manage the factors that contribute to its invasion and proper management of those factors.

***Riparian Ecosystem Restoration and* Arundo donax**

Degradation of ecosystem processes and functions by man-made physical and biological alterations threatens river systems worldwide (Naiman and Decamps 1997). River restoration projects have increased exponentially since 1995 and are being conducted across the U.S. to improve water quality, enhance in-stream and riparian habitat quality, re-establish fish passage, and provide bank stabilization (Bernhardt et al. 2005). Current watershed-level river and stream restoration efforts in California include removal of dams for fish passage, elimination of levees to allow for more natural channel migrating and meandering, releases of water from dams to simulate natural flooding, implementation of policies to reduce pollutants, and revegetation of natural riparian ecosystems. However, regardless of the restoration goal or activity, restoration success will depend on control of *A. donax* in the streams that it infests. For example, removing a

dam with upstream *A. donax* infestations without implementing control programs first would result in widespread dispersal of this species. Understanding the relationship between nutrient levels found in rivers, the sources of these nutrients, and *A. donax* versus native riparian species growth will help watershed managers formulate more realistic nutrient reduction policies and implementation plans. Understanding water use by *A. donax* compared to native riparian plants is critical to justifying funding of removal efforts due to its presumed high use of water in arid regions where water is limited (Abichandani 2007).

Watershed managers, restoration planners, *A. donax* eradication groups, conservation organizations, and many others require scientifically based management recommendations to control expansion of and remove *A. donax* effectively. Knowledge of how factors such as nutrient levels, water, light, and fire contribute to growth and invasion of *A. donax* is essential to long-term, large-scale control. However, little is know about the *A. donax* invasion process related to the factors. In this dissertation, I address the influence of water, nutrients, light, and fire on the *A. donax* invasion process. My aim was to provide valuable information about *A. donax* invasion and long-term restoration of riparian ecosystems in California and other Mediterranean-type climate regions.

Influence of Water, Nutrients, Light, and Fire on Invasion by **Arundo donax**

Water Availability

Mediterranean-type climate regions are characterized by wet winters and warm, dry summers that regulate natural ecosystems processes. Many rivers and streams in

these regions are intermittent (i.e., with loosing and gaining reaches) or ephemeral because of wetting and drying periods (Gasith and Resh 1999) and underlying geology (Malanson 1993). Ever-increasing population pressure in these regions has created intense competition for water, resulting in serious alterations to water quantity and quality in rivers and streams (Gasith and Resh 1999). The city of Los Angeles, for example, imports 88% of its water to supply water for drinking, agricultural irrigation, and industrial uses (Hazy 2006). This imported water is discharged into natural water bodies after use, in many cases with degraded water quality, thereby increasing flow in many streams and creating perennial systems. Groundwater abstracted for agricultural irrigation and rural residential uses adjacent to rivers may decrease flow.

Increased water quantity in stream systems of Mediterranean-type climates may promote growth of invasive species such as *A. donax*. Although *A. donax* reportedly can tolerate a wide variety of ecological conditions, it thrives in areas with high soil moisture such as along canals, ditches, and stream banks (Perdue 1958, Rezk and Edany 1979). Much higher transpiration of *A. donax* compared to native riparian plants such as *Salix* spp. and *Populus* spp. and mixed riparian communities typical of arid and Mediterranean-type climates may give it an advantage where water is abundant (Zimmerman 1999, Hendrickson and McGaugh 2005, Shafroth et al. 2005, Abichandani 2007). I hypothesized that *A. donax* would have a competitive advantage over those native species found to uptake water at a lower rates in river floodplains and terraces that receive increased water inputs from anthropogenic sources.

In riparian ecosystems in which water tables are lowered due to groundwater extraction or along naturally loosing reaches (i.e., river reaches that contribute water to the groundwater supply), the scenario is more complicated. The presence of sustained high soil moisture or near-surface shallow groundwater during the growing season is important for establishment of most species, although both *A. donax* (Perdue 1958) and *Bacharris salicifolia* are known to establish under very low soil moisture conditions. Once established, rooting depth, distribution, and structure relative to soil moisture and groundwater likely play a large role in growth and competition between *A. donax* and native species. *Salix* spp., *Populus* spp., *B. salicifolia*, and other woody riparian species are phreatophytes with adaptations to low soil moisture conditions; their roots follow the receding soil moisture and can use water from depths of up to 30 m (Robinson 1958). *Arundo donax* is a perennial grass with roots that can only reach ~3 m below the soil surface.

Nutrient Loading

During the twentieth century, nutrient inputs to river systems worldwide increased dramatically due primarily to expanding agricultural practices and municipal sewage discharge (Rundel et al. 1983, Tilman et al. 2000, Nicola 2003, FAOUN 2004). Follett and Hatfield (2001) reported groundwater nitrate concentrations under agricultural systems in the U.S. to be as high as 30mg/L in 2001, which is much higher than the EPA drinking water standards [less than 10ppm (mg/L)]. Southern California is no exception; agricultural activities and their associated nutrient inputs are widespread along river systems of southern California (Mount 1995, Pedersen 2001). Other important

anthropogenic and natural sources of N and P that likely contribute to nutrient loading in river systems include: atmospheric N; manure from animal feedlots and corrals; fertilizer applied to lawns; leaky septic tanks; oxidation of organic materials; and the increased abundance of symbiotic N-fixing plants (Verhoeven et al. 1996, USEPA 1999).

Composition and increase in use of fertilizer has led to extensive nutrient loading of river systems, with mainly nitrogen (N) and phosphorus (P) (Nicola 2003). Global fertilizer use has increased more than fourfold, from 31.2 million tons in 1961 to 137.7 million tons in 2001 (FAO 2004). Total global nitrogen fertilization is expected to increase by 12.9% during the next 15 years and 23.7% in the next thirty years (FAOUN 2004). By 2050, Tilman et al. (2000) predicted that the global rates of nitrogen and phosphorus fertilization will be 2.5 times and 2.4 times, respectively, that of current levels. In the U.S., annual fertilizer use in agricultural areas has increased from 24.9 in 1959 to 53 million tons in 2001 and continues to increase (FAOUN 2004). Currently, nitrogen fertilizers represent about 55% of all fertilizer uses, followed by phosphate at 26%. In the U.S., the average percent of nitrogen, the main constituent in commercial fertilizers, has risen from 11% in 1959 to 22.7% in 2001 (FAOUN 2004).

Anthropogenic nutrient enrichment of natural ecosystems has been linked to plant invasions worldwide (Mooney et al. 1986, Drake et al. 1989, D'Antonio and Vitousek 1992, Hobbs and Huenneke 1992, Vitousek et al. 1996, Brooks 2003). Excess N and P from fertilizers used in agriculture, golf courses, and residential lawns, as well as treated wastewater effluent, have contributed to nutrient loading in rivers across the U.S. (USEPA 1999). Nutrient enrichment and the dynamics of riparian ecosystems in

agricultural landscapes in the eastern U.S. and Western Europe have been well studied (Peterjohn and Correll 1984, Gilliam 1994, Hill 1996, Bennett et al. 2005). However, limited information exists about these processes in Mediterranean-type climates such as southern California (Kim 2003, Robinson et al. 2005).

The effects of increased nutrient levels on plant composition and invasion may be even more profound in streams of Mediterranean-type climate regions compared to other regions of the world because they have naturally low levels of nitrogen and phosphorous (Day 1983, diCastri 1991, Dallman 1998). Plant species that are restricted to non-fertile sites generally respond less to nutrient addition or nutrient supply than do the same species from more fertile soils (Chapin et al. 1986). Hellmers et al. (1955) reported that the nitrogen-limiting conditions found in chaparral communities in southern California also exist in riparian ecosystems; thus, excess nitrogen from adjacent land use practices might promote *A. donax* growth and invasion in riparian ecosystems of southern California and other Mediterranean-type climate regions (Wang 1998). A demographic study of *A. donax* in southern California indicated that *A. donax* tends to spread radially or invade under nutrient-rich conditions, and it ceases spreading and establishes relatively dense clumps under nutrient-poor conditions (Decruyenaere and Holt 2001, Decruyenaere pers. comm. October 5, 2001). Preliminary results of another study indicate that *A. donax* biomass is greater than that of *Salix laevigata* under conditions of no nitrogen (0 g/m^2 N) and high levels of nitrogen addition (12–14 g/m^2 N) (Dudley unpublished data), whereas *S. laevigata* grows larger than *A. donax* at nutrient addition levels of $4g/m^2$. Seasonal drought conditions confine nutrient availability to wetter times

of the year and to areas with perennially high soil moisture retention regardless of nutrient inputs, potentially influencing invasion dynamics.

Excess nitrogen and phosphorus contained in surface and shallow groundwater are transported from land use activities to adjacent river ecosystems (Schlosser and Karr 1981, Correll 1984, Correll et al. 1992, Triska et al. 1994, Rodda 1995, Basnyat et al. 1999). Although the quantity of N and P in the shallow groundwater and soil is important to plant productivity, only certain constituents of N and P are readily available to plants. Plants absorb and assimilate both NO_3^- and NH_4^+ most readily. Nitrogen found in the form of NO_3^- and NH_4^+ in fertilizer and wastewater is water-soluble and moves quickly through soils in the shallow groundwater between agricultural practices, wastewater treatment plants, and adjacent river systems. Widely known as the primary productivity-enhancing nutrient, N assimilation and metabolism is complex and under genetic control (Duncan 1994). Although not addressed in this study, atmospheric N in the form of air pollution is a growing source of this nutrient for plants (Verhoeven et al. 1996). Because plant species vary in their ability to uptake atmospheric N through their stomata (Stark 1994), this anthropogenic source should be examined further.

Phosphorus is an insoluble mineral that readily adsorbs to soil particles, which are then transported to river systems through overland runoff and soil erosion. Required for many metabolic processes, P is absorbed rapidly into plant roots but requires active uptake due to steep concentration gradients between the soil solution and plant roots (Shuman 1994). Plants can uptake P only when dissolved in water as ortho-phosphates

or poly-phosphates, and the rate of uptake is highly pH-dependent (optimal uptake at pH 6.5) (Shuman 1994).

The majority of water and minerals absorbed by plants enters through the root system. The ability of plants to assimilate nutrients available in the surrounding soil and groundwater depends on the development of an extensive root system and on rooting structure (Kozlowski et al. 1991). Root morphology and architecture differ between monocots, such as *A. donax,* and dicots like *Salix laevigata* (Taiz and Zeiger 1991). The physiological strategies of both plants differ greatly due to their inherent structure. *A. donax* roots are fibrous and tend to be shallower than those of *S. laevigata*, which has a taproot that can extend 30 m or more to groundwater. Thus, *A. donax* may utilize nutrients in the upper soil profile and shallower groundwater compared to phreatophytes like *S. laevigata* from loosing stream reaches in which groundwater is deep.

The supply of N and P in the soil and the availability of these nutrients to plants in the soil medium can vary greatly based on soil grain size and pH (Metz et al. 1966). Variability in soil grain size leads to variability in soil moisture content, which in turn affects rates of both nutrient diffusion transport and biological activity. Soil grain size has a strong influence on water and nutrient retention in soils: Coarser soil grain sizes retain less water than finer particle soils, such as clay and silt, and have a lower cation exchange capacity due to lower surface area (Kozlowski et al. 1991; Taiz and Zeiger 1991). Soils with higher cation exchange capacity supply more minerals to roots. Mineral ions are either adsorbed onto the surface of soil particles or exist in soil solution. The cation NH_4^+ may be found dissolved in water or associated with aerobic soils in

which it oxidizes quickly into NO_2^- and NO_3^- (nitrification) or reacts with other components in the soil to form ammonium salts. Because NO_2^- and NO_3^- are highly soluble in water due to their negative charge, concentrations of these nutrients in the soil water solution tend to be lower in well-drained coarser grained soils. Conversely, negative charges on the soil particle surface promote adsorption of mineral cations such as phosphate, which bind readily to clay particles (containing aluminum or iron) and are not easily lost to groundwater or available to plants.

Light Availability

Light availability influences plant invasion in many ecosystems, due to both vegetation removal and direct effects of shading by invasive species (Crawley 1987, D'Antonio and Vitousek 1992, Yamashita et al. 2000, Meekins and McCarthy 2001, Fargione and Tilman 2002). Reduction in light availability may act as a barrier to invasion in both disturbed and natural habitats (Richardson et al. 2000). Plant species vary greatly in the amount of light they require for colonization and optimal growth (Treshow 1970, Menges and Waller 1983). Although the specific light requirements of *A. donax* and the dominant riparian plant species in California are not well known (Braatne et al. 1996), D'Antonio and Vitousek (1992) reported that invasive grass species prevent establishment and growth of woody species by shading them. Dudley (1998) suggested that monocultures (large infestations) of *A. donax* limit native riparian plant recruitment through light reduction, but the mechanisms behind this phenomenon are still unknown (Dudley 1998). Furthermore, light limitations can promote strong belowground competition between species (Schenk 2006).

Occurrence of Fire

Wildfires ignited by man at unnatural and dangerous times of the year burn rapidly through riparian corridors infested with *A. donax* and may help spread fires across watersheds and along riparian corridors. Historically, dense biomass that accumulated over a period of 30–50 years or more in chaparral communities of California and shrublands in other Mediterranean-type climate regions caused fires to ignite (Minnich 1983, Keeley et al. 1999, Keeley and Fotheringham 2001, 2005). Although fire was once a natural part of shrubland ecosystems in many Mediterranean-type climate regions, large riparian ecosystems provided natural firebreaks because native vegetation retained foliar water that resisted ignition (Bell 1994). Lightning was the primary cause of wildfires, especially during the summer and fall under dry, low humidity conditions (Naveh 1975, Keeley 1982, Keeley et al. 1999). Currently, however, most wildfires in these areas are anthropogenic in origin (Rugen 1987, D'Antonio and Vitousek 1992, Keeley et al. 1999). For example, all 14 concurrent fires in southern California in October 2003 (739,597 acres burned) resulted from human activities (Keeley and Fotheringham 2005).

Fire suppression and, more recently, controlled burning of wildland vegetation are techniques used in the twentieth century to manage vegetation and to avoid wildfires (Kozlowski et al. 1991). However, when enough fuel accumulates due to changes in vegetation type (i.e., native shrublands and perennial grasslands in California have changed to Mediterranean annual grasslands) or a decrease in fire frequency in a region, fires are easily started.

Invasion of annual grass species has been linked to altered fire regimes in rangelands, deserts, and wildlands of California and the Western U.S. (D'Antonio and Vitousek 1992, D'Antonio 2000, Brooks 2002, Brooks et al. 2004, Keeley 2004, Keeley and Fotheringham 2005). *Arundo donax* may pose a more extensive problem in riparian ecosystems due to its perennial growth form (the large volume of biomass produced) and its rapid recovery after fire. Several accounts suggest that infestations of giant reed have increased fuel load as well as fire frequency and intensity along riparian corridors (Rieger and Kreager 1989, Bell 1994, Scott 1994, Dukes and Mooney 2004).

Natural, healthy riparian areas historically have acted as firebreaks primarily because native vegetation has high leaf moisture content (i.e., contains enough water to have low flammability) when fires typically occur in summer and fall. However, the October 2003 wildfire along the Santa Clara River clearly has shown that when natural riparian habitats are infested with *A. donax*, fires spread readily through this historically fire-hardy habitat (Coffman in press). For example, during the Simi/Verdale fire, the fire jumped across Highway 126 and the Santa Clara River through a section of the river densely invaded by *A. donax*, and from there made its way rapidly up and down the riparian corridor on either side of the river (estimated 5 miles per hour) (see Chapter 4). The fire then spread from the riparian corridor to the shrublands on the other side of the river and burned the Santa Suzanna Mountains, including the Simi Hills in the Calleguas Creek watershed to the south. This process was observed in several other locations along the Santa Clara River where shrublands were located close to the river floodplains and terraces (observation by G. Coffman and S. Hedrick 2003). In this way, fire spread

rapidly up and down river corridors through large patches of *A. donax*, especially along terraces where *A. donax* was very dry and provided more fuel than natural vegetation.

Although no scientific evidence exists, a few authors have suggested that fire in riparian ecosystems may increase the ability of *A. donax* to invade natural riparian systems (Rieger and Kreager 1989, Bell 1994, Scott 1994). The large quantity of highly flammable biomass produced by *A. donax*, and its rhizomes immediate growth response compared to native riparian species following fire contributes to its invasion success. Bell (1994) suggested that invasion of riparian ecosystems by *A. donax* is changing these systems from primarily flood-defined to fire-defined systems. Riparian ecosystems infested by *A. donax* that are adjacent to fire-prone shrublands in southern California appear to be on a trajectory towards an invasive plant-fire regime (Brooks et al. 2004).

ORGANIZATION OF DISSERTATION

My dissertation research focused on investigating the influence of nutrients, water, light, and fire on *A. donax* invasion of riparian ecosystems in Mediterranean-type climate regions. My main hypothesis is that increased nutrient, water, and light availability caused by anthropogenic sources in river systems throughout southern California have promoted invasion by *A. donax*. To test this hypothesis, I conducted three main studies employing two study approaches. First, I conducted a large-scale field experiment, located along a riparian terrace of the Santa Clara River in southern California, to test competition between *A. donax* and three native plant species for water, nutrient, and light availability. In a second watershed-scale observational field study, I investigated the influence of nutrients from various land use types and fluvial geomorphic

locations on *A. donax* invasion of riparian ecosystems along several coastal rivers in southern California. In my third study, I examined the role of fire in promoting *A. donax* invasion of riparian terraces of the Santa Clara River. Following this Introduction chapter, each of these three studies will be described in chapters 1–3. The final chapter (Conclusions Chapter) of the dissertation presents conclusions and management implications based on these studies.

FIGURES

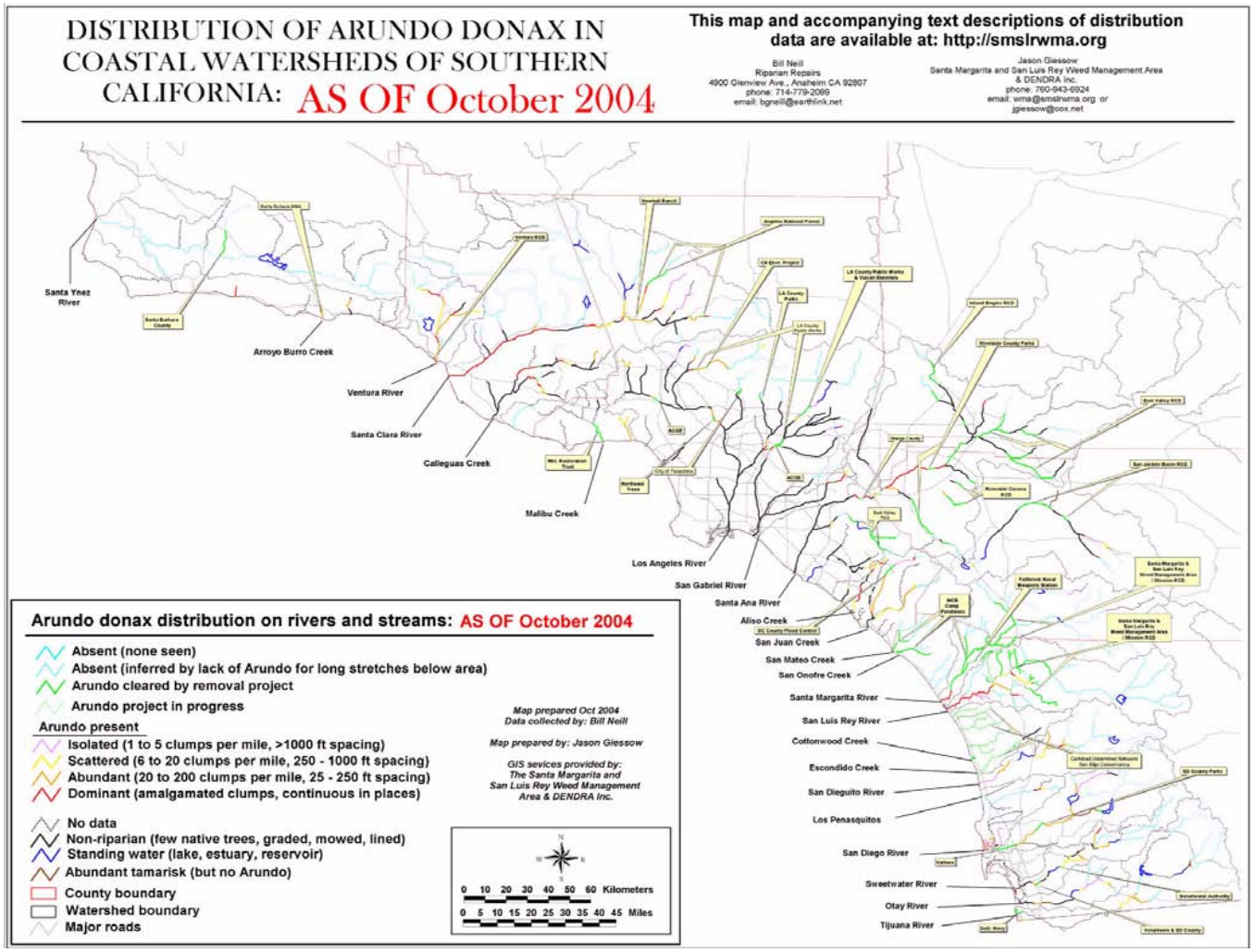

Figure 1. Distribution of *A. donax* throughout streams and rivers of Southern California (Used by the permission of Jason Giessow and Bill Neill, http://smslrwma.org/invasives/Arundo/ADRegionalMap.html).

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CHAPTER 2 -

EFFECTS OF WATER, NUTRIENT, AND LIGHT AVAILABILITY ON COMPETITION BETWEEN *ARUNDO DONAX*, A LARGE INVASIVE GRASS, AND NATIVE RIPARIAN SPECIES

Abstract: Invasion by alien plant species is currently one of the greatest threats to biodiversity and natural functioning of many ecosystems worldwide. Superior resource competition by alien grass species has been shown as the fundamental mechanism for invasion in many ecosystems. In this study, I tested the hypothesis that superior competition for soil moisture, light, and nutrient availability promotes invasion of a large bamboo-like grass, *Arundo donax* L., in riparian ecosystems. I established a large-scale field experiment with several competition plant groupings (mixed and single-species groupings), soil moisture, light, and nutrient treatments in a riparian ecosystem in southern California. I planted 168 four-plant groupings in 12 blocks perpendicular to shallow groundwater flow in a full factorial randomized block design. Effects of treatments on survivorship and aboveground biomass of *A. donax* were compared to native *Baccharis salicifolia*, *Salix laevigata*, and *Populus balsamifera* ssp. *trichocarpa*. Percent survivorship was high for all species (97.8% overall) and did not differ significantly for *A. donax* between treatments. Results show *A. donax* only suppressed one native species (*P. balsamifera* ssp. *trichocarpa*) under the most stressful environmental conditions. Competition from *B. salicifolia* and *S. laevigata* had a strong negative effect on *A. donax* biomass under high soil moisture, light, and nutrients.

Furthermore, *B. salicifolia* was facilitated by *A. donax* in half of the conditions tested. Despite negative effects of competition, *A. donax* produced a much higher biomass than native species under high soil moisture, light, and nutrient levels, and *A. donax* biomass in monoculture was much higher than all species within all treatment levels. Results suggest that high resource levels and the clonal growth form, not superior resource competition by the invasive *A. donax*, promote observed preemptive competitive exclusion of native riparian species. Its unique morphology and physiology, absent in this system before its introduction, allows *A. donax* to readily displace natives in many resource levels. *Arundo donax* appears to be a super invader, able to outperform native woody riparian species in almost every resource scenario tested.

Key Words: *Arundo donax, Salix laevigata*, *Populus balsamifera* ssp. *trichocarpa*, *Baccharis salicifolia*, giant reed, invasive species, alien, competition, nutrients, nitrogen, light, soil moisture, riparian, rivers, Mediterranean-type climate

INTRODUCTION

Invasion of natural ecosystems by alien plant species is a widespread phenomenon known to result in significant losses to biodiversity and impacts to ecosystem functioning (Elton 1958, Mooney and Drake 1986, Ramakrishnan and Vitousek 1989, D'Antonio and Vitousek 1992, Vitousek et al. 1996). Aquatic ecosystems such as rivers and wetlands are among the world's most heavily invaded systems (Mooney et al. 1986, Kruger et al. 1989, Pysek and Prach 1994, Alpert et al. 2000, Rundel 2000). Altered disturbance regimes, low stress environmental conditions, and anthropogenic enhancement of nutrients are thought to contribute to success of plant invasion in rivers and wetlands (Ashton and Mitchell 1989, Hobbs 1989, Hobbs and Huenneke 1992, Alpert et al. 2000). However, mechanisms by which invasive plant species exclude native plant species and dominate natural vegetation in these ecosystems are not well understood, yet are essential for developing effective control and restoration plans (Dudley 1998, Minchinton et al. 2006).

Superior interspecific competition between native and introduced species for water, light, and nutrient resources plays a critical role in plant invasion in many terrestrial ecosystems (D'Antonio and Vitousek 1992, Gordon and Rice 2000, Booth et al. 2003, Suding et al. 2004, White and Holt 2005, Richardson 2006). In the California grassland ecosystem, superior resource competition by Mediterranean annual grasses for water (Hamilton et al. 1999, Coleman and Levine 2007) and nutrients (Kolb et al. 2002) has been found to contribute to the almost total exclusion of native perennial bunchgrasses (D'Antonio and Vitousek 1992). Recent work by a number of authors has

revealed the relative importance of various resources and levels of each resource in this invasion process (Kolb and Alpert 2003, Corbin and D'Antonio 2004b, Thomsen et al. 2006). A few experimental studies in river and wetland ecosystems have demonstrated superior resource competition by invasive plants for either nutrients (Green and Galatowitsch 2002, Minchinton and Bertness 2003) or water (Sher and Marshall 2003), but no studies have examined effects of multiple resources simultaneously (i.e., various levels of water, light, and nutrients). Furthermore, controversy exists over the relative importance of competition in stressful, infertile versus productive ecosystems (Grime 1979, Tilman 1988, Goldberg and Novoplansky 1997, Alpert et al. 2000). Experimental studies addressing competitive interactions between invasive and native plants under multiple resources conditions (water, light, and nutrients) are needed to help elucidate the invasion process and aid in restoration of invaded ecosystems.

In the last half of the twentieth century, a tall bamboo-like member of the grass family (Poaceae), giant reed (*Arundo donax* L.), has become one of the most successful weedy riparian invaders in arid and Mediterranean-type climates worldwide (Bell 1997, Dudley 1998, Boose and Holt 1999). *Arundo donax* appears to be of a broad southern Eurasian origin, extending from Southeast Asia to the Mediterranean Basin, although the precise extent of its native distribution is unclear (Perdue 1958, Zohary 1962, Hickman 1993). Introduced extensively to other areas primarily for building materials, erosion control, and windbreaks, it is now successfully established in freshwater systems in tropical to temperate climates worldwide (Perdue 1958, Crampton 1974, Polunin and Huxley 1987, Hickman 1993, Sharma et al. 1998). Although the seeds are usually sterile

(Johnson et al. 2006), *A. donax* is dispersed downstream when pieces of culm or rhizome break off during flooding and land on bare, moist substrates (Else 1996, Else and Zedler 1996, Bell 1997, Boose and Holt 1999, Wijte et al. 2005). From these pieces, the plant grows at an extremely fast rate (up to 10 cm per day under optimal conditions), quickly establishing on exposed or sparsely vegetated soil and growing to more than 8 m in height after only a few months (Perdue 1958, Rieger and Kreager 1989, Bell 1994). Once established, *A. donax* expands outward in area by clonal propagation, displacing indigenous shrubs, herbs and grasses, and eventually even trees (Decruyenaere and Holt 2001). In this manner, *A. donax* forms extensive stands or monocultures in riparian ecosystems.

In Mediterranean-type climates, *A. donax* infestations have become especially devastating to riparian ecosystems, creating significant physical and biological impacts on natural river functioning and sustainability (Rieger and Kreager 1989, Bell 1997, DiTomaso 1998, Rundel 2003). High magnitude winter floods characteristic of many arid climates help distribute *A. donax* downstream, where it successfully establishes on a diverse array of substrates (Rieger and Kreager 1989, Else 1996, Else and Zedler 1996) much like the native riparian species in these systems. However, mechanisms of *A. donax* invasion in natural riparian ecosystems have been largely unexplored. Researchers have suggested that high resource levels and superior resource competition with native riparian plants (i.e., for elevated water, nutrients, and light availability) may promote invasion of *A. donax* in riparian ecosystems of southern California (Bell 1997, Wang 1998, Rundel 2003, Coffman et al. 2004), yet no experimental evidence of resource

competition by *A. donax* exists to support this hypothesis. Mechanisms that promote invasion of *A. donax* under various resource conditions in riparian ecosystems are essential to its control and restoration of these systems.

In this study, I examined the role of competition between *A. donax* and native species under varying resource scenarios found in riparian ecosystems in the plant invasion process. I predicted that aboveground biomass of native riparian plant species would be suppressed by high productivity of *A. donax* in high soil moisture, light and nutrient treatments, while under more stressful (and lower) resource conditions competitive interactions would favor native species which have evolved under these conditions (Alpert et al. 2000, Daehler 2003). Where *A. donax* establishes with native riparian plants in high resource conditions, growth rate will be high but competition from native plants for soil moisture and nutrients will be high as well. Differing habit, phenology, and rooting depth of *A. donax* (clonal) and native riparian species (phreatophytes) play a key role under these conditions (Fargione and Tilman 2005).

Physiological integration among culms and their spatial arrangement may provide *A. donax* with a competitive advantage over native woody riparian trees and shrubs (Gough et al. 2002). The clonal growth form of *A. donax* enables it to grow horizontally, preemptively acquiring space from competitors and to average out surrounding heterogeneity in soil resources (Decruyenaere and Holt 2005). Although *A. donax* has a much shallower rooting depth than native riparian phreatophytes, *S. laevigata* and *P. balsamifera* spp. *trichocarpa*, root depth of these plants should remain relatively shallow and density low when resources are abundant (Schade and Lewis 2006, Schenk 2006)

(See Chapter 3; Figure 9). Thus, substantial overlap in the density of root mass between species may result in stronger competition under these conditions. Depending on density (Gough et al. 2002) and native species competing, these conditions may lead to either successful competitive exclusion of all or some native species by *A. donax*. In high stress and low resource conditions, naturally found along rivers in Mediterranean-type climates, *A. donax* may avoid competition with native plants due to differential rooting depths; native phreatophytes will develop deeper roots than *A. donax* when soil moisture and nutrients are scarce.

I hypothesized that superior resource competition in high soil moisture, light, and nutrient regimes has promoted invasion of *A. donax* throughout rivers in Mediterranean-type climates. I investigated *A. donax* competition with several common native woody riparian plant species under various soil moisture, nutrient, and light levels in a large-scale field experiment in southern California. Plant survivorship and aboveground biomass of each species in intraspecific compared to interspecific competition groupings were analyzed. This experimental design allowed me to investigate the role of varying resource conditions thought to be most fundamental to competitive exclusion of indigenous riparian plants by *A. donax* using a natural, controlled approach.

METHODS

Study Site

The field experiment site was located on a private ranch on the south side of the Santa Clara River between Santa Paula and Fillmore, Ventura County, California (34.36° N, 118.99° W) (Figure 2). The 187 km long Santa Clara River and its tributaries drain a

4,185 square km watershed, the second largest coastal watershed in southern California. Prior to its clearing for agriculture, the riparian terrace in which the field experiment was established was once dominated by large riparian trees such as black cottonwood (*Populus* (L.) *balsamifera* ssp. *trichocarpa* Torrey & A. Gray) and red willow (*Salix laevigata* Bebb). A mixture of smaller trees and shrubs likely comprised the understory layer, including arroyo willow (*Salix lasiolepis* Benth.), mulefat [*Baccharis salicifolia* (Ruiz Lopez & Pavon) Pers.], and blue elderberry (*Sambucus mexicana* C. Presl.).

The experiment ran for two growing seasons, from December 2002 to December 2004. In October 2002, I began construction of the 0.5-hectare field experiment on a riparian terrace between agricultural fields and the river. Based on measurements of groundwater depth taken from a grid of borings throughout the experimental area, I found that shallow groundwater flowed in a southeast to northwest direction from the agricultural fields through the field experiment toward the river. Rows (or blocks) of plant groupings within the field experiment were located perpendicular to the direction of shallow groundwater flow to accommodate variance due to differing hydrology (Figure 3).

Baseline soil grain size (soil texture) and nutrient status were determined in Summer 2002, before construction of the experiment began to help in final placement of experimental groupings and treatments. The western side of the experimental area was primarily composed of a shallow horizon (soil surface to 26–66 cm) of sandy loam, silt loam, and loam with a deep horizon of fine sand and coarser sand below (to 171–199 cm and deeper). The eastern side of the experiment contained mostly loam (and silt loam) in

the top horizon (soil surface to 44–102 cm), loam and silt loam in a middle horizon, and sand in the lowest horizon (below 138–216 cm). Soil moisture was consistently higher on the eastern side of the experiment than the western side due to soil grain size composition and topography.

I conducted baseline soil nutrient analyses on 18 soil samples collected from 0–30 cm depth systematically throughout the experiment. In spring 2003, pre-fertilization soil nutrient levels in the experimental study area mean soil nitrate (5.2 ± 1.7 ppm) and phosphate (11.1 ± 1.1 ppm) levels were comparable to concentrations found in soil along similar riparian terraces along the Santa Clara River (see Chapter 3). Average soil pH (7.69 ± 0.02) did not differ markedly throughout the experimental site.

Study Species

Arundo donax is a robust, perennial, bamboo-like member of the Poaceae (grass) family that was introduced and is now widespread throughout the floodplains and terraces of rivers in California and other warm, temperate climates worldwide (Perdue 1958, Crampton 1974). It has erect stout (yet hollow) culms that are 1–4 cm thick and 2–8 m in height. Culms branch to form ramets, typically at the end of the first year of growth or after a culm is damaged. Leaf blades are broad (2–6 cm wide), less than 1 m long, flat, clasping at the base, strongly scabrous along their margins, and evenly spaced along the culm (Crampton 1974, Hickman 1993). *Arundo donax* reproduces vegetatively through a network of large, thick rhizomes that grow horizontally just below the ground surface. Under some conditions it produces a large (3–6 dm) terminal plume-like inflorescence (panicles) at the end of the growing season (Faber and Holland 1992, Hickman 1993).

I selected three native riparian plant species commonly found on terraces of rivers in southern California to use in the experiment: *Salix laevigata* (red willow) *Populus balsamifera* (black cottonwood) ssp. *trichocarpa*, and *Baccharis salicifolia* (mulefat). *Salix laevigata* is a riparian tree that can grow as tall as 15 m and is a member of the Salicaceae. Dominant in both floodplains and terraces along rivers in southern California, *S. laevigata* can be identified by its dark, deeply furrowed bark on mature trees and lanceolate leaves, which are shiny on the top and glaucous beneath. Also a member of Salicaceae, *P. balsamifera* ssp. *trichocarpa* grows to a height of 30 m in alluvial plains along rivers in southern California. *Populus balsamifera* ssp. *trichocarpa* trees can be identified by their broad crown and bicolored ovate leaves with acute tips, which are dark green on the top and glaucous underneath (Faber and Holland 1992, Hickman 1993). *Baccharis salicifolia* is the dominant shrub found throughout floodplains and terraces of streams and rivers in southern California. A member of the Asteraceae, *B. salicifolia* usually grows to a height of less than 4 m. Its long linear to lanceolate leaves resemble willow leaves, but they typically have three principal veins that extend the entire length of the leaf and are coarsely serrated (Faber and Holland 1992, Hickman 1993). In addition, *B. salicifolia* shrubs produce a rounded panicle of white simple compound dioecious flowers.

Experimental Design

This field experiment was organized as a full factorial randomized block design to minimize variation due to heterogeneous soil and shallow groundwater conditions found within the site. A total of 288 plant groupings (four plants per grouping) were organized

in 12 blocks (rows) of 24 groups each perpendicular to the general flow of shallow groundwater hydrology (Figure 3). Blocks of plant groupings were placed 4 m apart and plant groupings within blocks were placed 3 m apart. 756 cuttings of riparian trees (1 m long by approximately 2–3 cm in diameter) and 396 rhizomes of *A. donax* (200–400 g) were planted approximately 0.75 m apart in square configurations. Native riparian species cuttings were planted in December 2002, and *A. donax* rhizomes were planted in March 2003. Multiple levels of three resource treatments and competition treatment were applied randomly to plant groupings along rows before planting, including soil moisture (high and low), light (high and low), and nutrient additions (high and none). To simplify the interpretation and presentation of results, the 96 low-nutrient treatment plant groupings in the experiment are not included in the analyses.

I used two competition groupings (two-species and one-species groupings) in the experiment to compare interspecific versus intraspecific competitive interactions (Table 1). The two-species groupings, referred to as 'mixed species grouping' consisted of two *A. donax* plants and two plants of a single native species. Like species were planted diagonally across from each other in the mixed species groupings. One species-groupings, or monocultures, contained four plants of only one species per grouping. (The 36 four-species groupings in the experiment were not included in this study.) In this experiment, the criterion for existence of an interspecific competitive interaction was evidence of significantly different biomass in mixed plant groupings compared to monocultures. If mean biomass of a species was lower when grown with another species compared to in monoculture, an interspecific competitive interaction was present. An

interspecific interaction was deemed positive (facilitation) when the mean biomass of a species was higher in mixed species groupings compared to its biomass when grown in monoculture.

Two soil moisture treatments occurred naturally; the western half of the experiment contained soils that were better drained (referred to as low soil moisture), whereas the eastern half of the experiment retained higher soil moisture throughout the year (high soil moisture). To simulate natural establishment conditions, I did not apply artificial irrigation.

In Spring 2003, I built shade structures over half of the experiment to simulate shading by a mature riparian canopy and test the effects of light availability. The two light treatments consisted of full sun (referred to as high light) and 80% shade (low light). I used 80% black shade cloth on six shade structures (total dimensions were 200 feet x 10 feet x 15 feet high) that were erected along rows in two large blocks of the experiment to minimize the shade effect onto non-shaded rows. One block (three rows) was placed over the high soil moisture portion (northeast) and one block (three rows) was placed over the low soil moisture portion (southwest) (Figure 3). I applied nutrient treatments to designated plant groupings twice a year: a fertilized "high N" treatment and "no N" treatment control in which only water was added. Granular ammonium-nitrate fertilizer (N-P-K, 34-0-0) was used as the source of added nitrogen and was mixed with 2 gallons of water before application. High nitrogen treatments (100 g N/m^2/year or 56 g N/plant/year) were added to one-half of the plant groupings to simulate row crop fertilization levels adjacent to riparian areas. I applied half of the nutrient treatments at

the beginning of the growing season and the remainder at the peak of the growing season; this timing of fertilization application is similar to that used in agricultural practices in the area. Each plant in the no fertilizer treatment received 2 gallons of water at each of the two application periods.

Sampling Methods

I monitored soil moisture to characterize the soil water content throughout the experimental site using 14 soil moisture probes (20 cm ECH_2O Dielectric Aquameter sensors by Decagon Devices, Inc.), which I installed systematically throughout the experiment in the summer of 2004 (Figure 3). I placed 10 soil moisture probes in a soil horizon (between 60–80 cm from the soil surface) located roughly in the middle of the root system for most plants. The other four probes were placed in a shallower soil horizon (from 30–50 cm) to measure soil moisture in the area in which the cuttings were initially planted. I measured soil moisture content of these probes weekly from July 2004 to September 2005.

Annual mean soil moisture content (60–80 cm below ground surface) on the eastern side (Mean ± SE = 38.5% ± 0.5) of the experiment was significantly higher than on the western side (33.2% ± 1.0) during the 2004–2005 water year (one-way analysis of variance results: $F_{(1,383)} = 23.583$; $P < 0.001$). The shallower soil horizon (30–50 cm below the ground surface) in which cuttings were established exhibited a similar trend; soil moisture was 42.1% ± 0.4 on the eastern side and 37.8% ± 0.5 on the western side (one-way analysis of variance results: $F_{(1,166)} = 47.686$; $P < 0.001$). Mean soil moisture content fluctuated throughout the year but was consistently higher on the eastern side

than the western side (Figure 4). Although soil moisture probes were not installed until the end of the second growing season (Summer 2004), trends observed during 2004-2005 were likely similar or more pronounced in 2003-2004 due to lower annual precipitation. Thus, the eastern side was designated as the high soil moisture treatment and the western side as the low soil moisture treatment.

I measured plant survivorship at three time periods: 1) survivorship of planted cuttings in spring 2003, 2) plant survivorship at the end of 2003, and 3) plant survivorship at the end of 2004. A few cuttings and rhizomes that did not grow initially were replanted in spring 2003 and the replacement plant establishment success was included in the 2003 and 2004 percent survivorship results.

Biomass Estimation

The aboveground biomass of all plants in the field experiment was estimated over the two-year study period (2003 to 2004). I used non-destructive dimensional analyses to estimate aboveground biomass dry weight of plants in the experiment so that I would interfere as little as possible with plant growth and other measurements taken throughout the course of the study period (Whittaker 1961, 1965, Whittaker and Marks 1975, Sharifi et al. 1982, Spencer et al. 2006). Compartments of aboveground biomass measured included: branches, main trunk (cutting), leaves, flowers, and seeds of native species, and culms, leaves, and ramets of *A. donax*. Regression models were created using the basal diameter measurements to predict biomass of all compartments (except main trunks) of each plant. All data were natural log transformed in the regression models. Trunk biomass (the aboveground portion of the original cutting) of native species was estimated

by dividing the trunk volume (cm^3) by the density (cm^3/g) of a sample of wood of that particular species. Trunk volume was calculated using average diameter and length of the cutting in the equation for cylinder volume ($V = \pi r^2 h$).

At the end of each growing season (2003 and 2004), branches/culms were cut, basal diameter measured, biomass oven-dried, leaves separated from branches/culms, and biomass weighed separately. I collected a total of 320 branch/culm aboveground biomass samples in 2003 and 400 samples in 2004 for the dimensional analysis biomass estimation. In 2003, 20 branches/culms from the range of branch diameters present for each of the four species were harvested from monoculture competition groupings in each of the experimental quadrants (SE, NE, NW, SW – two soil moisture and two light levels) (20 x 4 x 4 = 320) (Figure 3). In addition, 20 second-year *A. donax* culms were collected in each experimental quadrant in 2004 (total of 80 culms). Only fully mature *A. donax* culms were sampled.

Regression equations for branch/culm basal diameter versus corresponding dry aboveground biomass samples were calculated for each species in each of the four soil moisture-light treatment combinations (16 for 2003 and 20 for 2004). Regression models for aboveground biomass were very highly significant for all species under various combinations of soil moisture and light treatments in 2003 and 2004 ($r^2 = 0.770–0.996$, $P < 0.001$) (see Appendix 2-1 for model equations). Therefore, I used these equations to estimate aboveground biomass for all plants within the field experiment.

At the end of the 2003 and 2004 growing seasons, I measured basal diameters (10 cm from the trunk of riparian plants or 10 cm above the ground surface for *A. donax*) of

each branch or culm growing from the original cutting. Only culms that were > 60% of mature height were measured. To calculate total biomass of each plant at the end of each growing season, I used the basal diameter of each branch/culm of an individual plant in the corresponding regression equation for that species and treatment and totaled the resulting biomass for all branches/culms. Trunk biomass estimates were added to total biomass for each native riparian plant.

Statistical Analyses

Descriptive statistics were performed on soil moisture and plant survivorship measurements. I conducted one-way ANOVAs on soil moisture content to validate high and low soil moisture treatments and establishment of plant species between the first and second growing season, with Tukey's post-hoc test for pair-wise comparisons of means.

The competition experiment was organized in a full multifactorial design in which combinations of four fixed factors (Model 1) were crossed with each other. Four-way analysis of variance (ANOVA) tests were used to analyze effects of various combinations of four factors (independent variables) on total aboveground biomass data (standing stock) collected at the end of the second growing season (dependent or response variables) (Systat Statistical Program [Version 10]). The four independent variables were competition plant groupings, soil moisture, light, and nutrient addition treatments. Data were analyzed for main effects of individual factors and interactions between factors. ANOVA F-tests were performed to evaluate a priori contrasts between means of grouping variables and levels in multifactor ANOVA results. Probability plots were examined to test for normality of data and to identify any data that required

transformation. Because soil moisture and percent survivorship data were normally distributed, data transformation was unnecessary. All biomass data were ln transformed. When means and standard errors were used to describe or present statistical differences, data were back-transformed and reported in original units.

RESULTS

Establishment

Plant establishment success between installation in winter 2002–2003 and the end of the growing season in 2004 was very high for all species. Cutting survivorship in spring 2003 was 97.7% for all plants. Total plant survivorship at the end of 2003 and 2004 was 98.4% and 97.8%, respectively, and slightly higher than cutting survivorship due to replanting of unsuccessful cuttings. Soil moisture, nutrient, and light treatments had no effect on *A. donax*, *S. laevigata*, or *B. salicifolia* survivorship (See Appendix 2-2 for analyses of species and resource treatment effects). However, establishment success of *P. balsamifera* ssp. *trichocarpa* at the end of the first growing season (2003) was significantly lower within the high soil moisture treatment than in any other species and soil moisture treatment combination. Percent survivorship did not decrease significantly during the two-year establishment period ($F_{(1,158)} = 0.485$; $P = 0.487$). Therefore, I considered plants fully established by the end of the first growing season (2003) and evaluated competitive interactions at the end of the second growing season (2004).

Biomass Production

Arundo donax biomass was higher than native plant species biomass under nearly all soil moisture, light, and nutrient conditions at the end of the second growing season. In fact, the mean biomass of *A. donax* in monoculture under high soil moisture, light and nutrient conditions was 2–34 times that of all native species under all conditions tested [range = 0.46 kg (SE 0.30–0.68) to 7.03 kg (SE 6.41–7.72)] (Figure 5). In high soil moisture, light, and nutrient conditions, monocultures of *A. donax* exhibited a significantly higher mean biomass [17.05 kg (SE 15.98–18.20)] than any native plant species under these conditions [2.63 kg (SE 2.24–3.10) to 4.21 kg (SE 3.69–4.80)] (Figure 6). Despite negative competitive interactions with *B. salicifolia* and *S. laevigata* under high resource conditions (high soil moisture, light, and nutrients), mean biomass of *A. donax* was nearly double that of *S. laevigata* and 20 percent higher than *B. salicifolia* in mixed groupings (Figure 5). Biomass of *A. donax* grown in monoculture was almost six times that of *P. balsamifera* spp. *trichocarpa* in high resource conditions. Facilitation by *P. balsamifera* spp. *trichocarpa* contributed to an even higher mean biomass of *A. donax* in the 2-species mixed grouping compared to monoculture in similar experimental conditions. *Arundo donax* biomass was consistently higher than that of most native species in other soil moisture, light, and nutrient treatments, however differences between biomass of *A. donax* and native species were not as great.

Biomass of *A. donax* grown under high soil moisture, light, and nutrient conditions was much higher than when grown under any other experimental condition (Figure 5 and Figure 6). Although native plant species show similar trends, differences in

mean biomass between these treatment conditions were much less than for *A. donax*. Under high resource conditions, mean biomass of *A. donax* was highest in monoculture [17.05 kg (SE 15.98–18.20)] and lowest in the low soil moisture-high light and high soil moisture-low light treatments (Figure 6). Of the native species grown in monoculture, *B. salicifolia* yielded the highest mean biomass [4.20 kg (SE 3.69–4.80)] in the high soil moisture, light, and nutrient treatment, but this was only one-quarter of the maximum biomass produced by *A. donax*. The lowest native species biomass in monoculture was produced by *P. balsamifera* spp. *trichocarpa* in the low soil moisture, light, and nutrient treatment [0.53 kg (SE 0.46–0.60)], more than 30 times lower than *A. donax* biomass in high resource conditions.

The 4-way ANOVA for aboveground biomass of all species by factors of plant grouping, soil moisture, light, and nutrients resulted in two 3-way interactions (Table 2). The plant grouping x soil moisture x light interaction was difficult to interpret but significance was mainly due to lower *S. laevigata* biomass than other species in low soil moisture-high light treatments as well as numerous significant competition interactions mentioned below. The significant soil moisture x light x nutrients interaction was explained by higher biomass in high soil moisture-high light than any other combination of these factors and levels.

Resource Competition

When I compared mean aboveground biomass by species in mixed groupings versus monocultures, effects of competition between *A. donax* and native plants varied significantly by species and resource treatment levels. *Arundo donax* was a superior

resource competitor to only one native plant, *P. balsamifera* spp. *trichocarpa*, under only one of the conditions tested. Under the most stressful experimental conditions of low soil moisture, full sun, and no nutrient additions, *A. donax* competition had a negative effect on *P. balsamifera* spp. *trichocarpa* biomass (Table 3). Under these conditions, *P. balsamifera* spp. *trichocarpa* obtained the lowest biomass of all native species [0.46 kg (SE 0.30–0.68)] (Figure 5). The 4-way ANOVA of *P. balsamifera* spp. *trichocarpa* biomass resulted in a significant 3-way interaction (plant grouping x light x nutrients) due to this competitive interaction (Table 3). In high resource conditions (high soil moisture, light, and nutrients), there was a suggestion of *A. donax* facilitation by *P. balsamifera* spp. *trichocarpa*, with *A. donax* biomass being 30% greater in the mixed species grouping with *P. balsamifera* spp. *trichocarpa* [22.95 kg (SE 20.13–26.16)] than in monoculture [17.05 kg (SE 15.98–18.20)], but this difference was not statistically significant. A significant negative effect of competition with *P. balsamifera* spp. *trichocarpa* was detected under high soil moisture, low light, and high nutrient levels, conditions in which *A. donax* was least productive [1.38 kg (SE 1.03–1.85)]. Significant 3-way interactions (plant grouping x light x nutrients and soil moisture x light x nutrients) in the 4-way ANOVA of *A. donax* biomass were found (Table 3). The plant grouping x light x nutrients interaction was due to facilitation of *A. donax* by *P. balsamifera* spp. *trichocarpa* under high soil moisture, light, and nutrients. Much higher biomass in high soil moisture-high light treatments than in all other treatments was the primary cause of the significant soil moisture x light x nutrients interaction.

When grown with *A. donax* in the mixed species grouping compared to in monoculture, *S. laevigata* exhibited no significant competitive interactions with *A. donax* regardless of resource levels. Although competitive effects were not significant, the trend throughout various combinations of treatments, especially under low soil moisture conditions, indicated slight facilitation of *S. laevigata* by *A. donax* (Figure 5). Two-way interactions (soil moisture x light and soil moisture x nutrients) were significant for *S. laevigata* biomass in the 4-way ANOVA (Table 4) due to differing trends among levels in these factors. The soil moisture x light interaction was significant due to lower biomass in high light-low soil moisture compared to the low light-low soil moisture treatments, and the significant soil moisture x nutrient interaction was caused primarily by higher biomass in high nutrient-high soil moisture treatments compared to low nutrient-high soil moisture treatments. *Arundo donax* aboveground biomass was significantly higher (roughly twice as high) in monoculture compared to in the 2-species grouping when grown with *S. laevigata* in the high soil moisture, light, and nutrient treatment (Figure 5). Results of the 4-way ANOVA indicate significant 2-way interactions between soil moisture and light as well as between light and nutrients. The soil moisture x light interaction was significant because in the shade biomass was similar with regard to soil moisture; however, biomass was significantly higher in full sun-high soil moisture compared to full sun-low soil moisture (Table 4). The significant light x nutrient interaction resulted from higher biomass in full sun-high nutrient treatment compared to full sun-no nutrient treatment.

When grown in the mixed species grouping compared to in monoculture, *A. donax* facilitated growth of *B. salicifolia* in half of the treatment combinations (Figure 5). When *B. salicifolia* was grown with *A. donax*, its mean aboveground biomass was almost two-fold higher on average than when grow in monoculture. In the 4-way ANOVA of *B. salicifolia* aboveground biomass, the 4-way interaction was significant (Table 5) due to the presence of strong facilitation effects on half of the treatment combinations and no significant effects on the other half. In contrast, *A. donax* biomass was suppressed by competition with *B. salicifolia* under high soil moisture, light, and nutrient conditions; its biomass was two times higher in monoculture [17.05 kg (SE 15.98–18.20)] than in the mixed grouping containing *A. donax* and *B. salicifolia* [8.74 kg (SE 6.55–1.17)]. Higher mean aboveground biomass of *A. donax* monocultures in high soil moisture-full sun treatments than in any other combination of treatments as well as the competitive suppression of *A. donax* by *B. salicifolia* (Figure 5) yielded a significant 3-way interaction between plant grouping, soil moisture, and light in the 4-way ANOVA (Table 5).

DISCUSSION

In this study, I experimentally investigated competition between a particularly invasive bamboo-like grass species and three native woody riparian species under varying multiple-resource conditions that are found in natural riparian ecosystems. Superior interspecific competitive interactions between native and introduced species for water, light, and nutrient resources are critical in the plant invasion process in many ecosystems (D'Antonio and Vitousek 1992, Hamilton et al. 1999, Gordon and Rice 2000,

Green and Galatowitsch 2002, Booth et al. 2003, Kolb and Alpert 2003, Sher and Marshall 2003, Suding et al. 2004, White and Holt 2005, Minchinton et al. 2006, Richardson 2006, Coleman and Levine 2007). Preemptive as well as interspecific competition for resources between plant species has been well documented in many ecosystems (Connell 1983, Schoener 1983, Tilman 1987, Goldberg and Barton 1992, Daehler 2003). Evidence of several positive, negative, and non-significant competitive interactions between species was observed in the experiment, but interactions were different than predicted. Surprisingly, results indicated only one negative competitive interaction of *A. donax* on a native riparian plant, although its biomass was higher than almost all native plants in almost every experimental condition tested during the length of this study. Competitive interactions between these species may change over time and should be studied over a longer time span.

Competition

The only instance in which *A. donax* outcompeted a native plant species for resources was under the most stressful experimental conditions tested (low soil moisture, high light, and no nutrient addition levels). Under these conditions, competition with *A. donax* resulted in lower *P. balsamifera* ssp. *trichocarpa* biomass than found in monoculture. In fact, the mean aboveground biomass of *P. balsamifera* ssp. *trichocarpa* under these conditions was lower than in any other combination of resource levels. It seems likely that exploitative competition (competition for limiting resources) for soil moisture and available nutrients accounts for this negative effect of competition, since *A. donax* did not grow large enough to shade out *P. balsamifera* ssp. *trichocarpa* by

preemptive (competition for space) or overgrowth (one species grows over another, blocking light or depriving other species of a limiting resource) competition (Schoener 1983). This finding does not concur with Grime's hypothesis that resource competition is relatively unimportant for plants in unproductive or stressful environments due to the low biomass produced and corresponding low resource depletion (Grime 1977, 1979). According to Tilman (1988) however, competition occurs across productivity gradients and plants compete strongly under low resource conditions for belowground resources, mainly nutrients and water. Alpert et al. (2000) asserted that environmental stress may shift the competitive balance between invasive and native plants; mainly invasive plants take advantage of high resource availability compared to natives and low resource availability tends to cause low invasibility. However, I found that *A. donax* grew much more rapidly than all three native species under nearly all treatment conditions and suppressed one native species under low resource conditions.

Despite these hypotheses and predictions, invasive-native competitive interactions in conditions of high environmental stress are not well understood and experimental results vary by species and ecosystem. In grasslands of the western U.S., low nitrogen levels were found to have no effect on competitive ability of invasive annual grasses (Kolb and Alpert 2003, Lowe et al. 2003, Thomsen et al. 2006) or an invasive herb (*Centaurea diffusa*) on native grassland species. An invasive perennial grass (*Phalaris arundinacea*) suppressed native aboveground and belowground biomass in a wetland sedge meadow at low nitrate levels (Green and Galatowitsch 2002), yet lower phosphorus levels decreased *C. diffusa* competitive advantage over native species (Suding et al.

2004). Lowered water availability had no effect on competitive interactions between an invasive grass compared to a native grass in a Canadian mixed-grass prairie; however, low water availability was found to favor a small invasive tree, *Tamarix ramosissima*, in a floodplain of the Mojave Desert (Cleverly et al. 1997). Only one published experiment has examined competitive interactions under stressful conditions similar to my study with low soil moisture, high light, and low soil nutrients. The non-native annual grass (*Lolium multiflorum*) outcompeted a native perennial grass (*Hordeum brachyantherum*) at all resource levels when germinated simultaneously (Kolb et al. 2002). No studies showed increase in (or higher) competitive ability of invasive species relative to native species in stressful conditions of low nutrients, low water, and/or high light availability (Alpert et al. 2000). My experiment demonstrates that resource competition between invasive and native species may be highly species-specific under stressful environmental conditions. Differences in physiology of competing species, including variation in soil moisture and associated nutrient use, phenology, and differing rooting depth, may be important in mediating competitive interactions between *A. donax* and native woody riparian species (Reynolds and Pacala 1993, Fargione and Tilman 2005, Schenk 2006).

Although specific light requirements of *A. donax* and dominant riparian plant species in California are not well known (Braatne et al. 1996), invasive grass species are known to prevent woody species establishment and growth by shading them (D'Antonio and Vitousek 1992). Under conditions of high soil moisture and nutrient levels but low light, such as those found in mature riparian forests along streams in California, *A. donax* biomass was lower when grown with *P. balsamifera* spp. *trichocarpa* compared to in

monoculture. Light limitations can promote strong belowground competition between species (Schenk 2006). Although not measured in this study, similarities in rooting depth and higher growth rate of roots versus shoots of *P. balsamifera* spp. *trichocarpa* (Braatne et al. 1996, Pregitzer and Friend 1996) compared to *A. donax* in these conditions may help explain suppression of *A. donax*. *Populus balsamifera* spp. *trichocarpa* develops a shallow, lateral root system primarily with occasional sinker roots (similar to a taproot) (Pregitzer and Friend 1996). Nonetheless, this finding was surprising given the documented shade-intolerance of riparian *Populus* spp. (Walters and Reich 2000, Portsmuth and Niinemets 2007), but competitive effects might differ if grown from seed due to high light germination requirements (Braatne et al. 1996). Conservation and restoration of structurally diverse mature riparian forest, including *P. balsamifera* spp. *trichocarpa*, may help suppress *A. donax* invasion where high water and nutrient conditions prevail.

Competition with both *S. laevigata* and *B. salicifolia* reduced *A. donax* biomass by half when grown together in mixed groupings in high soil moisture, light and nutrient conditions. Suppression of *A. donax* biomass by native trees in these high resource conditions was an unexpected result. I predicted *A. donax* would competitively suppress and exclude natives under high resource availability following Goldberg and Novoplanksy's (1997) two-phase resource dynamics hypothesis and Tilman's resource competition hypothesis (Tilman 1982, 1988). Native plant preemptive competition may be responsible for negative effects on *A. donax* biomass, since water, light, and nutrient resources were abundant. Although biomass of these two natives was much lower than

the *A. donax* they suppressed, their woody phenology (upward, wide branching growth habit) may have restricted *A. donax* from expanding horizontally in all directions as it does naturally when grown alone or with other *A. donax* individuals. After the first year of growth upward, *A. donax* adds biomass by growing outward in a clonal manner. It appears that *S. laevigata* and *B. salicifolia* were able to limit its growth outward toward them somewhat (although not totally). Close observation of *A. donax* removed after the experiment indicated that individual clones planted in monoculture (four individuals) grow laterally in all directions intertwining with other *A. donax* individuals.

Facilitation

The role of positive interspecific competition for multiple resources in the invasion process has been relatively unexplored, but potentially of considerable importance in explaining mechanisms of riparian ecosystems invasion. Most examples of invasive plant species exerting competitive exclusion on native species have focused on and demonstrated negative competitive effects varying only one resource condition. However, the importance of facilitation in plant community organization and structure and its role in ameliorating harsh physical environments have been elucidated recently (Bertness and Callaway 1994, Bruno et al. 2003). Several examples of positive competitive interactions, or facilitation, between invasive and native plant species have been documented (Maron and Connors 1996, Green and Galatowitsch 2001, Rodriguez 2006).

Direct positive interactions, including facilitation, between native and invasive species has been overlooked until recently (Bertness and Callaway 1994, Rodriguez

2006). In California coastal prairie, Maron and Connors (1996) demonstrated that the native bush lupine shrub (*Lupinus arboreus*) facilitates an invasive annual grass (*Bromus diandrus*) invasion through fertilizing of the surrounding soil by nitrogen fixing and deposition of nitrogen-rich litter. I found only one study exhibiting facilitation of a native plant species by an invasive plant species; evidence of weak facilitative effects of an invasive wetland monocot (*Typha* x *glauca*) on native sedge meadow community were documented under the highest nitrate levels applied (Green and Galatowitsch 2001). However, the authors admit that *T*. x *glauca* did not appear to be well established during the short duration (4-months) of the experiment and this likely effected results. I discovered that the invasive *A. donax* facilitated the native *B. salicifolia* under half of the conditions tested; *B. salicifolia* exhibited much higher biomass when grown with *A. donax* than when grown in monoculture. In three out of four treatments tested, facilitation of the native *B. salicifolia* was detected under high soil moisture, high light, or low nutrient conditions. Similar but weaker trends in facilitation of *S. laevigata* by *A. donax* were observed.

Plant facilitation may be a particularly common characteristic in harsh physical environments in which primary space-holders buffer neighbors from potentially limiting stresses (Bertness and Callaway 1994, Bruno et al. 2003, Rodriguez 2006). Introduction of novel habitats or physical structure provided by an invasive species can alter abiotic conditions that enable native species to survive (Rodriguez 2006). Although both plants occupy roughly the same rooting zone especially in the first few years under high soil moisture conditions, *A. donax* may ameliorate stressful conditions for *B. salicifolia*. For

example, *A. donax* may draw down high soil water content in the surrounding rooting zone in very high soil moisture levels or decrease high salinity levels, conditions that have been shown to limit *B. salicifolia* growth otherwise (Vandersande et al. 2001). Since *A. donax* is functionally unique compared to the native phreatophyte *S. laevigata* and slight facilitation was detected under almost all growing conditions, novel facilitation by *A. donax* could provide a new habitat structure for *S. laevigata* as well. Mechanisms responsible for this type of facilitative interaction should be addressed in future research. Finally, facilitation of *B. salicifolia* and *S. laevigata* by *A. donax* may be only present in paired species groupings or when surrounded by *A. donax* and absent or not as important in naturally diverse riparian communities due to more complex interspecific relationships with other species.

High Resource Levels and Competitive Exclusion

Contrary to my prediction, I found that *A. donax* did not exhibit superior resource competition or competitive exclusion of natives under high resource levels during the time period of my experiment. *Arundo donax* exhibits competitive exclusion of native species in riparian ecosystems in Mediterranean-type climates under most resource conditions, especially in high water, light, and nutrient levels. Although most competition experiments are 2 years or less in duration (Goldberg and Barton 1992), exclusion of native plant species by *A. donax* by resource competition was not observed due likely to the short duration of this study.

Arundo donax demonstrated inferior resource competition ability in almost all conditions, was suppressed by both a native tree and shrub in high resource conditions,

and even facilitated the native shrub *B. salicifolia* in half of the treatments. Despite these disadvantages, *A. donax* was still much more productive in high soil moisture, light, and nutrients compared to the native plants and under other experimental conditions. *Arundo donax* appears to be on a trajectory to competitive exclusion of natives when resource availability is high (high soil moisture, light, and nutrient levels) regardless of its inferior resource competitive ability.

Results of resource competition experiments between invaders and native species vary considerably by resource level (Alpert et al. 2000), but most invaders benefited from elevated nutrient and water conditions. In a review of invader versus native plant species performance, invaders exhibited either universal superior competitive performance or superior performance in high nutrient conditions in two-thirds of the studies examined, but under low resource conditions native species usually outperformed invaders (Daehler 2003). Daehler (2003) concluded from his evaluation that relative performance of invasive compared to native species may shift in high resource conditions; increased resource availability combined with altered disturbance regimes, not universal performance advantages, often increase performance of invasive relative to native species. High biomass production of *A. donax* compared to native species in high resource conditions revealed in this study supports Daehler's hypothesis.

Invasion Mechanisms in Varying Resource Conditions

Results of this study suggest that mechanisms of *A. donax* invasion in riparian ecosystems may vary depending on availability for multiple resources and competition from native species. When resources are abundant (high soil moisture, light, and

nutrients) and no competition from native species exists, high allocation to photosynthetic tissue, high growth rate, and phenology of *A. donax* allow it to accumulate biomass faster than natives and eventually competitively exclude natives in these areas. In this study, *A. donax* monocultures grew exceptionally well under high soil moisture, nutrient, and light conditions, producing between four to six times more biomass than other native species under these optimal conditions. Several other invasive versus native plant comparative studies in wetlands have reported similar trends in clonal plant performance under conditions of high resource availability (Green and Galatowitsch 2001, Svengsouk and Mitsch 2001, Green and Galatowitsch 2002).

When resources are abundant, Tilman (1988) suggested differences in growth rates between species are due to a greater allocation of growth to photosynthetic tissues compared to non-photosynthetic roots, seeds, and branches/trunk. In contrast, plants that allocate to more non-photosynthetic tissues are favored in resource limiting environments (Tilman 1988). All *A. donax* biomass produced in the first year of growth, both leaves and culms, contains photosynthetic tissue (Sharma et al. 1998, Decruyenaere and Holt 2001), whereas *B. salicifolia*, *S. laevigata*, and *P. balsamifera* ssp. *trichocarpa* allocate a significant percentage of their biomass to non-photosynthetic trunks, branches, roots, and reproductive parts. *Arundo donax* has an extremely high growth rate, with shoot elongation of up to 10 cm per day and a relative growth rate of 0.13 g $g^{-1}day^{-1}$ under optimal conditions (Perdue 1958, Else 1996, Bell 1997, DiTomaso 1998, Spencer et al. 2005). At the end of two growing seasons, the mean height of *A. donax* throughout the experiment was 4.01 m (SE ± 0.04) and ranged from 0.64–7.84m. On average native

riparian species grown from cuttings attained much lower heights than *A. donax* after two years growth [*P. balsamifera* ssp. *trichocarpa* = 2.71 m (SE ± 0.03); *S. laevigata* = 2.75 m (SE ± 0.05); *B. salicifolia* = 2.94 m (SE ± 0.03)] or when grown from seedlings. Seedlings of native species such as *P. balsamifera* ssp. *trichocarpa* are known to reach only 5–60 cm after two years (Braatne et al. 1996). Furthermore, Decruyenaere and Holt (2005) documented year-round growth of *A. donax* and recruitment of new culms in sites with high nitrogen levels in southern California.

High resource conditions appear optimal for competitive exclusion of natives by *A. donax*. However, *A. donax* exhibited higher biomass production than either *S. laevigata* or *P. balsamifera* ssp. *trichocarpa* in most other treatments and greatest differences between *A. donax* and native species were seen in low soil moisture treatments. This evidence of plant plasticity (ability of a plant to thrive under all resource availability levels) may contribute to *A. donax* invasibility (Rezk and Edany 1979, Claridge and Franklin 2002) in other resource conditions, as is often the case with other invaders (Daehler 2003). When resource levels are lower, soil resource availability for *A. donax* versus riparian species is likely more distinctly partitioned (niche differences greater) and interspecific competition is avoided. Fargione and Tilman (2005) attributed coexistence of two prairie bunchgrasses to niche differences of phenology and rooting depth. Phreatophyte adaptations to resource limitation, such as greater root:shoot allocation (Vandersande et al. 2001, Schade and Lewis 2006) and deep tap roots (Tilman 1988) provide *A. donax* almost exclusive use of soil moisture and nutrients in shallow soil horizons. Interspecific competition between *A. donax* and native phreatophytes may

only be important when native aboveground biomass is extremely low and thus rooting depths are similar. For example, evidence of negative competitive effects of *A. donax* on native plants was only found in the most stressful environmental conditions (low soil moisture, light, and nutrients); competition from *A. donax* reduced *P. balsamifera* spp. *trichocarpa* biomass to the lowest values found in the experiment. Native woody riparian plants were not found to have a competitive advantage in low resource conditions as predicted (Tilman 1988) or shown in other studies (Alpert et al. 2000, Daehler 2003).

Arundo donax appears to be a "super invader", outperforming three common native species under high as well as low resource conditions (Daehler 2003) due to its unique morphology and physiology in riparian ecosystems of Mediterranean-type climates. However, the competitive ability of *A. donax* is strongest under high resource conditions. Strong novel facilitation of *B. salicifolia* (and week facilitation of *S. laevigata*) by *A. donax* in several resource conditions and competition from *P. balsamifera* spp. *trichocarpa* in high soil moisture-low light-high nutrient conditions may partially combat this invasion, but further study is required. Community-level competition experiments are needed to identify any indirect competitive interactions and verify the magnitude of pairwise or individual-level competitive interactions found in this study. Also, competitive interactions and productivity are likely to change over time and should be studied over a longer-time frame to validate invasion predictions.

CONCLUSIONS

This experiment demonstrated the absence of competitive advantages for resource use by a highly invasive grass, *A. donax*. Under high resource levels, *A. donax* is

extremely productive, but is slightly suppressed by two native species. Nonetheless, it still obtains a higher biomass than all native plant species under these conditions. Relatively high plant plasticity allows *A. donax* to obtain a higher biomass than natives under lower resource level conditions as well. The unique morphology and physiology of *A. donax* compared to native woody riparian species enable *A. donax* to dominate the aboveground biomass under most environmental conditions. Under high resource levels, *A. donax* appears to be on a trajectory of competitive exclusion despite little observed resource competition with two common native species.

The results of this study have broad application to managing *A. donax* in rivers and wetlands worldwide, especially in areas where high soil moisture, elevated nutrients, and disturbance (high light availability) all exist. In arid and Mediterranean-type climates with naturally low soil nutrients (Pettijohn 1975, Day 1983, diCastri 1991, Dallman 1998) and groundwater levels, dense urbanization and intense agricultural practices have elevated both nutrient and water levels in streams (Hazy 2006). Both the natural dynamic flood regime characteristic of these climates and anthropogenic enhancement of water, nutrients, and light levels have created the ideal conditions for invasion of river and stream systems by *A. donax* (see Chapter 3).

If we continue to create or promote high resource conditions in riparian ecosystems, invasion of *A. donax* will continue and may eventually lead to its expanded dominance in riparian ecosystems. Displacement of native riparian species by *A. donax* will only continue to lead to decreased biodiversity, altered ecosystem functioning, loss

of wildlife habitat, and changes in natural flood and fire (Bell 1997, DiTomaso 1998, Dudley 2000).

My findings will help organizations working on riparian habitat conservation and restoration predict locations where it is most invasive and least invasive, contributing to successful control of this invasive species. Large-scale restoration projects (levee and dam removal) need to consider the effects of these restoration actions on the potential spread of fast growing invasive plants like *A. donax*. *Arundo donax* will be most invasive in high soil moisture, nutrient and light levels and most difficult to manage or remove. These conditions are commonly found along urbanized or agricultural river floodplains after large storms and along interfaces between high nutrient land use practices (agricultural fields) and riparian ecosystems (see Chapter 3). Areas exhibiting the most stressful environmental conditions (low soil moisture, low nutrients, high light, and competition from native species) will have the lowest risk of *A. donax* invasion. *Arundo donax* control efforts should focus in these stressful environments, such as dry reaches of rivers or ephemeral streams where *B. salicifolia* and other native species are established along with *A. donax*.

Knowledge of the effects of environmental conditions on *A. donax* growth provides valuable insight into the timing and selection of management techniques in *A. donax* control projects. Active revegetation with natives after *A. donax* removal is recommended in areas with high soil moisture and nutrients. However, *B. salicifolia* planting may be lower priority because it naturally colonizes riparian ecosystems. Active revegetation may also be effective in the low soil moisture, low nutrients, and full sun

conditions found in many arid stream systems; under such condition in this study, *B. salicifolia* had a higher biomass and was facilitated by *A. donax*.. Because plants are more susceptible to herbicide treatments when carbohydrates are translocated from aboveground to belowground organs, *A. donax* in low soil moisture and full sun conditions may require treatment earlier in the growing season than those growing along streams with high water availability (Spencer et al. 2005).

Long-term control of invasive species such as *A. donax* in natural ecosystems may require management of resource levels that promote invasion to reduce growth and competition. Manipulation of resource availability in favor of a given native (desired) species may create a competitive advantage and a barrier to reinvasion (Blumenthal et al. 2003, Corbin and D'Antonio 2004a, Suding et al. 2004, Prober et al. 2005, Perry and Galatowitsch 2006). Watershed management organizations should consider reducing nutrient levels from urban runoff and excess treated wastewater released into rivers to reduce growth and invasion by *A. donax*. Suppression of *A. donax* via competition from several native species under high soil moisture and low light conditions has implications for riparian forest conservation and restoration efforts aimed at controlling *A. donax*, but further research is needed to verify these finding over a longer time frame. Conservation and restoration of structurally and species diverse riparian forests may help to suppress and reduce *A. donax* invasion in areas of high soil moisture.

TABLES

Table 1. Plant distribution in competition plant groupings (four plants per grouping) used in the field experiment.

Competition grouping treatment	**Plant species (number of species per grouping)**			
	Arundo donax	***Baccharis salicifolia***	***Salix laevigata***	***Populus balsamifera* ssp. *trichocarpa***
2-species grouping	2	2		
	2		2	
	2			2
1-species grouping (monoculture)	4			
		4		
			4	
				4

Table 2. Four-way ANOVA significance table for aboveground biomass (total biomass at end of 2004 growing season) by factors of competition groupings [2-species mixed grouping of *A. donax* and one native riparian species (*S. laevigata*, *P. balsamifera* ssp. *trichocarpa*, and *B. salicifolia)* and monocultures groupings)], soil moisture (high and low), and light (high and low), and nutrients (high and none). Significant results are reported in bold.

Factors and interactions	Mean aboveground biomass
Plant grouping	**$F_{(9,560)}$ = 33.384, P < 0.001*** **
Soil moisture	**$F_{(1,560)}$ = 145.772, P < 0.001*** **
Light	**$F_{(1,560)}$ = 26.615, P < 0.001*** **
Nutrients	**$F_{(1,560)}$ = 16.339, P < 0.001*** **
Plant grouping x soil moisture	**$F_{(9,560)}$ = 1.917, P = 0.047***
Plant grouping x light	**$F_{(9,560)}$ = 3.633, P < 0.001*** **
Plant grouping x nutrients	$F_{(9,560)}$ = 1.100, P = 0.361
Soil moisture x light	**$F_{(1,560)}$ = 81.422, P < 0.001*** **
Soil moisture x nutrients	$F_{(1,560)}$ = 3.365, P = 0.067
Light x nutrients	**$F_{(1,560)}$ = 5.593, P = 0.018***
Plant grouping x soil moisture x light	**$F_{(9,560)}$ = 2.974, P = 0.002** **
Plant grouping x soil moisture x nutrients	$F_{(9,560)}$ = 1.124, P = 0.343
Plant grouping x light x nutrients	$F_{(9,560)}$ = 1.789, P = 0.067
Soil moisture x light x nutrients	**$F_{(1,560)}$ = 4.689, P = 0.031***
Plant grouping x soil moisture x light x nutrients	$F_{(9,560)}$ = 0.694, P = 0.715
r^2	0.581

Legend: * = 0.05 ≥ P > 0.01 = significant, ** = 0.01 ≥ P > 0.001 = highly significant, *** = P ≤ 0.001 = very highly significant

Table 3. Four-way ANOVA significance table for mean aboveground biomass (total biomass at end of 2004 growing season) of *A. donax* and *P. balsamifera* ssp. *trichocarpa* by factors of plant groupings (2-species mixed grouping and monocultures), soil moisture (high and low), light (high and low), and nutrients (high and none). Significant results are reported in bold.

Factors and interactions	*A. donax*	*P. balsamifera* ssp. *trichocarpa*
Plant grouping	$F_{(1,122)} = 1.789$, $P = 0.184$	$F_{(1,115)} = 0.053$, $P = 0.819$
Soil moisture	**$F_{(1,122)} = 35.445$, $P < 0.001$*** **	**$F_{(1,115)} = 63.190$, $P < 0.001$*** **
Light	**$F_{(1,122)} = 36.561$, $P < 0.001$*** **	**$F_{(1,115)} = 4.094$, $P = 0.045$* **
Nutrients	**$F_{(1,122)} = 7.682$, $P = 0.006$** **	**$F_{(1,115)} = 6.966$, $P = 0.009$** **
Plant grouping x soil moisture	$F_{(1,122)} = 1.027$, $P = 0.313$	$F_{(1,115)} = 0.900$, $P = 0.345$
Plant grouping x light	$F_{(1,122)} = 2.118$, $P = 0.148$	$F_{(1,115)} = 2.340$, $P = 0.129$
Plant grouping x nutrients	$F_{(1,122)} = 0.881$, $P = 0.350$	$F_{(1,115)} = 1.017$, $P = 0.315$
Soil moisture x light	**$F_{(1,122)} = 87.616$, $P < 0.001$*** **	**$F_{(1,115)} = 5.376$, $P = 0.022$* **
Soil moisture x nutrients	$F_{(1,122)} = 1.838$, $P = 0.178$	$F_{(1,115)} = 0.068$, $P = 0.795$
Light x nutrients	**$F_{(1,122)} = 12.246$, $P = 0.001$*** **	$F_{(1,115)} = 0.061$, $P = 0.805$
Plant grouping x soil moisture x light	$F_{(1,122)} = 1.024$, $P = 0.314$	$F_{(1,115)} = 0.241$, $P = 0.624$
Plant grouping x soil moisture x nutrients	$F_{(1,122)} = 0.706$, $P = 0.402$	$F_{(1,115)} = 0.165$, $P = 0.686$
Plant grouping x light x nutrients	**$F_{(1,122)} = 4.564$, $P = 0.035$* **	**$F_{(1,115)} = 5.022$, $P = 0.027$* **
Soil moisture x light x nutrients	**$F_{(1,122)} = 8.449$, $P = 0.004$** **	$F_{(1,115)} = 0.369$, $P = 0.545$
Plant grouping x soil moisture x light x nutrients	$F_{(1,122)} = 0.242$, $P = 0.623$	$F_{(1,115)} = 0.265$, $P = 0.608$
r^2	0.646	0.457

Table 4. Four-way ANOVA significance table for mean aboveground biomass (total biomass at end of 2004 growing season) of *A. donax* and *S. laevigata* by factors of plant groupings (2-species mixed grouping and monocultures), soil moisture (high and low), light (high and low), and nutrients (high and none). Significant results are reported in bold.

Factors and interactions	***A. donax***	***S. laevigata***
Plant grouping	$F_{(1,122)} = 0.034$, $P = 0.854$	**$F_{(1,120)} = 5.348$, $P = 0.022$***
Soil moisture	**$F_{(1,122)} = 52.395$, $P < 0.001$*****	**$F_{(1,120)} = 21.523$, $P < 0.001$*****
Light	**$F_{(1,122)} = 23.905$, $P < 0.001$*****	$F_{(1,120)} = 1.303$, $P = 0.256$
Nutrients	$F_{(1,122)} = 0.873$, $P = 0.352$	$F_{(1,120)} = 0.636$, $P = 0.427$
Plant grouping x soil moisture	$F_{(1,122)} = 1.364$, $P = 0.245$	$F_{(1,120)} = 0.076$, $P = 0.783$
Plant grouping x light	$F_{(1,122)} = 0.423$, $P = 0.516$	$F_{(1,120)} = 0.084$, $P = 0.772$
Plant grouping x nutrients	$F_{(1,122)} = 1.631$, $P = 0.204$	$F_{(1,120)} = 1.076$, $P = 0.302$
Soil moisture x light	**$F_{(1,122)} = 73.333$, $P < 0.001$*****	**$F_{(1,120)} = 5.427$, $P = 0.022$***
Soil moisture x nutrients	$F_{(1,122)} = 0.477$, $P = 0.491$	**$F_{(1,120)} = 4.416$, $P = 0.038$***
Light x nutrients	**$F_{(1,122)} = 4.349$, $P = 0.039$***	$F_{(1,120)} = 0.904$, $P = 0.344$
Plant grouping x soil moisture x light	$F_{(1,122)} = 2.279$, $P = 0.134$	$F_{(1,120)} = 0.918$, $P = 0.340$
Plant grouping x soil moisture x nutrients	$F_{(1,122)} = 3.837$, $P = 0.052$	$F_{(1,120)} = 0.514$, $P = 0.475$
Plant grouping x light x nutrients	$F_{(1,122)} = 0.194$, $P = 0.660$	$F_{(1,120)} = 0.407$, $P = 0.525$
Soil moisture x light x nutrients	$F_{(1,122)} = 3.866$, $P = 0.052$	$F_{(1,120)} = 0.060$, $P = 0.808$
Plant grouping x soil moisture x light x nutrients	$F_{(1,122)} = 0.897$, $P = 0.345$	$F_{(1,120)} = 0.013$, $P = 0.908$
r^2	0.652	0.310

Table 5. Four-way ANOVA significance table for mean aboveground biomass (total biomass at end of 2004 growing season) of *A. donax* and *B. salicifolia* by factors of plant groupings (2-species mixed grouping and monocultures), soil moisture (high and low), light (high and low), and nutrients (high and none). Significant results are reported in bold.

Factors and interactions	***A. donax***	***B. salicifolia***
Plant grouping	**$F_{(1,125)} = 4.715$, $P = 0.032$***	**$F_{(1,128)} = 21.950$, $P < 0.001$*****
Soil moisture	**$F_{(1,125)} = 56.410$, $P < 0.001$*****	**$F_{(1,128)} = 27.082$, $P < 0.001$*****
Light	**$F_{(1,125)} = 18.760$, $P < 0.001$*****	**$F_{(1,128)} = 32.204$, $P < 0.001$*****
Nutrients	**$F_{(1,125)} = 14.659$, $P < 0.001$*****	$F_{(1,128)} = 3.708$, $P = 0.056$
Plant grouping x soil moisture	$F_{(1,125)} = 0.483$, $P = 0.488$	$F_{(1,128)} = 1.033$, $P = 0.311$
Plant grouping x light	$F_{(1,125)} = 1.159$, $P = 0.284$	$F_{(1,128)} = 3.079$, $P = 0.082$
Plant grouping x nutrients	$F_{(1,125)} = 2.789$, $P = 0.097$	**$F_{(1,128)} = 5.154$, $P = 0.025$***
Soil moisture x light	**$F_{(1,125)} = 55.937$, $P < 0.001$*****	**$F_{(1,128)} = 16.483$, $P < 0.001$*****
Soil moisture x nutrients	$F_{(1,125)} = 2.668$, $P = 0.105$	$F_{(1,128)} = 0.009$, $P = 0.925$
Light x nutrients	$F_{(1,125)} = 0.801$, $P = 0.373$	$F_{(1,128)} = 0.093$, $P = 0.761$
Plant grouping x soil moisture x light	**$F_{(1,125)} = 5.539$, $P = 0.020$***	$F_{(1,128)} = 0.488$, $P = 0.486$
Plant grouping x soil moisture x nutrients	$F_{(1,125)} = 0.908$, $P = 0.342$	**$F_{(1,128)} = 5.346$, $P = 0.022$***
Plant grouping x light x nutrients	$F_{(1,125)} = 0.505$, $P = 0.479$	$F_{(1,128)} = 0.548$, $P = 0.460$
Soil moisture x light x nutrients	$F_{(1,125)} = 2.519$, $P = 0.115$	$F_{(1,128)} = 2.638$, $P = 0.107$
Plant grouping x soil moisture x light x nutrients	$F_{(1,125)} = 1.579$, $P = 0.211$	**$F_{(1,128)} = 6.267$, $P = 0.014$***
r^2	0.633	0.496

FIGURES

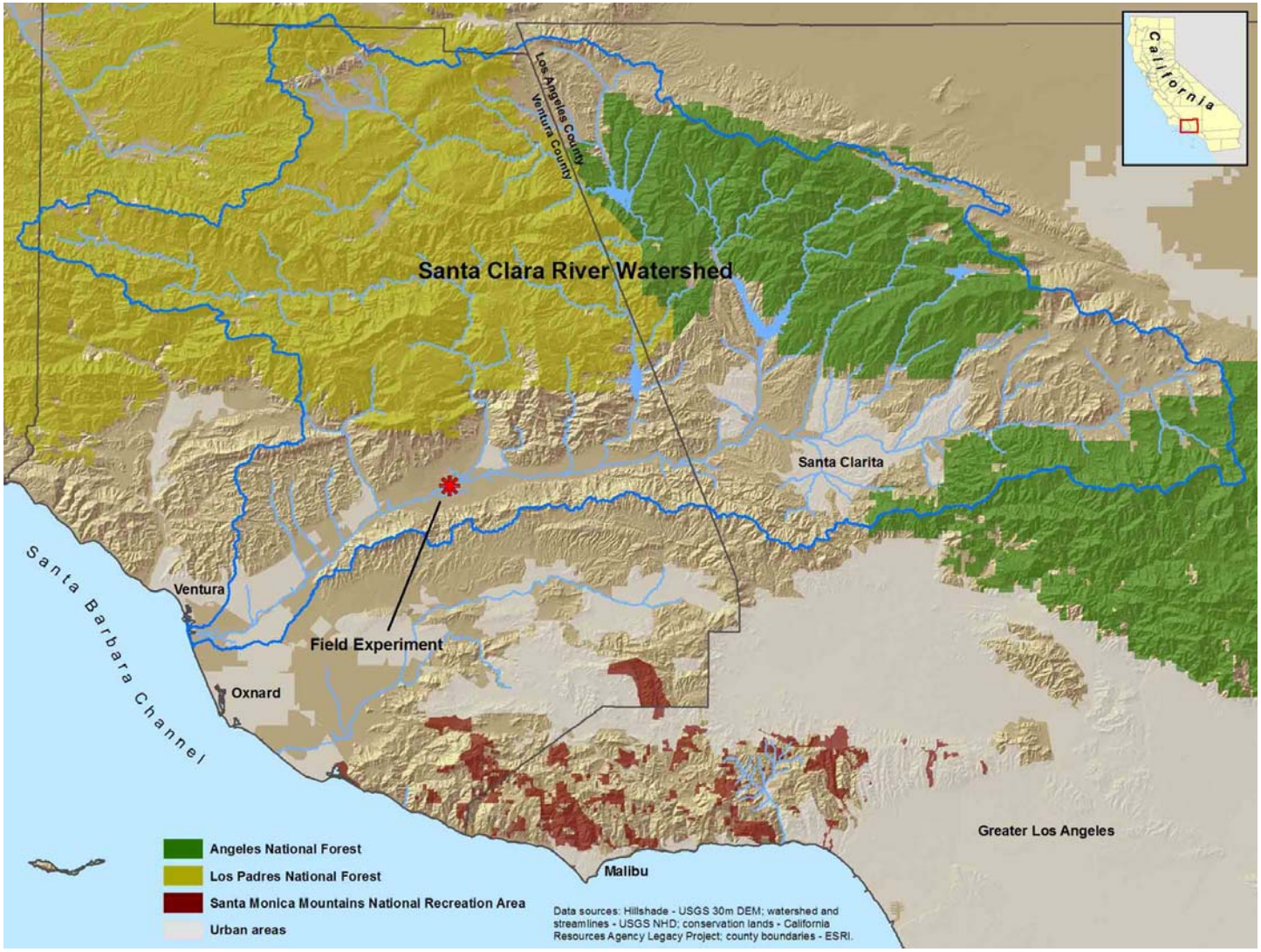

Figure 2. Location of field experiment study site, Santa Clara River Watershed, Ventura County, California.

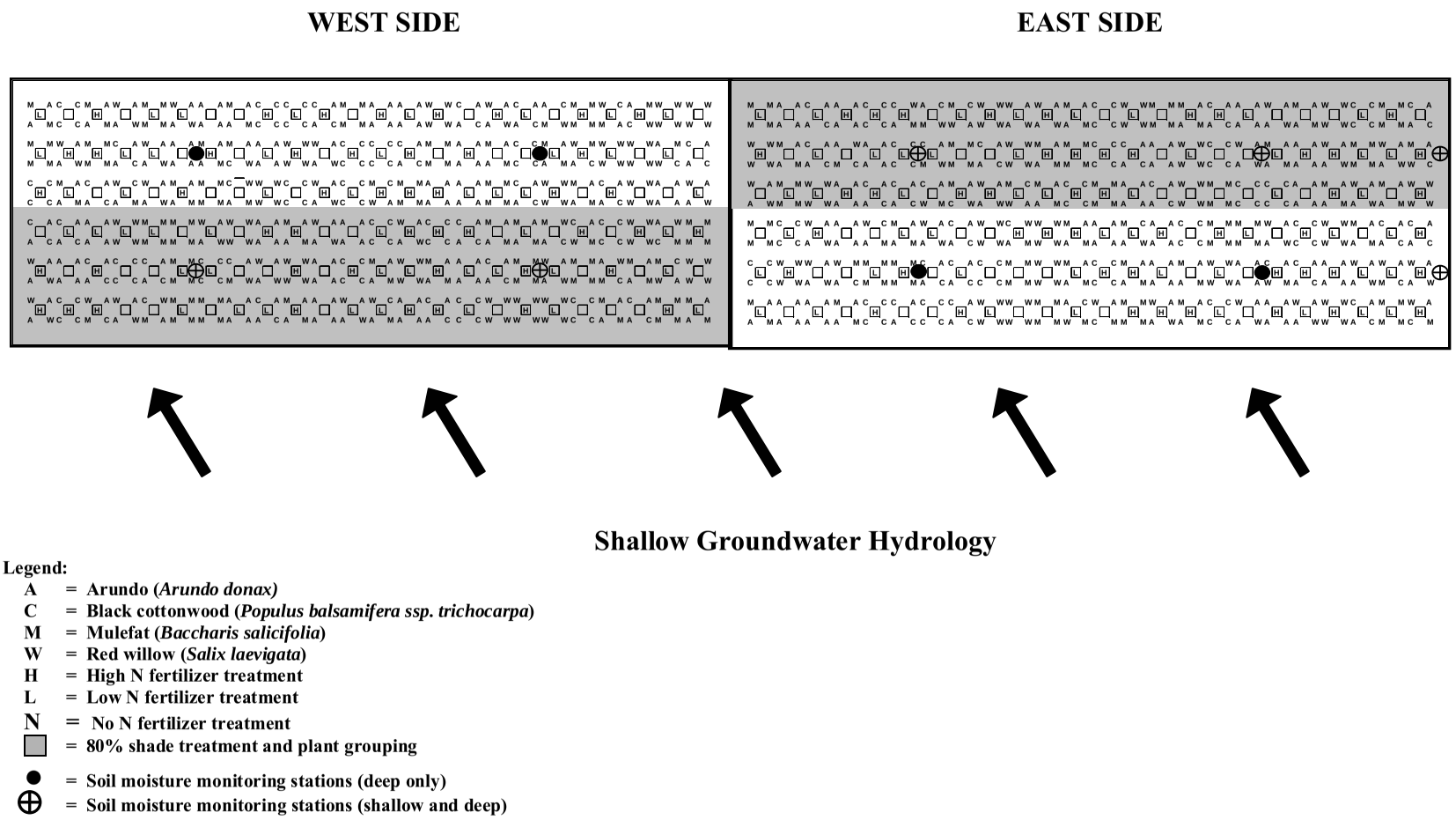

Figure 3. Field experiment planting and sampling layout.

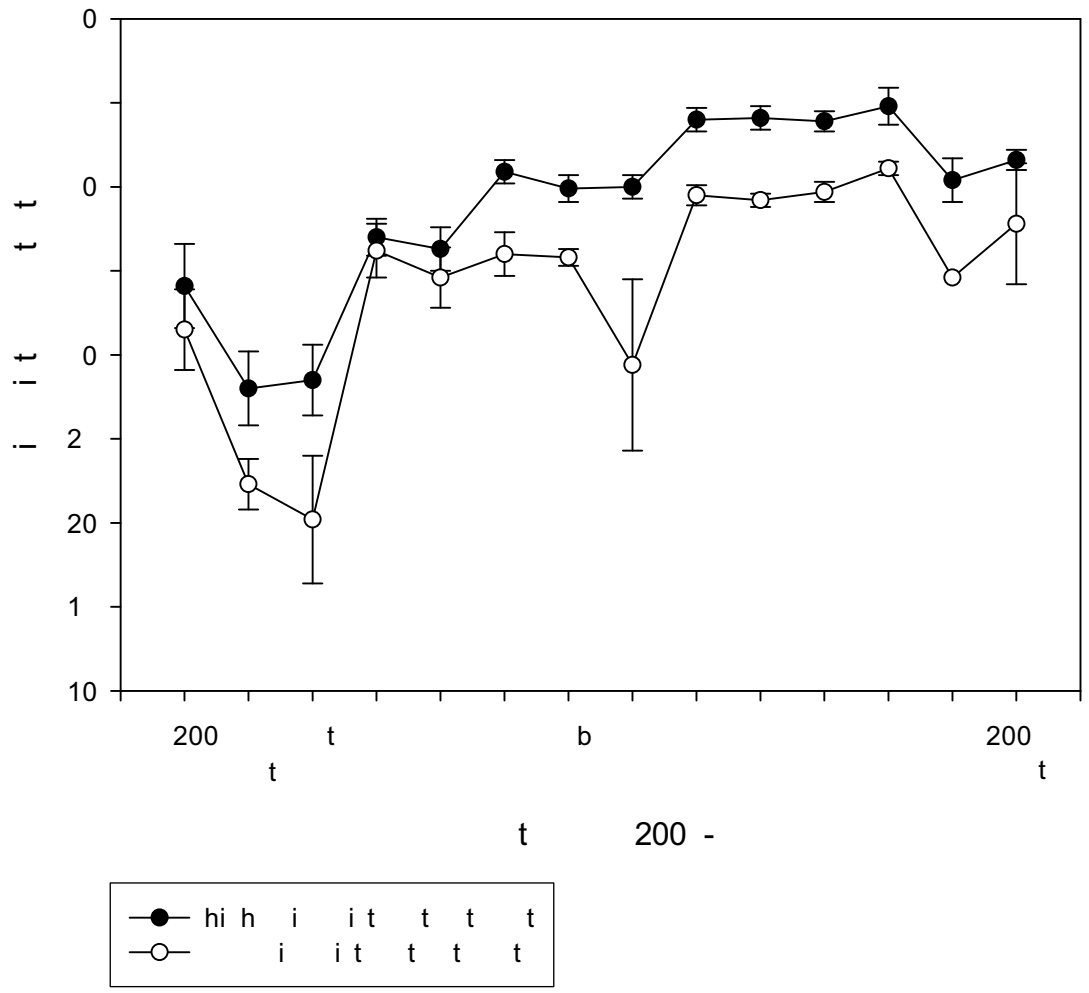

Figure 4. Mean monthly soil moisture content (percent) at 60–80 cm depth in the east and west sides of the experiment (high and low soil moisture treatments).

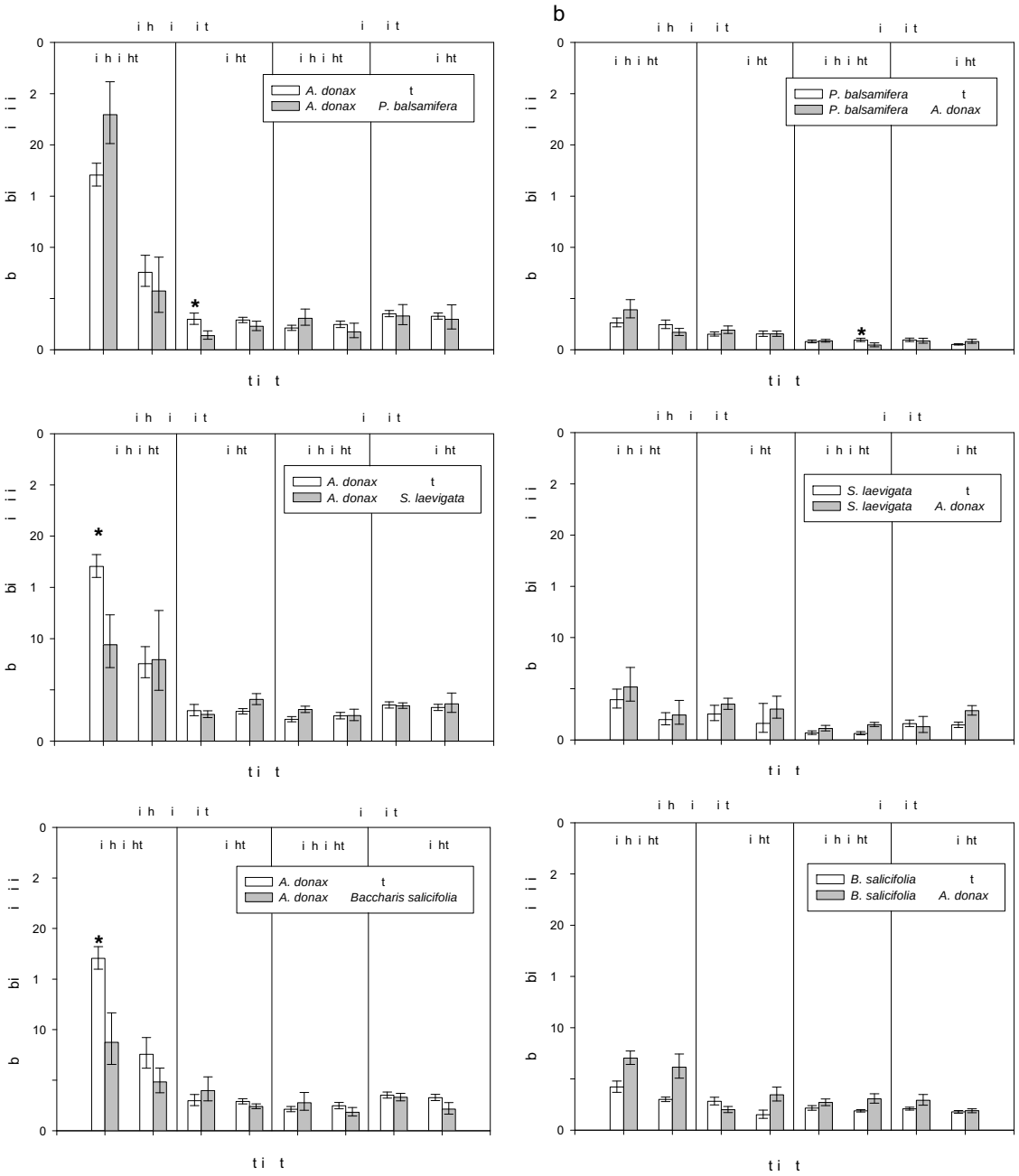

Figure 5. Mean aboveground biomass (± SE represented by error bars) of plants grown in monoculture compared to with a single competitor in the field experiment at the end of the 2004 growing season. Graphs show competitive effects by species pairings: a) *A. donax* by *P. balsamifera* spp. *trichocarpa*, b) *P. balsamifera* spp. *trichocarpa* by *A. donax*, c) *A. donax* by *S. laevigata*, d) *S. laevigata* by *A. donax*, e) *A. donax* by *B. salicifolia*, and f) *B. salicifolia* by *A. donax*. Asterisks denote results of post-hoc hypothesis tests (comparison of means) between plant groupings within similar treatments, with significance recognized at $\alpha < 0.05$.

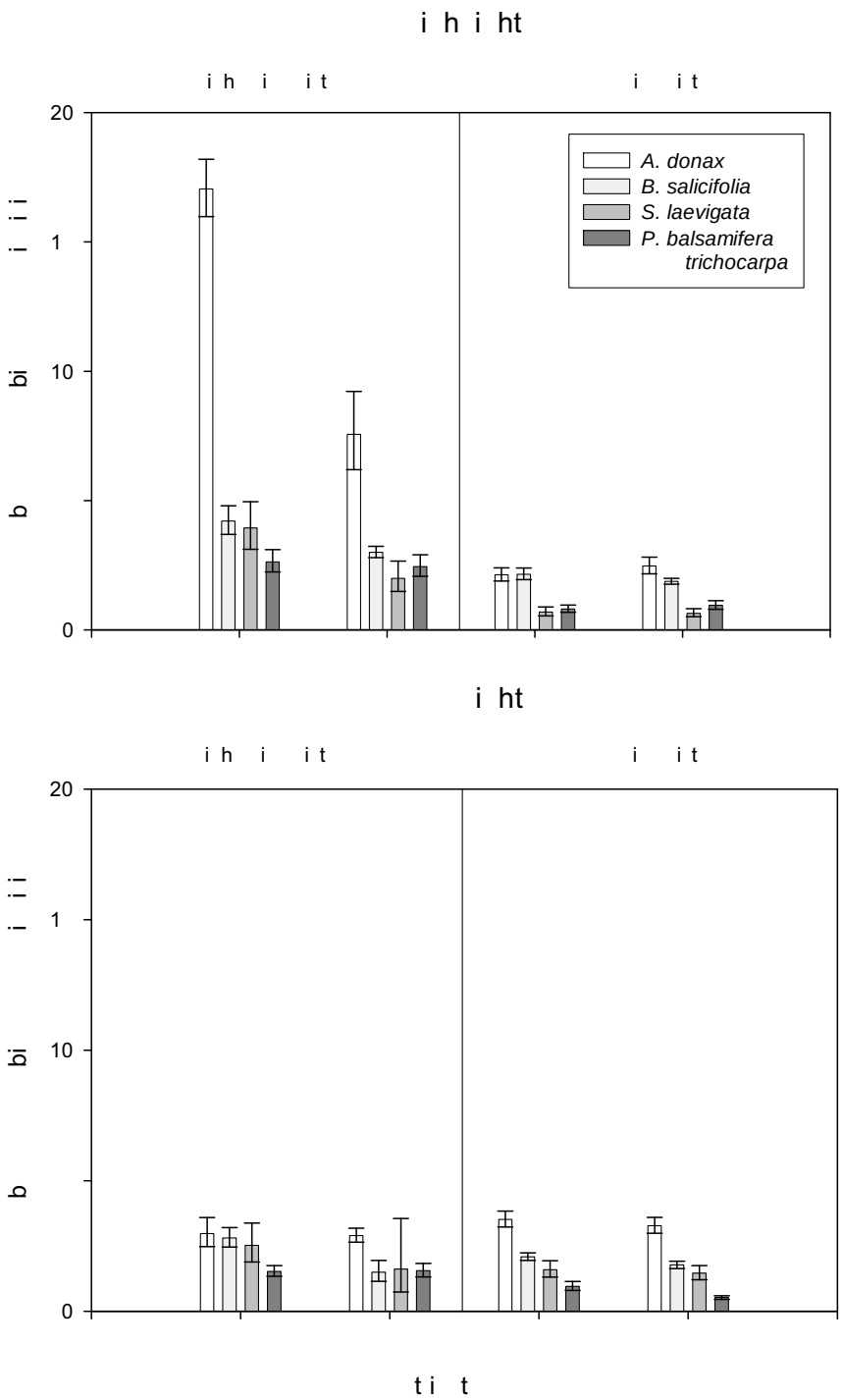

Figure 6. Mean aboveground biomass (± SE represented by error bars) of all plants grown in monoculture in the field experiment at the end of the 2004 growing season by species, soil moisture, nutrient, and light factors. Graphs are grouped by high light (a) and low light growing conditions (b).

APPENDICES

APPENDIX 2-1

BIOMASS REGRESSION EQUATIONS

Figure 1. Regression equations for *A. donax*, *Baccharis salicifolia*, *Salix laevigata*, and *Populus balsamifera* ssp. *trichocarpa* used to predict aboveground biomass of all plants under various soil moisture and light treatments in the field experiment in 2003. Equations ($y = b_1x_1 + c$) were based on aboveground biomass (g) of sample culms/branches (dependent variable or y), a

	High soil moisture						**Low soil moisture**					
	Full sun			**80% shade**			**Full sun**			**80% shade**		
Plant species	**b**	**c**	**r^2**	**b**	**c**	**r^2**	**b**	**c**	**r^2**	**b**	**c**	**r^2**
A. donax *(< 1 year)*	1.878	-0.197	0.906	3.097	-3.192	0.936	1.142	0.794	0.425	2.086	-0.760	0.923
B. salicifolia	2.287	-1.502	0.969	2.503	-2.110	0.995	2.455	-2.101	0.989	2.402	-1.905	0.969
S. laevigata	2.172	-1.023	0.989	2.173	-1.042	0.985	2.130	-1.248	0.979	2.335	-1.421	0.992
P. balsamifera* ssp. *trichocarpa	2.273	-1.037	0.993	2.256	-1.150	0.993	2.092	-1.266	0.982	2.210	-1.127	0.933

regression coefficient (b_1), basal diameter (mm) of sample culms/branches (independent variable or x_1), and a constant (y-intercept or c). All data were ln transformed. All regressions were significant.

Table 2. Regression equations for *A. donax*, *Baccharis salicifolia*, *Salix laevigata*, and *Populus balsamifera* ssp. *trichocarpa* used to predict aboveground biomass of all plants under various soil moisture and light treatments in the field experiment in 2004. Equations ($y = b_1x_1 + c$) were based on aboveground biomass (g) of sample culms/branches (dependent variable or y), a

	High soil moisture						**Low soil moisture**					
	Full sun			**80% shade**			**Full sun**			**80% shade**		
Plant species	**b**	**c**	**r^2**	**b**	**c**	**r^2**	**b**	**c**	**r^2**	**b**	**c**	**r^2**
A. donax *(< 1 year)*	2.516	-1.744	0.980	1.609	0.770	0.908	1.864	-0.020	0.956	1.634	0.686	0.891
A. *donax* (> 1 year)	2.636	-1.910	0.971	2.301	-0.918	0.895	2.316	-1.290	0.936	2.856	-2.336	0.947
B. salicifolia	2.625	-2.132	0.995	2.511	-1.869	0.994	2.657	-2.314	0.993	2.658	-2.302	0.994
S. laevigata	2.195	-0.983	0.993	2.305	-1.228	0.990	2.295	-1.358	0.988	2.321	-1.337	0.995
P. balsamifera* ssp. *trichocarpa	2.408	-1.352	0.993	2.413	-1.498	0.996	2.306	-1.285	0.992	2.353	-1.445	0.993

regression coefficient (b_1), basal diameter (mm) of sample culms/branches (independent variable or x_1), and a constant (y-intercept or c). All data were ln transformed.

APPENDIX 2-2

PLANT SURVIVORSHIP IN FIELD EXPERIMENT

METHODS

Sampling Methods

I measured plant survivorship at three time periods: 1) survivorship of planted cuttings in March 2003, 2) plant survivorship at the end of 2003, and 3) plant survivorship at the end of 2004. A few cuttings (14) and rhizomes (9) that did not grow initially were replanted in spring 2003. 2003 and 2004 percent survivorship results represented the establishment success for all initial and replacement cuttings.

Statistical Analyses

Descriptive statistics were performed on plant survivorship measurements. Four-way ANOVAs (all combinations of competition groupings, soil moisture, light, and nutrient factors and levels) were performed on percent survivorship data for three time periods (cuttings and at the end of the two growing seasons) to determine treatment effects during the plant establishment period. Percent plant survivorship measured at the end of 2003 and 2004 was compared in the two-way ANOVA (year x competition grouping). The 36 four-species groupings and 96 low nutrient treatments plant groupings in the experiment were not included in these statistical analyses.

RESULTS

The four-way ANOVA (species x soil moisture x nutrients x light) for percent survivorship yielded no significant main effects or interactions for cuttings and plants at

the end of the 2004 growing season (Table 1), yet resulted in one two-way interaction between species and soil moisture for plant survivorship at the end of 2003 growing season (Table 1). Only five plants (0.8% of plants in groupings analyzed) did not survive the second growing season. First year plant survivorship of *P. balsamifera* ssp. *trichocarpa* was significantly lower within the high soil moisture treatment than in any other species and soil moisture treatment combination (Figure 1).

Table 1. Four-way ANOVA significance table for percent plant survivorship during establishment by factors of species from one-species and two-species groupings combined (*Arundo donax* and three native riparian species, *Salix laevigata*, *Populus balsamifera* ssp. *trichocarpa*, and *Baccharis salicifolia*), soil moisture (high and low), nutrient additions (high and none), and light (high and low). Results are for three time periods: 1) cutting survivorship (March 2003), 2) plant survivorship at end of 2003, and 3) plant survivorship at end of 2004. Significant results are in bold.

Factors and interactions	Cuttings	2003	2004
Species	$F_{(3,48)} = 1.821$, $P = 0.156$	$F_{(3,48)} = 2.352$, $P = 0.084$	$F_{(3,48)} = 2.523$, $P = 0.069$
Soil moisture	$F_{(1,48)} = 1.346$, $P = 0.252$	$F_{(1,48)} = 4.029$, $P = 0.050$	$F_{(1,48)} = 1.858$, $P = 0.179$
Nutrients	$F_{(1,48)} = 0.050$, $P = 0.824$	$F_{(1,48)} = 0.042$, $P = 0.839$	$F_{(1,48)} = 0.046$, $P = 0.831$
Light	$F_{(1,48)} = 1.625$, $P = 0.208$	$F_{(1,48)} = 0.855$, $P = 0.360$	$F_{(1,48)} = 0.170$, $P = 0.682$
Species x soil moisture	$F_{(3,48)} = 1.456$, $P = 0.238$	**$F_{(3,48)} = 3.628$, $P = 0.019$***	$F_{(3,48)} = 2.100$, $P = 0.113$
Species x nutrients	$F_{(3,48)} = 0.398$, $P = 0.755$	$F_{(3,48)} = 0.513$, $P = 0.675$	$F_{(3,48)} = 0.723$, $P = 0.543$
Species x light	$F_{(3,48)} = 0.400$, $P = 0.754$	$F_{(3,48)} = 1.197$, $P = 0.321$	$F_{(3,48)} = 0.412$, $P = 0.745$
Soil moisture x nutrients	$F_{(1,48)} = 0.361$, $P = 0.551$	$F_{(1,48)} = 0.490$, $P = 0.487$	$F_{(1,48)} = 1.018$, $P = 0.318$
Soil moisture x light	$F_{(1,48)} = 0.022$, $P = 0.884$	$F_{(1,48)} = 0.000$, $P = 0.984$	$F_{(1,48)} = 1.455$, $P = 0.234$
Nutrients x light	$F_{(1,48)} = 0.624$, $P = 0.434$	$F_{(1,48)} = 0.001$, $P = 0.980$	$F_{(1,48)} = 0.138$, $P = 0.712$
Species x soil moisture x nutrients	$F_{(3,48)} = 0.124$, $P = 0.946$	$F_{(3,48)} = 0.265$, $P = 0.850$	$F_{(3,48)} = 1.266$, $P = 0.296$
Species x soil moisture x light	$F_{(3,48)} = 2.431$, $P = 0.077$	$F_{(3,48)} = 1.253$, $P = 0.301$	$F_{(3,48)} = 1.543$, $P = 0.215$
Species x nutrients x light	$F_{(3,48)} = 1.193$, $P = 0.322$	$F_{(3,48)} = 2.046$, $P = 0.120$	$F_{(3,48)} = 0.921$, $P = 0.438$
Soil moisture x nutrients x light	$F_{(1,48)} = 0.111$, $P = 0.740$	$F_{(1,48)} = 0.772$, $P = 0.384$	$F_{(1,48)} = 1.359$, $P = 0.249$
Species x soil moisture x nutrients x light	$F_{(3,48)} = 2.212$, $P = 0.099$	$F_{(3,48)} = 2.104$, $P = 0.112$	$F_{(3,48)} = 2.431$, $P = 0.077$
r^2	0.428	0.490	0.457

* = $0.05 \geq P > 0.01$ = significant; ** = $0.01 \geq P > 0.001$ = highly significant; *** = $P \leq 0.001$ = very highly significant.

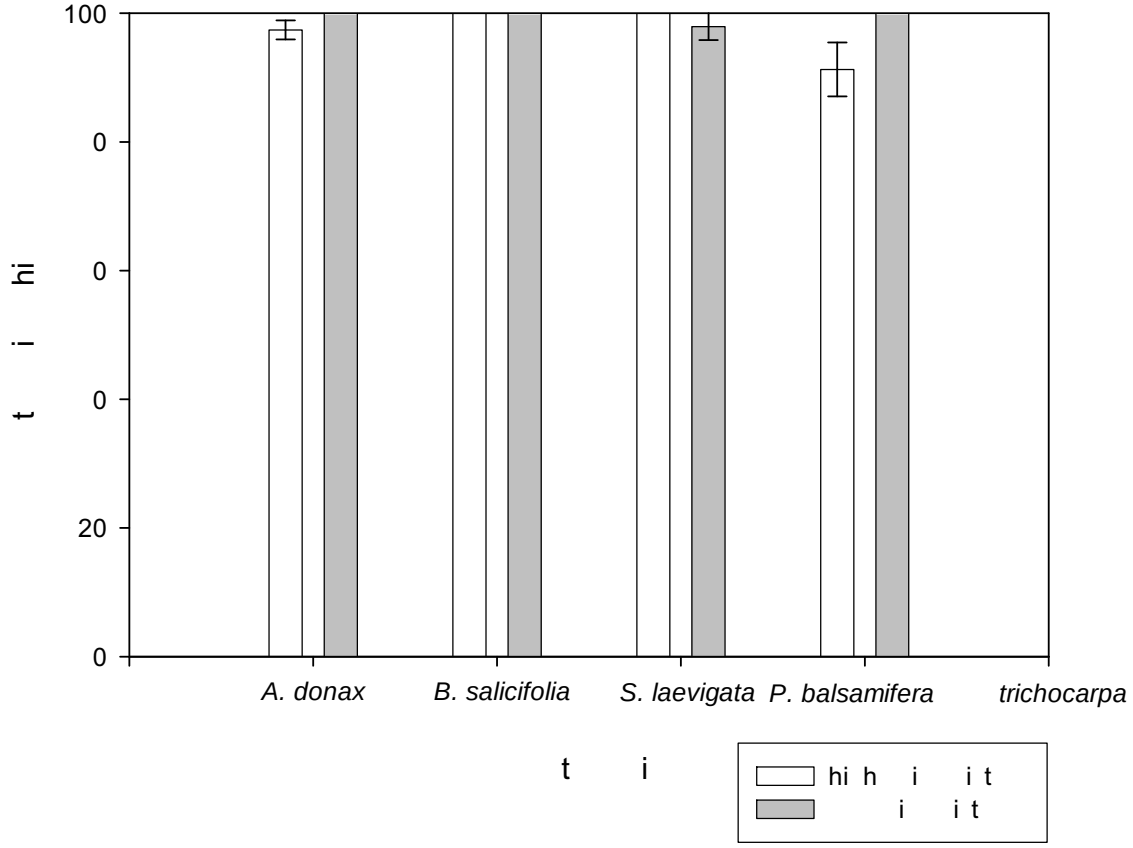

Figure 1. Effects of soil moisture availability on percent plant survivorship of *A. donax* compared to three native riparian plant species at the end of the first growing season (fall 2003) based on the four-way ANOVA (competition x soil moisture x nutrients x light). Letters denote results of post-hoc hypothesis tests (comparison of means) between individual treatments within each graph only, with significance recognized at $\alpha < 0.05$.

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CHAPTER 3 -

INFLUENCE OF ANTHROPOGENIC NUTRIENT ENRICHMENT ON INVASION OF RIPARIAN ECOSYSTEMS BY *ARUNDO DONAX* IN SOUTHERN CALIFORNIA

Abstract: One of the greatest threats to riparian ecosystems of Mediterranean-type climate regions, including California, is a member of the grass family (Poaceae), giant reed (*Arundo donax* L.). I tested the hypothesis that anthropogenic nutrient enrichment is one of the most significant factors contributing to the recent invasion of riparian ecosystems by *A. donax* in southern California. I examined the influence of nutrient enrichment of shallow groundwater and soil from various land use practices on the degree of infestation of *A. donax* throughout several coastal watersheds. Elevated levels of N (nitrogen) found in shallow groundwater and soils of floodplains were associated with adjacent land use and watersheds with higher anthropogenic nutrient inputs. Both large and small *A. donax* infestations on floodplains contained higher soil NO_3-N concentrations than did non-infested areas. Higher N and K (potassium) leaf tissue content of *A. donax* in large and small infestations compared to native red willow (*Salix laevigata* Bebb.) in non-infested and reference sites suggests that these nutrients may be more available to *A. donax*. Unlike *S. laevigata*, *A. donax* may take advantage of anthropogenically enriched N levels in riparian ecosystems, as illustrated by its positive response to all forms of shallow groundwater N in floodplains and soil N on riparian terraces. Results of this study suggest that N limiting conditions may naturally occur in

riparian ecosystems in this geologically young landscape, but anthropogenic nutrient inputs have elevated groundwater N:P ratios in study watersheds. Results of this study can help predict optimal nutrient conditions for *A. donax* invasion. Reducing excess N supply to riparian ecosystems associated with agricultural and residential land use activities may aid in the long-term control of *A. donax*.

Key Words: Arundo donax, giant reed, invasive species, alien species, nutrients, nutrient loading, nitrogen, phosphorus, land use, riparian, Mediterranean-type climate, watershed, rivers

INTRODUCTION

Both natural and anthropogenic disturbances along rivers in Mediterranean-type climate regions are thought to promote the spread of invasive plant species (Drake et al. 1989, Gregory et al. 1991, Pysek and Prach 1994, Else 1996, Else and Zedler 1996, Dudley 1998). Several experimental studies in wetland ecosystems have demonstrated higher response to nitrogen by clonal, invasive plants than natives (Green and Galatowitsch 2002, Maurer and Zedler 2002, Minchinton and Bertness 2003). Elevated nutrient levels have been linked to plant invasion in many ecosystems (Kolb et al. 2002, Booth et al. 2003, Brooks 2003, Kolb and Alpert 2003, Suding et al. 2004), however little is known about the role of nutrients in promoting invasion in riparian ecosystems (Wang 1998). In this paper, I explore the influence of anthropogenic nutrient enrichment on the invasion of riparian ecosystems by the clonal grass species *Arundo donax* in southern California.

Due to the intense but infrequent winter storm patterns characteristic of Mediterranean-type climates, rivers are heavily scoured every few years. Strong floods remove and disperse riparian vegetation downstream, creating open floodplains for colonization. Weedy plant species are able to establish and grow quickly in disturbed areas such as these (Elton 1958, Tilman 1988, Drake et al. 1989, Richardson et al. 2000), the most invasive of which often physically compete with native species for light, nutrients, and water. Historically, riparian ecosystems in Mediterranean-type climates have been severely altered by human perturbation. Since early human settlement of these areas, rivers have been dammed, channelized, mined, diverted, and subjected to

residential and commercial development in Mediterranean-type climates (Palmer 1993, Mount 1995). These alterations have magnified their susceptibility to plant invasions by weedy plant species (Randall et al. 1998, Rundel 1998). Currently, one of the greatest invasive threats to riparian ecosystems in Mediterranean-type climates is a tall, perennial bamboo-like member of the grass family (Poaceae) called giant reed (*Arundo donax* L.).

Indigenous to southern Eurasia, *A. donax* was introduced extensively to other locales and now thrives in many warm climates worldwide (Perdue 1958, Crampton 1974, Polunin and Huxley 1987, Hickman 1993, Sharma et al. 1998). In the United States, *A. donax* has become especially devastating to riparian habitats in California's Mediterranean-type climate region, creating significant impacts to natural-river functioning and sustainability (Rundel 2000). *Arundo donax* was introduced to agricultural landscapes in the Los Angeles area for building materials and erosion control along irrigation canals. Carried by floodwaters, *A. donax* eventually made its way to adjacent streams and rivers and by the 1820s patches were commonly found along floodplains of many streams (Robbins et al. 1951). However, it appears that *A. donax* has only recently succeeded in invading (i.e., expanding its distribution and displacing native vegetation) riparian ecosystems along floodplains and terraces in southern California after large floods in 1969 (Sanger Hedrick pers. comm.) (Bell 1997).

Arundo donax is one of the most successful weedy invaders in the disturbance-defined riparian ecosystems of Mediterranean-type climates (Bell 1997, Boose and Holt 1999). Although inflorescences (0.5 m long terminal panicles) are not known to produce seed in California (Johnson et al. 2006), *A. donax* reproduces readily by vegetative

propagation; it is dispersed downstream when small pieces of rhizomes or culms break off during flooding and land on bare, moist substrates (Else 1996, Else and Zedler 1996, Bell 1997, Boose and Holt 1999, Wijte et al. 2005). Growing at an extremely fast rate (up to 10 cm per day under optimal conditions), *A. donax* quickly establishes on exposed or sparsely vegetated soil and grows to more than 4 m in height after only a few months (Rieger and Kreager 1989) and may attain heights of up to 8 m a few years after establishment (Perdue 1958). Once established, *A. donax* then expands outward in area by clonal propagation (Decruyenaere and Holt 2001), crowding and displacing indigenous shrubs, herbs and grasses, and trees under elevated soil moisture, nutrient, and light conditions (Rieger and Kreager 1989). In this manner, *A. donax* forms extensive stands, or monocultures, along floodplains and terraces of California's river and stream systems.

Infestations of *A. donax* have created serious physical and biological problems along rivers in Mediterranean-type climate regions (Dudley and Collins 1995, DiTomaso 1998, Dudley 2000, Rundel 2003). Where it grows extensively along floodplains, *A. donax* physically obstructs natural water flow, thereby increasing the risk of flooding. As the aboveground biomass dries in the hot, dry summer months, *A. donax* creates a fire hazard where moisture-rich riparian corridors would normally form natural barriers to fire (Scott 1994, Rundel and Gustafson 2005). Furthermore, *A. donax* may outcompete native riparian species for scarce water resources (Iverson 1994, Coffman in press), thereby decreasing biodiversity and reducing the value of riparian habitats for wildlife (Kisner 2004).

Millions of dollars have been spent in efforts to remove *A. donax* from riparian ecosystems in southern California. Although these attempts have been successful in removing small infestations of *A. donax* on riparian terraces, it continues to thrive in floodplains. An understanding of the ecological conditions that promote continued growth and invasion of *A. donax* is needed for its effective control. Ever expanding residential and agricultural development in coastal southern California and other Mediterranean-type climates has led to increased water import and discharge into rivers, declining water quality, and removal of the once vast low-lying areas of riparian forest. The result – increased nutrient, water, and light availability – may promote invasion of riparian ecosystems by *A. donax* (Bell 1997, Wang 1998, Rundel 2003, Coffman et al. 2004). This study investigated one of the most important factors influencing *A. donax* invasion: elevated nutrient levels in riparian ecosystems caused by anthropogenic inputs.

Soils in Mediterranean-type climates commonly contain low levels of nitrogen (N) and phosphorus (P) (Day 1983, diCastri 1991, Dallman 1998). In southern California, the young sedimentary geology is naturally high in P, but has N-limiting conditions (Pettijohn 1975). Nutrient enrichment of riparian ecosystems (especially by N) from adjacent land use practices may promote *A. donax* growth and invasion in river systems of southern California. Excess N, P, and potassium (K) are transported in surface and shallow groundwater from various land use activities to adjacent riparian ecosystems (Schlosser and Karr 1981, Correll 1984, Correll et al. 1992, Triska et al. 1994, Rodda 1995, Basnyat et al. 1999). Weedy and invasive plant species often differ in their nutrient requirements and uptake efficiency compared to native plants, resulting in a

competitive advantage for the former in nutrient rich environments (Claridge and Franklin 2002). Thus, elevated nutrient levels in riparian ecosystems are thought to promote invasion of plants such as *A. donax*.

This study investigated the influence of anthropogenic nutrient enrichment on invasion of *A. donax* in three river systems of southern California. I hypothesized that nutrient enrichment of riparian ecosystems from anthropogenic sources has contributed significantly to invasion of river systems by *A. donax* in southern California. To test this hypothesis, I examined relationships between the degree of *A. donax* infestation and nutrient levels in the associated shallow groundwater, soil, and leaf tissue using a correlational approach.

METHODS

Study Area

The study area lies northwest of Los Angeles in Ventura and Los Angeles Counties, California. Three river systems (Calleguas Creek, the Santa Clara River, and Topanga Canyon) located in watersheds with varying compositions of land use were studied (Figure 7). Ten reference subwatersheds from within this region where *A. donax* is absent were used as indicators of natural conditions.

The Calleguas Creek watershed drains an area of approximately 888 km^2, predominantly in southern Ventura County. It contains a roughly equal mix of three main land use categories: ~30% residential development, ~32% agricultural areas (both row crops and orchards mostly in the western and lower watershed), and ~38% open

space (mainly in the mountains of the upper watershed) (Figure 8). This watershed was chosen for its relatively high level of anthropogenic nutrient input.

The Santa Clara River is one of southern California's last remaining large, unregulated river systems. The river and its tributaries drain a watershed of approximately 4,185 km^2, the second largest coastal watershed in southern California. The 187-km long river flows in a westerly direction from its headwaters on the northern slopes of the San Gabriel Mountains in Los Angeles County to the Oxnard Plain in Ventura County, emptying into the Pacific Ocean near the City of Ventura. The Santa Clara River contains a mix of land use types representing moderate anthropogenic nutrient input, although over 80% of the watershed (mainly upper and higher elevation portions) remains as open space (Figure 8). The floodplain of the lower watershed is dominated by agricultural land use (orchards and row crops), and urban and residential development is rapidly expanding in the mid to upper watershed.

The Topanga Canyon Watershed, approximately 91 km^2, is located in the heart of the Santa Monica Mountains in western Los Angeles County. Topanga Canyon is a low anthropogenic nutrient input system. The watershed is composed primarily of low-density rural residential development (6%) and open space (93%) in the upper parts of the watershed, with almost no agricultural land use (Figure 8).

To fully test my hypothesis that riparian ecosystems in developed watersheds were invaded due to increased nutrient supply from anthropogenic inputs, I documented reference conditions in undeveloped watersheds throughout the study area to compare to developed watersheds. In this coastal geographic region, none of the undeveloped

watersheds contained *A. donax*, so they were not true controls for testing my hypothesis. However to establish reference conditions, I sampled shallow groundwater, soil, and leaf tissue nutrients within ten undeveloped watersheds (reference sites) in the region: three subwatersheds (tributaries) of the Santa Clara River Watershed and seven smaller undeveloped watersheds in the Santa Monica Mountains. Reference sites were located in open space areas containing no upstream anthropogenic nutrient inputs and were dominated by red willow, *Salix laevigata* (no *A. donax* was present). I could not control for N inputs from atmospheric deposition, but based on model results for dry atmospheric N deposition for watersheds in the Los Angeles Region, I assumed similar levels of atmospheric N dry deposition among watersheds (Lu et al. unpublished data).

Study Design and Sampling Locations

I established stratified sampling locations along the main stem of each of the three river systems based on three factors and different levels within each factor: adjacent land use type (agricultural, residential development, and open space); fluvial geomorphic landform (floodplains and terraces); and degree of *A. donax* infestation (none, small, and large) (Table 6; Figure 8). Effects of nutrient inputs from land use activities on *A. donax* invasion were thought to be more directly related to adjacent land use type in higher riparian terraces (called terraces), whereas the watershed factor was used to address cumulative effects of upstream land use activities on floodplain sampling locations (lower terraces immediately adjacent to main channels with baseflow).

Each sampling location was approximately 600 m^2. Floodplain sampling sites were roughly 30 m in length (parallel and immediately adjacent to the main stream

channel, containing baseflow) by 20 m in width (perpendicular to the channel). Terrace sampling sites had similar dimensions but were located immediately adjacent to upland land use areas. I also selected locations where *A. donax* was: (1) completely absent and native riparian vegetation (*Salix laevigata*) dominated, (2) only present as small infestations (between 1–9 m^2), and (3) the dominant component of the vegetation (> 100 m^2), representing heavily invaded river reaches. *Salix laevigata* Bebb. (Salicaceae family) was selected because it is the most common woody plant consistently found throughout riparian ecosystems in the study area. Roots of the phreatophyte *S. laevigata* can reach up to 30 m when the groundwater table is deep, whereas *A. donax* roots have been observed to grow to only 8 feet in depth (Figure 9) (See Appendix 3-1 for site locations).

Sampling Methods

Samples of *A. donax* or *S. laevigata* leaf tissue and associated shallow groundwater and soils were taken once at each sampling location from July to September 2003. Ten *A. donax* or *S. laevigata* leaves from at least three plants were collected at each sampling location for leaf tissue nutrient analyses. *Arundo donax* leaves were collected at large and small infestation sampling sites. *Salix laevigata* leaves were collected from riparian ecosystem sampling sites with no *A. donax* and at reference sites where *A. donax* was absent. Only newly mature, healthy, full sun leaves were collected from the top of *A. donax* culms and the middle of *S. laevigata* canopies. Leaf tissue was analyzed for relative nutrient content to evaluate nutrient use and availability to plants (Taiz and Zeiger 1991).

Shallow groundwater samples were collected in the center of each sampling location next to the target plant (either *A. donax* or *S. laevigata*). An 8-cm diameter bucket auger was used to create sampling holes, and a temporary stainless steel piezometer connected to a bailer was used to collect the groundwater samples. After purging the bailer several times, a groundwater sample was collected. Each day, these samples were kept on ice until delivered to a local laboratory for immediate analysis. Because groundwater was too deep to sample at terrace study sites, only soil and leaf tissue nutrient contents were collected in these areas. Five subsamples of soil were collected adjacent to target plants and combined into a composite sample by mixing together thoroughly in a stainless steel bowl. Each soil subsample was collected with an 8-cm diameter bucket auger from the upper 30 cm of the soil surface, where nutrient concentrations are expected to be greatest (Day 1983).

Leaf tissue and soil samples were air-dried and ground to a powder in preparation for nutrient content analyses at the DANR Analytical Laboratory in Davis, California. Leaf tissue was analyzed for total percent N, P, and K. Total N content of leaf tissue was determined using a Nitrogen Gas Analyzer combustion method (LECO FP-528) (AOAC International 1997a), total P content by microwave acid digestion/dissolution of leaf tissue samples and quantitative determination by AAS and ICP-AES (Meyer and Keliher 1992, Sah and Miller 1992), and total K content by the 2% acetic acid extraction method and a quantitative determination using atomic emission spectrometry (Johnson and Ulrich 1959).

Soil samples were analyzed for total N (%), nitrate-N (NO_3-N/ppm), ammonia-N (NH_4-N/ppm), orthophosphate (PO_4-P/ppm), and pH. Total N in the soil was determined by the combustion gas analyzer method (Method 972.43) (AOAC International 1997b). Concentrations of NO_3-N and NH_4-N in the soil were determined by equilibrium extraction of soil with potassium chloride and a flow-injection analyzer (Hofer 2003, Knepel 2003). Because the soils studied were neutral to alkaline, the Olsen-P method was used to estimate the relative availability of inorganic PO_4-P in soils (Olsen and Sommers 1982, Prokopy 1995). Soil pH was determined using a saturated paste prepared from the soil and a pH meter (USDA 1954). Soil grain size was analyzed using a hydrometer to determine the particle size distribution of sand, silt, and clay in soil suspension (Sheldrick and Wang 1993).

Shallow groundwater samples were analyzed for NH_4-N, NO_3-N + NO_2-N, PO_4-P, total Kjeldahl nitrogen (TKN), total N (total N = TKN + NO_3-N + NO_2-N), and pH by Fruit Growers Environmental Laboratories in Santa Paula, California. NH_4-N (4500NH3H), NO_3-N + NO_2-N (SM4500-NO3 F/EPA 300.0), and pH (Method 4500-H B) were analyzed according to the *Standard Methods for the Examination of Water and Wastewater* (Franson et al. 1998). TKN (EPA Method 351.1) and PO_4-P (Olsen P Methods 300.0 and 4500) were analyzed per *Methods for Chemical Analysis of Water and Wastes* (USEPA 1983).

Statistical Analyses

In this study, I used a multifactorial design in which combinations of four fixed factors (Model 1) were crossed with each other. The factors and associated levels were:

watersheds (Santa Clara River, Calleguas Creek, Topanga Canyon, and reference watersheds), land use types (agricultural, residential, and open space), fluvial geomorphic location (floodplain and terrace), and degree of *A. donax* infestation (none, small, and large). Sampling sites with small *A. donax* infestations represented areas where *A. donax* presence may indicate different invasion trajectories (i.e., depending on site conditions *A. donax* will either invade the area or persist as a small patch). ANOVA tests were used to analyze effects of various combinations of the four factors (independent variables) on nutrient concentrations in shallow groundwater, soil, and leaf tissue, soil grain size, pH, and leaf tissue and shallow groundwater N:P (dependent or response variables) (Systat Statistical Program [Version 10]).

Since data for terrace locations were only collected within the Santa Clara River Watershed, four-way ANOVAs could not be conducted. Instead, two three-way ANOVAs (watershed x land use x degree of infestation and land use x fluvial geomorphic location x degree of infestation) were performed on a combination of the fixed factors and response variables. To further investigate differences between invaded and non-invaded sites, small *A. donax* infestation data were removed and three-way ANOVAs repeated. Because soil nutrients can be strongly influenced by soil grain size, three-way ANOVAs for soil nutrients were conducted using soil grain size (percent silt + clay) as a covariate. This parameter covaried significantly with all soil nutrient analytes. Since *A. donax* and *S. laevigata* leaves were not collected from the same sample locations to test species specific variation in leaf tissue nutrients, one-way ANOVAs were performed by the species factor (*A. donax* and *S. laevigata*, data from all infestation types

combined) using groundwater nutrient analytes as covariates. *Arundo donax* leaf tissue nutrient content was significantly greater than *S. laevigata* in all cases. Therefore, *A. donax* and *S. laevigata* leaf tissue nutrient results were compared separately in ANOVAs because variation in species nutrient uptake and use efficiency could potentially confound results (Chapin et al. 1986). F tests were performed to evaluate contrasts between means of grouping variables and levels in three-way ANOVA results.

I conducted one-way ANOVAs for watershed identity using all response variables to analyze the main effects of three study watersheds compared to reference watersheds. Nutrient content of leaf tissue was analyzed and reported separately by species in this one-way ANOVA. In addition, one-way ANOVAs by degree of infestation across all watersheds were conducted for *A. donax* leaf tissue nutrients in small and large infestations to compare foliar nutrient concentrations between infestation levels. Tukey's post hoc tests were conducted to determine significant differences between factor means in these one-way ANOVAs.

Linear regression analyses were performed to investigate relationships between *A. donax* and *S. laevigata* leaf total N and P content and various shallow groundwater and soil nutrient analyte concentrations on floodplains and terraces. Significance levels for regressions were determined from P values (ANOVA). I selected shallow groundwater and soil nutrient analytes with the strongest relationships to leaf tissue nutrients to analyze further in one- and three-way ANOVAs. All forms of N and P in the shallow groundwater in floodplains were analyzed. However, only soil NO_3-N and PO_4-P were analyzed along floodplains and terraces on the Santa Clara River.

Probability plots were used to test for normality of data and to identify data that required transformation. Most of the data were $\log_{10}$ base transformed. Raw data were used for leaf tissue N and K and shallow groundwater PO_4-P and pH. Square root transformations were used on percent silt + clay. When means and standard errors were used to describe or present statistical differences, data were back-transformed and reported in original units as an asymmetrical range.

RESULTS

Naturally Occurring Nutrient Levels

I used reference watershed data collected in this study to represent natural conditions for comparison to study watersheds, since historic data on natural conditions in neither study watersheds nor other watersheds in the southern California region were not available. Mean total soil N was much higher in reference watersheds than in floodplain or terraces of study watersheds (Table 7). However, NO_3-N and PO4-P levels in reference watersheds were similar to study floodplains but much lower than levels found on terraces. N and P levels of the shallow groundwater in reference watersheds were low (mean 0.13-1.11 mg/L) compared to study watersheds (mean 0.37-5.74 mg/L). The mean shallow groundwater molar N:P ratio (NO_3-N:PO_4-P) from reference sites was 2.4:1 (SE 2.0:1–3.0:1), which is considered to be N limiting according to the Redfield ratio (< 15:1 = N limiting and > 15:1 = P limiting for sea water or 15 atoms of N for every 1 atom of P). The N:P ratio of shallow groundwater in study watersheds was higher than found in reference watersheds but also in the range of N limiting [4.4:1 (SE 3.9:1–5.0:1)].

The mean N:P ratio of *S. laevigata* leaf tissue from the reference sites was 12.1:1 (SE 11.5:1–12.8:1), which is also considered to be N limiting (< 14:1 = N limiting and > 16:1 = P limiting on a per mass basis) (Koerselman and Meuleman 1996) (Table 8). Mean leaf tissue of both *S. laevigata* and *A. donax* collected from study watersheds had much higher N:P ratios, but considered neither N nor P limiting. The *S. laevigata* leaf tissue N:K ratio of 1.5:1 (SE 1.4:1–1.6:1) from the reference sites was optimal for plant growth (< 1.5:1 = N limiting and > 1.5:1 = K limiting) (Knecht and Goransson 2004). However, the N:K ratio is below the N limiting threshold for *A. donax* in study watersheds [0.99:1 (SE 0.96:1.02)].

Shallow Groundwater Nutrients

The three-way ANOVA (watershed x land use x degree of infestation) showed that the two-way interaction of watershed and land use factors best explained total N distribution in the shallow groundwater along the floodplains studied (Table 9). Concentrations of total N in the shallow groundwater were significantly higher in Calleguas Creek than in the Santa Clara River adjacent to agricultural and open space land uses (Figure 10a). No variation between the two watersheds existed for total N concentrations adjacent to residential land uses. However, shallow groundwater total N levels were significantly lower adjacent to residential land uses compared to agriculture and open space within Calleguas Creek. Results of the one-way ANOVA by watershed indicated that reference sites contained significantly lower total N in the shallow groundwater compared to any of the three study watersheds (Table 10). TKN results in shallow groundwater were similar to those of total N.

The watershed main effect for the three-way ANOVA was very highly significant for NO_3-N + NO_2-N concentration in the shallow groundwater (Table 9). These concentrations were significantly higher throughout Calleguas Creek (1.08 mg/L, SE 0.80–1.46 mg/L) compared to the Santa Clara River watershed (0.27 mg/L, SE 0.23–0.31 mg/L). When data from small *A. donax* infestations were removed, the interaction of watershed and land use type was significant for the three-way ANOVA ($F_{(2,50)} = 3.866$; $P = 0.027$). NO_3-N + NO_2-N concentrations in the shallow groundwater adjacent to agricultural land uses were significantly higher along Calleguas Creek than any other combination of land use and watershed (Figure 10b). The one-way ANOVA for NO_3-N + NO_2-N concentrations by watershed was very highly significant (Table 10). Shallow groundwater NO_3-N + NO_2-N levels were significantly higher along floodplains in Calleguas Creek compared to levels measured along the Santa Clara River, Topanga Canyon, or reference watersheds.

The three-way ANOVA resulted in a significant three-way interaction for shallow groundwater NH_4-N levels found in floodplains (Table 9). Significantly higher mean NH_4-N concentrations in the shallow groundwater were associated with small infestations next to open space along Calleguas Creek compared to sites with any other combination of land use and degree of infestation (Figure 10d and e). Large infestations adjacent to open space on Calleguas Creek contained higher shallow groundwater NH_4-N levels than many other combinations of factors. However, the one-way ANOVA by watershed indicated that levels of NH_4-N in shallow groundwater did not differ significantly between reference watersheds and any of the main study watersheds (Table 10).

Reference watersheds contained an average of 0.26 mg/L (SE 0.21–0.33) NH_4-N in shallow groundwater, which is lower only than levels found within small *A. donax* infestations on floodplains adjacent to open space within the Calleguas Creek watershed.

The main effect of watershed was very highly significant for PO_4-P in the three-way ANOVA (Table 9). The watershed with the highest proportion of total anthropogenic land cover, Calleguas Creek, contained the highest shallow groundwater PO_4-P concentrations (Figure 8). Orthophosphate concentrations in the shallow groundwater were significantly higher along Calleguas Creek (2.67 ± SE 0.38 mg/L) than Santa Clara River (0.64 ± SE 0.10 mg/L). The one-way ANOVA for shallow groundwater PO_4-P levels by watershed was also very highly significant (Table 10). Shallow groundwater PO_4-P concentrations on floodplains were significantly lower at reference sites and along the Santa Clara River compared to Calleguas Creek.

The one-way ANOVA for shallow groundwater pH levels by watershed was very highly significant (Table 10). Calleguas Creek and the Santa Clara River had significantly more acidic shallow groundwater than did Topanga Canyon and the reference watersheds.

Soils Nutrients and Grain Size

Nutrients

The relative availability of nutrients in soil made the soil nutrient results quite complex, due to variability in soil grain size and pH levels among sites, as well as different rooting depths of the two plant species (Figure 9). Availability of nitrogen varies considerably depending on soil grain size, which determines cation exchange

capacity and moisture holding capacity. NH_4^+ and NO_3^- are highly charged ions that readily dissolve in water. Percent silt + clay grain size was used as a covariate in ANOVAs for soil nutrients to account for variation due to soil grain size. Significant relationships between *A. donax* leaf tissue N and soil total N, NH_4-N and NO_3-N found on riparian terraces suggested that this species may rely more heavily on soil nutrients in the upper 30 cm of soil on terraces than *S. laevigata*, which may have much deeper roots in these areas (Figure 11).

HPO_4^{-2} adsorbs readily to soil particles (especially finer textured soils) and is most available to plants when dissolved in water at pH ~6.5 (Havlin et al. 1999). The mean soil pH of floodplains of reference watersheds was 7.38 (SE 7.26–7.50), which was similar to floodplains (7.41, SE 7.38–7.45) and terraces (7.38, SE 7.33–7.43) along the Santa Clara River. Higher than optimal pH levels in these areas may cause lower PO_4-P availability for both plant species. The three-way ANOVA (land use x location x degree of infestation) of soil pH resulted in a very highly significant land use main effect (Table 6). Mean soil pH levels varied significantly from one another by land use type as follows: open space (7.57, SE 7.51–7.62), agricultural (7.40, SE 7.35–7.45), and residential (7.23, SE 7.18–7.28). Thus, PO_4-P may be more available to plants adjacent to land use with higher anthropogenic inputs due to lower soil pH.

In the three-way ANOVA (watershed x land use x degree of infestation), the main effect of watershed was significant for percent total N content in the soil (Table 9); floodplain soils in Calleguas Creek (0.05%, SE 0.047–0.052%) contained significantly lower levels of mean total N than did soils along the Santa Clara River (0.06 ± SE

0.003%). NO_3-N levels in the soil varied significantly by all factors (all main effects significant). The mean content of NO_3-N was significantly higher in Calleguas Creek (2.1 ppm, SE 1.8–2.6ppm) than the Santa Clara River (0.7 ppm, SE 0.6–0.9 ppm). Floodplains adjacent to agricultural (1.6 ± 0.4 ppm) and open space (1.4 ppm, SE 1.1–1.8 ppm) contained significantly higher levels of NO_3-N than those adjacent to residential land uses (0.9 ± 0.2 ppm). Both large and small degrees of infestation were found to contain significantly higher mean NO_3-N soil levels (1.6 SE 0.4 ppm and 1.5 ppm, 1.1 –1.8 ppm, respectively) then non-infested areas (0.8 ppm, SE 0.7–1.1 ppm). Levels of NH_4-N were found to be significantly higher in floodplain soils of Calleguas Creek (1.5 ± 0.1 ppm) compared to the Santa Clara River (1.4 ± 0.1 ppm). The three-way interaction for mean PO_4-P levels found in floodplain soils was significant (Table 9). In most cases, levels of soil PO_4-P were higher in Calleguas Creek than along the Santa Clara River (Figure 12). Levels of PO_4-P in floodplain soils adjacent to agricultural land uses in Calleguas Creek were higher than levels found in soil anywhere along the Santa Clara River. Large infestations of *A. donax* were associated with higher soil PO_4-P levels than small or non-infested floodplains next to open space along the Santa Clara River.

Soil NO_3-N and PO_4-P concentrations were significantly higher on terraces versus floodplains of the Santa Clara River for all degrees of *A. donax* infestation according to the land use x fluvial geomorphic location x degree of infestation three-way ANOVA (Figure 13a and c). Soil nutrient levels did not differ significantly along floodplains, with the exception of lower PO_4-P levels adjacent to residential compared to agricultural land uses (Figure 13d). However, soil associated with the deeper-rooted *S. laevigata* from

non-infested riparian terraces contained significantly higher NO_3-N and PO_4-P concentrations than soil associated with either *A. donax* infestation stage (Figure 13a and c). Soil PO_4-P levels associated with all land uses were significantly higher on terraces compared to floodplains (except between terrace open space and floodplain agricultural areas) (Figure 13d). Terrace sites adjacent to anthropogenic land uses had significantly higher soil PO_4-P concentrations (as well as lower pH values allowing for greater availability) versus open space. Small and large *A. donax* infestations contained significantly more soil PO_4-P adjacent to agricultural versus open space land use (Figure 13e).

One-way ANOVAs for mean soil NO_3-N and PO_4-P content by watershed were very highly significant (Table 10). Mean NO_3-N content of soil along the floodplains of Calleguas Creek was significantly higher than content of soil along Santa Clara River. Soils sampled along Calleguas Creek contained significantly higher mean PO_4-P content than soils along the Santa Clara River or Topanga Canyon.

Grain Size

In general, soil grain size was highly correlated with the watershed from which it was sampled and adjacency to certain land use types. However, the combination of fluvial geomorphic location and degree of infestation affected soil grain size distribution in the 3-way ANOVA (land use x geomorphic location x degree of infestation, Santa Clara River only) (Table 11). Percent silt + clay content was significantly higher on terraces verses floodplains in non-infested sites and small infestations of *A. donax* (Figure 13b). However, this parameter did not differ significantly by geomorphic landform

within large infestations of *A. donax*. In addition, percent silt + clay did not differ by degree of infestation within floodplains but was significantly higher in non-infested sites versus large *A. donax* infestations on terraces. Reference sites contained 20.1% (SE 17.4–22.9%) silt + clay in floodplains, which was similar to small infestations of *A. donax* along floodplains but much lower than non-infested sites and small infestations along terraces. One-way ANOVAs for mean percent silt + clay in floodplains by watershed were very highly significant (Table 11). Mean silt + clay content found in floodplain soils along the Santa Clara River was significantly higher than silt + clay content found along Calleguas Creek or Topanga Canyon floodplains.

Relationship between Shallow Groundwater, Soil, and Leaf Tissue Nutrients

Various forms of N and P found in the shallow groundwater and soils had positive linear relationships with N and P content of *A. donax* and *S. laevigata* leaves (Figure 11 and Figure 14). However, pools of N and P available to plants varied considerably by species, medium, and fluvial geomorphic location. In floodplains, linear regressions showed significant positive relationships between *A. donax* leaf tissue N and each form of N individually (total N, NO_3-N + NO_2-N, and NH_4-N) in the shallow groundwater (Figure 14). In fact, as groundwater nutrients increased, *A. donax* N content increased more than *S. laevigata* N content in each case. However, only relationships between total N and NO_3-N + NO_2-N in the shallow groundwater and *S. laevigata* leaf tissue N content were significant. Relationships between P content of *S. laevigata* leaves and shallow groundwater PO_4-P levels were highly significant in floodplains, but were not found between *A. donax* leaves and shallow groundwater PO_4-P levels. A strong positive

relationship was found between *A. donax* leaf N content and soil NO_3-N on riparian terraces (Figure 11). Also, *A. donax* leaf N content indicated a positive relationship with both soil total N and NH_4-N on terraces and NO_3-N on floodplains; similar trends were not found for *S. laevigata*. No significant relationships were found between mean P content found in leaves of either species and soil PO_4-P concentrations in terrace or floodplain locations.

Leaf tissue Nutrients

Total Nitrogen

Mean leaf tissue N content of *A. donax* varied by watershed and land use in the three-way ANOVA (watershed x land use x degree of infestation – non-infested sites excluded) (Table 9). N content of *A. donax* leaves was significantly higher adjacent to open space land use within Calleguas Creek than any other land use types along either stream (Figure 15a). The three-way ANOVA (land use x fluvial geomorphic location x degree of infestation – non-infested sites excluded) for *A. donax* leaf tissue N content revealed significant main effects for land use and degree of infestation on the Santa Clara River (Table 11). Mean leaf tissue N content was higher in sites adjacent to agricultural (2.54 ± SE 0.08%) and residential (2.64 ± SE 0.08%) land uses compared to open space (2.21 ± SE 0.09%). Large *A. donax* infestations (2.59 ± SE 0.07%) contained significantly higher mean leaf tissue N than small infestations (2.36 ± SE 0.08%).

The one-way ANOVA for mean N content of *A. donax* leaf tissue by infestation stage for all study watersheds was highly significant ($F_{(1,79)} = 8.858$; $P = 0.004$). Mean N of *A. donax* leaves was higher in large infestations (2.67 ± SE 0.06%, n = 62) than in

small infestations (2.38 ± SE 0.07%, n = 60). The one-way ANOVAs for mean N leaf content by watershed were very highly significant for *A. donax* only and *S. laevigata* only (Table 10). N content of *S. laevigata* leaves in reference sites and from Topanga Canyon was significantly lower than N content sampled along the floodplains of Calleguas Creek or the Santa Clara River. *Arundo donax* leaves sampled in Calleguas Creek contained significantly higher N content than leaves from either the Santa Clara River or Topanga Canyon. Although leaf tissue nutrient content could not be compared statistically between species because species-specific differences might confound comparisons, N content of *A. donax* leaves from all watersheds was higher than that of *S. laevigata* leaves in reference sites.

Total Phosphorus

Mean P content of *A. donax* leaves varied by watershed only in the three-way ANOVA (watershed x land use x degree of infestation – non-infested sites excluded)(Table 9). Leaf tissue mean P content was higher in Calleguas Creek (0.19%, SE 0.184–0.193%) than in the Santa Clara River (0.17 ± SE 0.006%). The three-way ANOVA (land use x fluvial geomorphic location x degree of infestation – non-infested sites excluded) for *A. donax* leaf tissue P content was not significant for any main effects or interactions (Table 11).

The one-way ANOVA for mean P content of *A. donax* leaf tissue by degree of infestation for all study watersheds was significant ($F_{(1,79)} = 4.817$; $P = 0.031$). Mean P of *A. donax* leaves was higher in large infestations (0.18% SE 0.173–0.180%, n = 62) than in small infestations (0.16% SE 0.155–0.164%, n = 60).

One-way ANOVAs for mean P content of leaves by watershed were significant for *S. laevigata* only and *A. donax* only (Table 10). *Salix laevigata* leaves contained higher P content along floodplains of Calleguas Creek than along floodplains of the Santa Clara River, Topanga Canyon, or reference sites. Mean leaf P content of *A. donax* leaves was significantly higher in Calleguas Creek than in the Santa Clara River. Although leaf tissue nutrient content could not be compared statistically between species, P content of *A. donax* leaves from all watersheds was higher than that of *S. laevigata* leaves in reference sites.

Total Potassium

Mean K content of leaf tissue varied by land use and degree of infestation in the three-way ANOVA (watershed x land use x degree of infestation – non-infested sites excluded) (Table 9). Leaf tissue K content was significantly higher in large infestations adjacent to residential land uses than in any other combination of land use and infestation stage (Figure 15b). The degree of infestation main effect was highly significant in the three-way ANOVA (land use x fluvial geomorphic location x degree of infestation – non-infested sites excluded) for *A. donax* leaf tissue K (Table 11). Mean leaf tissue K content was significantly higher in large *A. donax* infestations (2.94 ± SE 0.08%) than in small infestations (2.66 ± SE 0.06%).

Although the one-way ANOVA for mean K content of *A. donax* leaf tissue by degree of infestation for all study watersheds was not significant ($F_{(1,79)} = 3.578$; $P = 0.062$), mean K of *A. donax* leaves was higher in large infestations (2.79 ± SE 0.07%, n = 62) than in small infestations (2.55 ± SE 0.05%, n = 60). The one-way ANOVA for K

content by watershed was not significant for *S. laevigata* leaves, but K content of *A. donax* leaves was significantly higher in the Santa Clara River compared to Calleguas Creek or Topanga Canyon (Table 10). Leaf tissue nutrient content could not be compared statistically between species, but K content of *A. donax* leaves from all watersheds was higher than that of *S. laevigata* leaves from reference sites or any of the study watersheds.

N:P and N:K Ratios

Shallow groundwater molar N:P ratios did not vary significantly in either three-way ANOVA or the one-way ANOVA by watershed. However, reference watersheds [2.1:1 (SE 2.0–3.0:1)] had lower mean N:P ratios than all study watersheds and Calleguas Creek [5.7:1 (SE 4.4:1–7.5:1) had the highest ratio (Table 8). All mean N:P ratios were in the N limiting range (<15:1) according to the Redfield Ratio.

Arundo donax leaf tissue N:P ratios did not vary significantly in either of the three-way ANOVAs performed for the study watersheds (Table 8). When only *S. laevigata* leaves from floodplain locations were examined in the one-way ANOVA by watershed, leaf N:P ratios within reference watersheds were significantly lower than those within the Santa Clara River, and N:P ratios in Calleguas Creek were significantly lower than those in the Topanga Canyon or the Santa Clara River. In addition, the mean N:P ratio of *A. donax* leaf tissue was significantly higher in Calleguas Creek and the Santa Clara River compared to Topanga Canyon. Although statistical comparisons could not be made between the plant species, the mean N:P ratios of *S. laevigata* leaf tissue in

reference sites were lower than the N:P ratio of *A. donax* leaf tissue in all study watersheds.

The land use x location x degree of infestation ANOVA for N:K revealed a significant land use main effect ($F_{(2,60)} = 4.589$; $P = 0.014$). Higher N:K ratios of *A. donax* leaf tissue were observed adjacent to residential (0.93:1, SE 0.89:1–0.96:1) and agricultural land uses (0.91:1, SE 0.88:1–0.94:1) compared to open space (0.78:1, SE 0.75:1–0.82:1). Mean N:K ratios of *S. laevigata* leaf tissue from floodplains did not vary among watersheds in the one-way ANOVA by watershed (Table 8). However, *A. donax* leaf tissue mean N:K was significantly higher in Calleguas Creek compared to either Santa Clara River or Topanga Canyon. Although statistical comparisons were not possible, the mean leaf N:K of *S. laevigata* was much higher in reference watersheds compared to *A. donax* leaf mean N:K ratios found in other watersheds.

DISCUSSION

Anthropogenic nutrient enrichment of natural ecosystems has been linked to plant invasions worldwide (Mooney et al. 1986, Drake et al. 1989, D'Antonio and Vitousek 1992, Hobbs and Huenneke 1992, Vitousek et al. 1996, Brooks 2003). However, little is known about the influence of elevated nutrients on invasions in river systems of Mediterranean-type climates such as California (Rundel 2000, Kim 2003, Robinson et al. 2005). This analysis of nutrient levels in several river systems in southern California supports the hypothesis that excess nutrients associated with anthropogenic land use activities have helped promote the recent invasion of riparian ecosystems by *A. donax* in southern California. I tested this hypothesis by evaluating N and P pools in shallow

groundwater and soil within riparian ecosystems invaded to various degrees by *A. donax* adjacent to several land uses. All factors investigated – land use, watershed, and fluvial geomorphic location – were important in explaining nutrient distribution and *A. donax* invasion. Furthermore, my results indicate that the greater supply and availability of N and K to *A. donax* compared to native plants may contribute to invasion of riparian ecosystems by *A. donax* in southern California (Charbonneau and Kondolf 1993, CRWQCB-LA 1995).

Natural Nutrient Levels

Naturally occuring nutrient levels essential for terrestrial plant growth (primarily N and P) vary widely in soils and shallow groundwater due to climate, topography, organisms, parent material, and soil texture. Precipitation and nitrogen fixation are the main natural sources of N, but all other essential soil nutrients (including P and K) are inherited from the parent material or added anthropogenically (Day 1983, Rundel et al. 1983, Stark 1994). Soils in Mediterranean-type climate regions of the world are naturally deficient in N and/or P compared to other regions (Day 1983, diCastri 1991, Dallman 1998), but vary considerably within these regions especially in the extent to which they are available to plants.

Historical soil and shallow groundwater nutrient data for natural or undisturbed riparian ecosystems in southern California were not available for comparison with my study results. The highly erosive soils found throughout this region likely transport associated nutrients to the alluvium of low-lying river systems, especially after fire. Average total N levels found in floodplain soils of my reference watersheds were within

the range of levels (slightly nutrient-rich) found in adjacent shrubland ecosystems of California (Day 1983, diCastri 1991) (Table 2). The young sedimentary geology of my study region is composed primarily of marine deposits containing organisms very high in P (Pettijohn 1975), creating soils higher in P than found in older more weathered geologies (Walker and Syers 1976, Groves et al. 1983). N and P levels found in the shallow groundwater of reference watersheds were low, although slightly higher than flow-weighted nutrient concentrations found in streams of many other small undeveloped basins in the U.S. (Williams et al. 1998, Clark et al. 2000) (Table 2).

Nutrient Limitation

N, P, and K alone and in combination were found to limit terrestrial and wetland plant production in the eastern U.S. and Europe (Koerselman and Meuleman 1996, Verhoeven et al. 1996, Svengsouk and Mitsch 2001, Knecht and Goransson 2004). Researchers have shown that N limits plant production on young substrates, such as southern California, whereas P is limiting on older substrates (Walker and Syers 1976, Vitousek 1996). Although nutrient limitations in riparian ecosystems of southern California are undocumented, they may provide important insight into the invasion process; anthropogenic N inputs may be relatively more important to plant production than P in younger geologies of southern California.

Results of this study indicate that N limiting conditions (relatively higher P levels) may naturally occur in riparian ecosystems in this geologically young landscape as suggested by several researchers (Walker and Syers 1976, Vitousek 1996). The N:P (molar ratio) in shallow groundwater of reference sites in this study (2.4:1) was much

lower than levels in sea water (<15:1 = N limiting conditions) or freshwater (19-48:1) reported in the literature, indicating naturally N limiting conditions in floodplains of southern California (Redfield 1958, Hecky et al. 1993). Also, leaf tissue N:P for *S. laevigata* in reference sites [12:1 (SE 11.5–12.8:1] suggests that N may be naturally limiting to plants in this region (<14:1 = N limiting) (Koerselman and Meuleman 1996, Verhoeven et al. 1996).

Groundwater and leaf tissue N:P ratios found in this study suggest that N is naturally limiting in riparian ecosystems of southern California, but anthropogenic nutrient inputs have contributed to elevated ratios in more developed watersheds. Shallow groundwater N:P ratios were higher in study watersheds with higher anthropogenic nutrient inputs compared to no nutrient input reference sites. Mean surface water N:P ratios for rivers worldwide were much higher (24:1 or P limited according to the Redfield Ratio) than in my reference or study watersheds (Hecky et al. 1993). Warrick et al. (2005) found N:P molar ratios in the surface water of the Santa Clara River to be 5:1 during a winter storm event and <1:1 during the low-flow summer months, in a similar range (N limiting) to results found for reference and study watersheds.

The N:P and N:K ratios in leaf tissue have been used to indicate nutrient limitations in freshwater wetland plant communities (Koerselman and Meuleman 1996, Verhoeven et al. 1996, Svengsouk and Mitsch 2001, Knecht and Goransson 2004). According to Koerselman and Meuleman (1996), N:P ratios by mass ≤ 14:1 (molar ratio 31:1) indicate N limiting conditions and ratios ≥ 16:1 indicate P limitations. Similar to

the trend in shallow groundwater N:P ratios, *S. laevigata* and *A. donax* leaf tissue N:P ratios found in reference watersheds were in the N limiting range (12:1) and adequate levels for both nutrients (14:1). Knecht and Göransson (2004) suggested optimal N:K nutrient ratios should be around 1.5:1 for deciduous and herbaceous plants based on a free supply of these nutrients under laboratory conditions. N:K ratios associated with *S. laevigata* leaf tissue in this study were similar to this optimal index (1.4:1–1.7:1) and did not differ by watershed. The *A. donax* leaf tissue N:K ratio was much lower (1:1) than that of optimal N:K, indicating that *A. donax* can assimilate K in excess of requirements (luxury consumption) or N may be limiting in relation to K.

Anthropogenic Nutrient Levels

Nutrient enrichment of rivers due to land use inputs is a global phenomenon. Increased use and composition of N and P in fertilizer have contributed to nutrient enrichment in rivers in agricultural landscapes (Charbonneau and Kondolf 1993, USEPA 1999, Nicola 2003). Surface and shallow groundwater run off from both agricultural and residential land use types contains excess N and P from fertilizers and drains into streams. Sewage treatment plants discharge treated wastewater that contains N, P, and K constituents into streams and rivers in southern California. Rural residential development throughout all of the studied watersheds may contribute NH_4-N, NO_3-N, and NO_2-N from septic tank leakage. In addition, levels of atmospheric N deposition are known to be high (from 1-45 kg/ha/year) around the Metropolitan Los Angeles Area (Padgett et al. 1999, Bytnerowicz et al. 2001, Meixner 2003, Lu et al. unpublished data). Although not widely known, K is required for biological phosphorus removal processes in sewage treatment

plants (Brdjanovic et al. 1996). Thus, excess amounts of K may be associated with wastewater discharged into rivers in this study, especially Calleguas Creek or the Santa Clara River that receive sewage discharge throughout their course. Alternatively, if not enough K is used in wastewater treatment, treated water may contain higher levels of P. Levels of K were not measured in shallow groundwater or soil in this study but may be important in understanding higher K content of *A. donax* versus *S. laevigata* leaf tissue found and thus invasion success of *A. donax*.

Higher levels of N and P in the shallow groundwater and soil of riparian ecosystems were associated with sites invaded by *A. donax*. However, nutrient levels in riparian ecosystems were found to vary considerably by watershed, land use, and fluvial geomorphic location. These factors helped explain the influence of nutrients from anthropogenic inputs on invasion of riparian ecosystems by *A. donax* on both floodplains and terraces throughout the study area.

Watershed

Many studies have shown that nutrient inputs from agricultural and urban land uses result in elevated N and P concentrations in adjacent water bodies (Peterjohn and Correll 1984, Fail et al. 1986, Frink 1991, Correll et al. 1992, Rodda 1995, Warrick et al. 2005), but few have focused on variation among multiple watersheds or cumulative effects of upstream land use inputs (Correll 1984, Correll et al. 1992, Basnyat et al. 1999, Ahearn et al. 2005, Robinson et al. 2005). Although many similarities exist between watersheds located within a given region (i.e., geology, climate, riparian vegetation), variation in factors such as land use composition and soil type can greatly influence

nutrient levels found in riparian ecosystems (Ahearn et al. 2005, Robinson et al. 2005). By comparing multiple watersheds with varying levels of anthropogenic nutrient inputs, my findings help disentangle the cumulative effects of both agricultural and residential land use on nutrient supply in floodplains at a watershed-scale. The general trend observed in total N, NO_3-N + NO_2-N, NH_4-N, and PO_4-P concentrations in the shallow groundwater and soil on floodplains was Calleguas Creek > Santa Clara River > Topanga Canyon > reference sites. In addition, pH of the shallow groundwater was more acidic in the watersheds with the highest anthropogenic land use.

Shallow groundwater and soil in floodplains of Calleguas Creek contained much higher levels of PO_4-P than the other study and reference watersheds. The higher percentage of agricultural and residential land uses and associated nutrients in this watershed compared to the other study watersheds might account for the observed P enrichment and lower pH levels. Agricultural nutrient sources may be the primary contributor to the elevated NO_3-N + NO_2-N levels found in groundwater in the floodplains of Calleguas Creek. Similar relationships between agricultural inputs and elevated nitrate were reported in other watershed-scale studies (Correll 1984, Peterjohn and Correll 1984, Correll et al. 1992, Rodda 1995, Basnyat et al. 1999, Ahearn et al. 2005, Robinson et al. 2005, Warrick et al. 2005).

Land Use

At a more local scale, adjacency to land uses was found to be important in characterizing nutrient supply on riparian terraces and floodplains. Adjacency to land use helped explain variation in nutrient supply in shallow groundwater total N and NH_4-N in

floodplain locations. Although NO_3-N and PO_4-P levels were higher in groundwater and soil on floodplains adjacent to agriculture than next to residential and open space land use in several cases, clearer trends were found on terraces in which PO_4-P levels were higher adjacent to both agriculture and residential land use than next to open space.

Fluvial Geomorphic Location

N and P levels in the soil were much higher on riparian terraces than on floodplains regardless of land use type or degree of infestation. NO_3-N and PO_4-P soil content was lower in floodplains of reference sites than on riparian terraces of the rivers with anthropogenic inputs. Lower soil pH as well as percent silt + clay grain size (no and small infestations) on terraces contributed to higher availability of PO_4-P on terraces compared to floodplains.

Degree of Infestation

Riparian ecosystems infested by *A. donax* contained higher NO_3-N levels in floodplain soils than did non-infested or reference sites, which may be the result of high nutrient input and adjacency to agricultural land use of invaded sites. Non-infested riparian terrace sites contained higher NO_3-N and PO_4-P levels than did sites invaded by *A. donax* on the Santa Clara River. This trend likely reflects the better utilization of surface soil nutrients on terraces by the shallow, extensive root system of *A. donax* compared to the much deeper tap root of *S. laevigata* trees (Phillips 1963, Russell 1963) (Figure 9). Conversely, *A. donax* and *S. laevigata* are likely to derive nutrients from similar depths in floodplains where available nutrients (and water) are much closer to the surface. Relationships among nutrient sources, nutrient pools, and *A. donax* infestation

level also were controlled by differences in nutrient availability to plant species, which in turn were controlled by physical constraints in the environment and species-specific rates of nutrient uptake, assimilation, metabolism, and limitation.

Factors Controlling Nutrient Availability

Nutrient availability in relation to supply of nutrients is key to understanding the *A. donax* invasion process, but quantification of nutrient availability is complex (Day 1983). Wetting and drying cycles, high soil temperatures, and wildfires characteristic of Mediterranean-type climates promote the release of nutrients by increasing the turnover of microbial biomass and organic matter that is otherwise sequestered (Stark 1994). Decomposition of litter releases nutrients, but quantities may vary by leaf species. Nutrients are thought to be most available in spring and autumn when water availability and temperature do not limit plant productivity (Day 1983). However, nutrient supply to floodplains of river systems in California was found to be greatest during winter storms (Robinson et al. 2005, Warrick et al. 2005). Supply to riparian terraces may occur throughout the year due to nutrient inputs from agricultural runoff, and supply to floodplains may occur year round due to sewage treatment plant releases. Ash from wildfires may contribute high proportions of N to riparian ecosystems and is considered to be a main factor promoting growth after fire (Day 1983).

Supply of N and P in the soil and their availability to plants vary greatly based on grain size, pH, and rooting depth (Metz et al. 1966). Variability in soil grain size and associated cation exchange and moisture holding capacity affects rates of diffusion transport of nutrients in the soil. Soil grain size has a strong influence on water and

nutrient retention in soils: Coarser soils retain less water than finer particle soils, such as clay and silt, and have a lower cation exchange capacity due to lower surface area (Kozlowski et al. 1991, Taiz and Zeiger 1991). Soils with higher cation exchange capacity supply more minerals to roots. In this study, nutrient content in the soil was strongly correlated with grain size. On riparian terraces, different degrees of infestation had similar trends in soil grain size and NO_3-N and PO_4-P concentrations. The relatively higher amount of finer soil particles in non-infested terrace sites relative to infested sites may have contributed to the higher soil nutrient levels found in the former.

Rate of P uptake by plants is strongly related to soil pH. Typically, basic soil pH values result in lower solubility of phosphate salts and thus a lowered ability of plant roots to assimilate P (Taiz and Zeiger 1991). At soil pH levels near 7.5 found in this study, P was slightly less available to plants than at optimal pH conditions (optimal pH = 6.5). However, native plants that have evolved under these conditions may have adapted mechanisms to extract P under lower than optimal pH conditions (Koerselman and Meuleman 1996). The ability to assimilate nutrients available in the surrounding soil and groundwater depends on development of an extensive root system and rooting structure, as well as mycorrhizal symbionts that maximize uptake (Kozlowski et al. 1991). For example, higher root surface area increases uptake rates and high P influx and root/shoot ratio results in higher P efficiency. Root morphology and architecture differ between monocots, such as *A. donax,* and dicots, like *S. laevigata* (Taiz and Zeiger 1991). Roots of *A. donax* are composed primarily of fibrous roots and tend to be much shallower than those of *S. laevigata*, which has a taproot that can extend 20 m or more to groundwater

(Figure 9). Physiological strategies of these plants differ greatly due to their inherent structure. Although *A. donax* has a shallower and less extensive rooting system, it is aided by a large rhizome that stores carbohydrates, water, and minerals under stressful conditions (Else 1996, Wijte et al. 2005). In contrast, *S. laevigata*, a large woody phreatophyte, has a long taproot and well-developed root system that can reach deeper groundwater and associated nutrients (Robinson 1958). Nutrient availability of N, P, and K to terrestrial plants is usually higher in surface layers of the soil, due to the more neutral pH, ease of root penetration, and accumulation of organic matter. Thus, *A. donax* may utilize nutrients in the upper soil profile and shallower groundwater, whereas *S. laevigata* may rely on a greater percentage of nutrients from deeper sources where a higher percentage of its roots are distributed.

On riparian terraces in which shallow groundwater occurs at a much greater depth than in floodplains, the differences in rooting structure of *A. donax* versus *S. laevigata* must be considered. *Salix laevigata* can use much deeper water (and associated nutrient sources) than *A. donax*. Results of this study reflect this difference, indicating significantly higher concentrations of NO_3-N and PO_4-P in terrace soils associated with *S. laevigata* in non-infested sites. However, higher soil nutrient levels observed next to non-infested sites may be due partly to variation in nutrient fluctuation rates as well. It follows that growth and invasion of *A. donax* depends more on shallower soil moisture and associated nutrients than *S. laevigata* (Figure 9). Soil nutrient results suggest that these two species may avoid competition for nutrients on riparian terraces after establishment, due to their varying rooting depths at maturity (Verhoeven et al. 1996).

However, *A. donax* may have other adaptations as well, such as higher growth response to N or nitrogen-use efficiency that result in its invasion success on terraces.

Variation in availability of N, P, and K to *A. donax* versus native *S. laevigata* is important in understanding the invasion process. Rates of nutrient assimilation and efficiency vary genetically by plant species (Duncan 1994). Plants adapted to more-fertile soils exhibit higher maximum potential growth rates compared with plants that have evolved under low soil nutrient conditions (Chapin et al. 1986). Thus, levels of available N, P, and K may vary greatly in their importance to the growth response of *A. donax* compared to *S. laevigata*. Data are not currently available on species-specific growth response of *A. donax* or *S. laevigata*, but fertilization studies should be conducted to measure their growth response to N, P, and K levels. Due to unknown species-specific assimilation rates and efficiency, leaf nutrient content of *A. donax* and *S. laevigata* could not be compared statistically to evaluate nutrient content of leaf tissue with respect to degree of infestation and other factors. However, several analyses are presented below in which availability to both species could be assessed.

Nutrient Supply and Availability

The nutrient content of leaf tissue is closely correlated with changes in nutrient availability due to supply during the growing season (Bouma 1983, Chapin and Cleve 1989). Relationships between N and P content of *A. donax* and *S. laevigata* leaf tissue and concentrations of nutrient in the surrounding shallow groundwater and soil indicate relative sources of N and P that may be used by each species on riparian floodplains versus terraces in this study. In floodplains, *A. donax* exhibited a significant positive

response to all forms of N in the shallow groundwater and NO_3-N in the soil, whereas *S. laevigata* showed a significant positive response to only NO_3-N + NO_2-N and PO_4-P pools in shallow groundwater. No significant relationships were found between soil N or P and *S. laevigata* leaf tissue nutrients in either floodplains or terraces, which suggests that this species may use primarily deeper nutrient pools. On riparian terraces, *A. donax* appears to use all forms of soil N, unlike *S. laevigata*. Relationships between nutrient supply and nutrient status of leaves support the assertion that these two plants may use different sources of nutrients on riparian terraces. These findings suggest that *A. donax* may have two main advantages over *S. laevigata*: (1) it is better able to uptake nutrients in the surface soils of riparian terraces due to different root distribution of the two species; and (2) it does not appear to require as much P.

Analysis of leaf tissue nutrient content revealed a clear link between *A. donax* invasion and anthropogenic supply of nutrients. In general, for both species percent total N, P, and K content of leaf tissue was higher in watersheds with greater anthropogenic inputs. In addition, *A. donax* leaf tissue N was higher in riparian ecosystems adjacent to both agricultural and residential land use types compared to open space. Total N, P, and K content of leaf tissue were much higher in areas heavily infested by *A. donax* than in areas with small infestations. These results suggest that a greater supply of N, P, and K from anthropogenic nutrient sources may be more available to *A. donax* in highly invaded riparian ecosystems than elsewhere. Preliminary analyses show that *A. donax* leaf litter contains significantly lower N content and higher C:N than litter from a mix of native species including *Salix* spp. (Lambert unpublished data). However, species-specific

nutrient assimilation and efficiency may vary and must be considered when comparing results for both species.

High levels of K found in *A. donax* leaf tissue were of particular interest and may be critical to the invasion process. Spencer et al. (2005) found that soluble K levels in the soil were higher where *A. donax* relative growth rate was greatest in northern California. K fertilization studies indicate a positive growth response and an increase in tissue K with increasing K availability in forest soils (Tripler et al. 2006). Although soil K was not measured in this study, *A. donax* leaves exhibited higher K levels in heavily infested sites adjacent to residential land use compared to areas with small infestations and were found to contain almost twice as much K as the native *S. laevigata*. Terrestrial plants use large amounts of K for various physiological activities, including stomatal regulation, but uptake mechanisms and efficiencies vary among plant species (Stark 1994). Adequate K is also known to prevent drought stress in crop plants (Spencer et al. 2005). High levels of K supply may give *A. donax* a competitive advantage during the hot, dry summer months in southern California. *Arundo donax* may either assimilate K more effectively than *S. laevigata* and/or levels of K in the soil or shallow groundwater may have been higher around *A. donax*. Fertilization studies measuring K uptake by *A. donax* compared to other native riparian species are needed to further understand its role in *A. donax* invasion.

MANAGEMENT AND RESTORATION IMPLICATIONS

This study elucidated the influence of anthropogenic nutrient inputs on invasion of riparian ecosystems of southern California by an alien plant species. Enrichment of

shallow groundwater with excess total N, NO_3-N, and NH_4-N from adjacent land appeared to have facilitated the rapid expansion of *A. donax* in the riparian ecosystems studied. Riparian terraces heavily invaded by the large, perennial grass *A. donax* were associated with nutrient inputs from adjacent agricultural and residential land uses. Contribution of nutrients from a combination of land use practices had an even stronger cumulative effect on invasion in floodplains at a watershed scale. Although not addressed in this study, the role of atmospheric N deposition as an important source of NO_3^- around large urban areas in *A. donax* invasion requires further attention.

Arundo donax will likely continue to spread rapidly in watersheds and locations within watersheds with higher anthropogenic nutrient loading regardless of the source. Reducing nutrient inputs to riparian ecosystems in California and other Mediterranean-type climate regions may help reduce the rate of spread of *A. donax* in watersheds where its distribution is low or it is not yet present. Within these watersheds, evaluation of nutrient levels in riparian ecosystems may help predict the threat of invasion; however, other factors (i.e., water availability) likely contribute to the invasion process. Results of this study indicate that riparian ecosystems adjacent to intensive agricultural operations or wastewater treatment plant discharge on terraces are at the greatest risk of invasion by *A. donax* if this species is introduced. Also, watersheds with high percentage of agricultural and residential land use composition are at risk. Recent expansion of urbanization and agricultural practices in watersheds of other Mediterranean-type climate regions, such as the Western Cape of South Africa, has resulted in similar trends in rapid expansion of *A. donax* in more urbanized streams and rivers (Samuels and Knight 2003).

Land management practices related to both agricultural and residential development should be evaluated to determine their nutrient inputs to riparian ecosystems, and best management practices should be employed to lower nutrient inputs to help control *A. donax* invasion along river systems.

Fluvial processes of flooding or scouring of streams in years with heavy rainfall are certainly primary factors in promoting spread of *A. donax*. My results showed that higher supply and availability of N, P, and K may also contribute to *A. donax* invasion after it is dispersed. However, manipulative experiments are needed to determine clear causal relationships between nutrient supply and availability to *A. donax* compared to dominant native riparian species under various water availability conditions. Further experimental investigation of the effects of light, water, and fire relative to nutrients on invasion of riparian ecosystems by *A. donax* will help elucidate the invasion process. Investigation of *A. donax* distribution and age of infestation related to land use change over time throughout watersheds in Mediterranean-type climates may provide further insight into contribution of anthropogenic land use to the invasion process.

Removal of invader species is often the initial step and prime component of stream restoration and mitigation in southern California (Coffman et al. 2004). Restoration plans for river systems and associated riparian revegetation must address anthropogenic nutrient levels if eradication or control of *A. donax* is a desired objective. In watersheds where nutrient levels are high, dam or levee removal projects need to consider the possibility that restoration actions might further distribute *A. donax* and promote its invasion. Revegetation or restoration on high terrace locations should

proceed with caution; high levels of nutrients added by land use practices or released by wildfires may promote *A. donax* invasion. With nutrient enrichment that exists throughout urbanized watersheds in southern California, aggressive maintenance programs and native riparian plant revegetation are essential elements of comprehensive *A. donax* removal and control programs.

TABLES

Table 6. Number and distribution of sampling locations in three study watersheds.

	Santa Clara River	**Calleguas Creek**	**Topanga Canyon**
Land use type	3	3	2 (no agricultural)
Floodplain/terrace	2	1 (no terrace)	1 (no terrace)
Degree of *A. donax* infestation	3	3	3
Number of replicates	5–6	5	5
TOTAL	93	45	30

Table 7. Natural and anthropogenic soil and shallow groundwater nutrient levels (means ± SE).

	Shrubland Ecosystems[3]			Streams draining undeveloped basins in U.S. (median)[4]	Riparian Ecosystems		
	Nutrient-poor; strongly-leached; oligotrophic	Nutrient-rich; moderately-leached; mesotrophic	Agriculturally-rich; weakly-leached; eutrophic		Reference watersheds (mean)	All study watersheds (mean)	
					Floodplains	Floodplains	Terraces
Soil							
Total N (%)	< 0.12 (CA: 0.03–0.12)	0.12–0.30 (CA: 0.12–0.21)	> 0.30	-	0.13 (0.11–0.16)	0.056 ± 0.002	0.095 (0.088–0.103)
NO_3-N (ppm)	-	-	-	-	1.3 (0.9–2.0)	1.2 (1.1–1.4)	3.8 (3.2–4.5)
Total P (%)	< 0.022	0.022–0.06 (CA: 0.022–0.06)	0.06 (CA: 0.06–0.082)	-	-	-	-
PO_4-P (ppm)	-	-	-	-	7.2 (6.1–8.6)	5.9 ± 0.4	12.2 (10.8–13.7)
Shallow groundwater							
Total N (mg/L)	-	-	-	0.26	1.11 (0.87–1.43)	5.74 (5.30–6.22)	-
NO_3-N (mg/L)	-	-	-	0.087	0.13 (0.11–0.16)[3]	0.40 (0.34–0.46)	-
NH_4-N (mg/L)	-	-	-	0.02	0.26 (0.21–0.33)	0.37 (0.33–0.40)	-
PO_4-P (mg/L)	-	-	-	0.01	0.53 (± 0.03)	1.39 (± 1.22–1.56)	-
N:P (molar)	-	-	-	19.2:1	2.4:1 (2.0:1–3.0:1)	4.4:1 (3.9:1–5.0:1)	-

Legend: CA = nutrient levels found in California SE = standard error

[3] Shrubland ecosystem soil nutrient data for 5 Mediterranean-type climate regions (Day 1983).
[4] Clark et al. 2000
[3] Values are NO_3-N + NO_2-N for reference and study watersheds.

Table 8. N:P and N:K ratios (on a mass basis) of *Salix laevigata* and *Arundo donax* leaf tissue and associated shallow groundwater (molar ratio) along floodplains of study watersheds (mean ± SE) and results of one-way ANOVAs by watershed.

	Reference Watersheds	**Topanga Canyon**	**Santa Clara River**	**Calleguas Creek**	**All Study Watersheds**	**Significance values**[5]
N:P						
Shallow groundwater	2.4:1 (2.0:1–3.0:1)	2.7:1 (2.3:1–3.2:1)	4.7:1 (3.9:1–5.7:1)	5.7:1 (4.4:1–7.5:1)	4.4:1 (3.9:1–5.0:1)	$F_{(3,128)} = 2.385$; $P = 0.072$
Leaf tissue (*S. laevigata*)	12.1:1 (11.5–12.8)	14.2:1 (13.5–14.9)	15.2:1 (14.4–16.1)	11.8:1 (11.2–12.7)	13.7:1 (13.2–14.1)	$F_{(3,47)} = 5.250$; $P = 0.003$**
Leaf tissue (*A. donax*)	ND	13.3:1 (13.0-13.6)	14.9:1 (14.5-15.3)	13.8:1 (13.4-14.3)	14.4:1 (14.1-14.6)	$F_{(2,78)} = 6.289$; $P = 0.003$**
N:K						
Leaf tissue (*S. laevigata*)	1.5:1 (1.4–1.6)	1.4:1 (1.3–1.5)	1.7:1 (1.6–1.8)	1.6:1 (1.5–1.7)	1.6:1 (1.5–1.6)	$F_{(3,47)} = 1.015$; $P = 0.356$
Leaf tissue (*A. donax*)	ND	0.9:1 (0.86-0.93)	0.9:1 (0.88-0.94)	1.2:1 (1.10–1.22)	1.0:1 (0.96–1.02)	$F_{(2,78)} = 12.109$; $P < 0.001$***

Legend:
SE = standard error
ND = no data since no *A. donax* in reference watersheds
* = $0.05 \geq P > 0.01$ = significant
** = $0.01 \geq P > 0.001$ = highly significant
*** = $P \leq 0.001$ = very highly significant

[5] No terrace data used in this analysis

Table 9. Three-way ANOVA significance table for shallow groundwater, soil, and leaf tissue nutrients by watershed (Santa Clara River[6], Calleguas Creek), land use (agricultural, residential, open space) and degree of infestation (none, small, large).

	Factors						
Nutrient analyte	**Watershed**	**Land use**	**Degree of infestation**	**Watershed x land use**	**Watershed x degree of infestation**	**Land use x degree of infestation**	**Watershed x land use x degree of infestation**
Shallow Groundwater							
Total N (mg/L)[7]	**$F_{(1,74)} = 5.474$; $P = 0.022$***	**$F_{(2,74)} = 3.630$; $P = 0.031$***	$F_{(2,74)} = 1.639$; $P = 0.201$	**$F_{(2,74)} = 3.848$; $P = 0.026$***	$F_{(2,74)} = 0.323$; $P = 0.725$	$F_{(4,74)} = 1.030$; $P = 0.398$	$F_{(4,74)} = 0.981$; $P = 0.423$
NO_3-N + NO_2-N (mg/L)	**$F_{(1,74)} = 18.788$; $P < 0.001$*** **	$F_{(2,74)} = 1.559$; $P = 0.217$	$F_{(2,74)} = 0.168$; $P = 0.846$	$F_{(2,74)} = 2.969$; $P = 0.057$	$F_{(2,74)} = 1.520$; $P = 0.225$	$F_{(4,74)} = 0.897$; $P = 0.470$	$F_{(4,74)} = 1.725$; $P = 0.154$
NH_4-N (mg/L)	**$F_{(1,74)} = 5.553$; $P = 0.021$***	**$F_{(2,74)} = 5.466$; $P = 0.006$****	**$F_{(2,74)} = 3.552$; $P = 0.034$***	**$F_{(2,74)} = 10.340$; $P < 0.001$*** **	**$F_{(2,74)} = 3.510$; $P = 0.035$***	$F_{(4,74)} = 1.044$; $P = 0.390$	**$F_{(4,74)} = 3.266$; $P = 0.016$***
PO_4 (mg/L)	**$F_{(1,74)} = 28.012$; $P < 0.001$*** **	$F_{(2,74)} = 0.160$; $P = 0.852$	$F_{(2,74)} = 1.276$; $P = 0.285$	$F_{(2,74)} = 0.383$; $P = 0.683$	$F_{(2,74)} = 2.201$; $P = 0.118$	$F_{(4,74)} = 0.948$; $P = 0.441$	$F_{(4,74)} = 0.982$; $P = 0.423$
pH	$F_{(1,74)} = 3.768$; $P = 0.056$	$F_{(2,74)} = 2.638$; $P = 0.078$	$F_{(2,74)} = 0.036$; $P = 0.964$	$F_{(2,74)} = 1.283$; $P = 0.283$	$F_{(2,74)} = 1.317$; $P = 0.274$	$F_{(4,74)} = 0.176$; $P = 0.950$	$F_{(2,74)} = 0.948$; $P = 0.441$
Soil[8]							
Total N (%)	**$F_{(1,73)} = 3.987$; $P = 0.050$***	$F_{(2,73)} = 0.859$; $P = 0.428$	$F_{(2,73)} = 0.002$; $P = 0.998$	$F_{(2,73)} = 0.241$; $P = 0.787$	$F_{(2,73)} = 0.931$; $P = 0.399$	$F_{(4,73)} = 1.313$; $P = 0.273$	$F_{(4,74)} = 2.071$; $P = 0.093$
NO_3-N (ppm)	**$F_{(1,73)} = 28.540$; $P < 0.001$*** **	**$F_{(2,73)} = 3.578$; $P = 0.033$***	**$F_{(2,73)} = 3.566$; $P = 0.033$***	$F_{(2,73)} = 0.544$; $P = 0.583$	$F_{(2,73)} = 1.983$; $P = 0.145$	$F_{(4,73)} = 1.771$; $P = 0.144$	$F_{(4,73)} = 0.390$; $P = 0.815$
NH_4-N (ppm)	**$F_{(1,73)} = 22.267$; $P < 0.001$*** **	$F_{(2,73)} = 2.286$; $P = 0.109$	$F_{(2,73)} = 0.347$; $P = 0.708$	$F_{(2,73)} = 2.340$; $P = 0.103$	$F_{(2,73)} = 1.750$; $P = 0.181$	$F_{(4,73)} = 0.871$; $P = 0.485$	$F_{(4,73)} = 1.340$; $P = 0.263$
PO_4 (ppm)	**$F_{(1,73)} = 102.353$; $P < 0.001$*** **	**$F_{(2,73)} = 14.664$; $P < 0.001$*** **	$F_{(2,73)} = 0.027$; $P = 0.974$	**$F_{(2,73)} = 3.162$; $P = 0.048$***	$F_{(2,73)} = 1.708$; $P = 0.188$	**$F_{(4,73)} = 5.517$; $P = 0.001$*** **	**$F_{(4,73)} = 3.259$; $P = 0.016$***

Legend: * = $0.05 \geq P > 0.01$ = significant, ** = $0.01 \geq P > 0.001$ = highly significant, *** = $P \leq 0.001$ = very highly significant

[6] No terrace data used in this analysis.
[7] All data log base 10 transformed except raw data were used for groundwater PO_4 and pH; and plant total N and K.
[8] Percent silt + clay (square root transformed) used as a covariate (significant for all soil nutrient analytes)

Table 9 (continued). Three-way ANOVA significance table for shallow groundwater, soil, and leaf tissue nutrients by watershed (Santa Clara River[9], Calleguas Creek), land use (agricultural, residential, open space), degree of infestation (none, small, large).

	Factors						
Nutrient analyte	**Watershed**	**Land use**	**Degree of infestation**	**Watershed x land use**	**Watershed x degree of infestation**	**Land use x degree of infestation**	**Watershed x land use x degree of infestation**
***Arundo donax* Leaf Tissue**							
Total N (%)	**$F_{(1,49)}$ = 10.511; P = 0.002****	$F_{(2,49)}$ = 2.223; P = 0.119	**$F_{(1,49)}$ = 5.081; P = 0.029***	**$F_{(2,49)}$ = 4.974; P = 0.011***	$F_{(1,49)}$ = 0.088; P = 0.522	$F_{(2,49)}$ = 0.799; P = 0.456	$F_{(2,49)}$ = 0.771; P = 0.468
Total P (%)	**$F_{(1,49)}$ = 7.947; P = 0.007****	$F_{(2,49)}$ = 2.424; P = 0.099	$F_{(1,49)}$ = 0.425; P = 0.517	$F_{(2,49)}$ = 1.927; P = 0.156	$F_{(1,49)}$ = 0.071; P = 0.792	$F_{(2,49)}$ = 0.535; P = 0.589	$F_{(2,49)}$ = 0.254; P = 0.777
Total K (%)	**$F_{(1,49)}$ = 5.651; P = 0.021***	**$F_{(2,49)}$ = 5.713; P = 0.006****	**$F_{(1,49)}$ = 4.528; P = 0.038***	$F_{(2,49)}$ = 0.315; P = 0.731	$F_{(1,49)}$ = 0.040; P = 0.843	**$F_{(2,49)}$ = 3.386; P = 0.042***	$F_{(2,49)}$ = 0.234; P = 0.793

Legend: * = 0.05 ≥ P > 0.01 = significant, ** = 0.01 ≥ P > 0.001 = highly significant, *** = P ≤ 0.001 = very highly significant

[9] No terrace data used in this analysis.

Table 10. Mean concentrations of shallow groundwater, soil, and leaf tissue nutrients and soil grain size in floodplains and results of the one-way ANOVA by watershed factor.

Nutrient analyte	Mean (± SE)				Significance values[10]
	Reference sites	Topanga Canyon	Santa Clara River	Calleguas Creek	
Shallow Groundwater Nutrients					
Total N (mg/L)[11]	1.11 (0.87–1.43)	4.03 (3.68–4.41)	5.22 (4.60–5.93)	8.02 (6.92–9.29)	**$F_{(3,128)}$ = 16.119; P < 0.001*** **
NO_3-N + NO_2-N (mg/L)	0.14 (0.11–0.16)	0.17 (0.14–0.19)	0.27 (0.23–0.32)	1.08 (0.80–1.46)	**$F_{(3,128)}$ = 14.711; P < 0.001*** **
NH_4-N (mg/L)	0.26 (0.21–0.33)	0.33 (0.27–0.40)	0.31 (0.28–0.35)	0.46 (0.39–0.54)	$F_{(3,128)}$ = 1.710; P = 0.168
PO_4 (mg/L)[12]	0.53 ± 0.03	0.66 ± 0.09	0.64 ± 0.10	2.67 ± 0.38	**$F_{(3,128)}$ = 16.664; P < 0.001*** **
pH	7.75 ± 0.09	7.80 ± 0.06	7.39 ± 0.05	7.25 ± 0.05	**$F_{(3,128)}$ = 20.847; P < 0.001*** **
Soil Nutrients and Grain Size[13]					
NO_3-N (ppm)	1.33 (0.89–1.98)	1.11 (0.91–1.36)	0.75 (0.65–0.87)	2.13 (1.75–2.60)	**$F_{(3,127)}$ = 9.047; P < 0.001*** **
PO_4-P (ppm)	7.23 (6.10–8.57)	4.84 (4.27–5.50)	4.14 (3.72–4.60)	9.71 (8.85–10.64)	**$F_{(3,12)}$ = 23.592; P < 0.001*** **
silt + clay (%)	20.1 (17.4–22.9)	12.8 (11.6–14.0)	25.3 (22.9–27.9)	11.18 (9.9–12.5)	**$F_{(3,128)}$ = 13.510; P < 0.001*** **
Leaf Tissue Nutrients					
Total N (%) (*Salix laevigata*)	1.78 ± 0.15	1.87 ± 0.13	2.40 ± 0.12	2.27 ± 0.10	**$F_{(3,47)}$ = 6.113; P = 0.001*** **
Total N (%) (*Arundo donax*)	No Data	2.19 ± 0.10	2.50 ± 0.08	2.88 ± 0.10	**$F_{(2,78)}$ = 11.982; P < 0.001*** **
Total P (%) (*Salix laevigata*)	0.14 ± 0.01	0.13 (0.125-0.134)	0.16 (0.147-0.164)	0.19 ± 0.01	**$F_{(3,47)}$ = 8.595; P < 0.001*** **
Total P (%) (*Arundo donax*)	No Data	0.17 ± 0.008	0.17 ± 0.006	0.19 (0.184-0.193)	**$F_{(2,78)}$ = 4.364; P = 0.016* **
Total K (%) (*Salix laevigata*)	1.25 ± 0.17	1.33 ± 0.06	1.44 ± 0.07	1.41 ± 0.07	$F_{(3,47)}$ = 0.860; P = 0.469
Total K (%) (*Arundo donax*)	No Data	2.49 ± 0.10	2.73 ± 0.07	2.49 ± 0.09	**$F_{(2,78)}$ = 3.172; P = 0.047* **

Legend: * = 0.05 ≥ P > 0.01 = significant, ** = 0.01 ≥ P > 0.001 = highly significant*** = P ≤ 0.001 = very highly significant
SE = standard error

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[10] No terrace data used in this analysis.
[11] All data log base 10 transformed except those noted otherwise.
[12] Raw data were used for groundwater PO_4 and pH; and plant total N and K.
[13] Percent silt + clay (square root transformed) was used as a covariate

Table 11. Three-way ANOVA significance table for soil and leaf tissue nutrients by land use (agricultural, residential, and open space), fluvial geomorphic location (terrace and floodplain), and degree of infestation (none, small, and large). Analyses were only conducted on Santa Clara River sites. Only *A. donax* from small and large infestations (levels) were used in leaf tissue ANOVAs.

	Factors						
Nutrient analyte	**Land use**	**Fluvial geomorphic location**	**Degree of infestation**	**Land use x fluvial geomorphic location**	**Land use x degree of infestation**	**Location x degree of infestation**	**Land use x location x degree of infestation**
Soil[14]							
NO_3-N (ppm)[15]	**$F_{(2,84)}$ = 5.101; P = 0.008***	**$F_{(1,84)}$ = 51.453; P < 0.001*****	$F_{(2,84)}$ = 2.662; P = 0.076	$F_{(2,84)}$ = 3.643; P = 0.030	$F_{(4,84)}$ = 1.661; P = 0.167	**$F_{(2,84)}$ = 4.626; P = 0.012***	$F_{(4,84)}$ = 1.636; P = 0.173
PO_4-P (ppm)	**$F_{(2,84)}$ = 8.081; P = 0.001*****	**$F_{(1,84)}$ = 60.137; P < 0.001*****	**$F_{(2,84)}$ = 4.613; P = 0.013***	**$F_{(2,84)}$ = 12.129; P < 0.001*****	**$F_{(4,84)}$ = 4.507; P = 0.002****	**$F_{(2,84)}$ = 3.689; P = 0.029***	**$F_{(2,84)}$ = 3.205; P = 0.017***
Silt + Clay (%)	$F_{(2,85)}$ = 1.772; P = 0.176	**$F_{(1,85)}$ = 4.343; P = 0.040***	$F_{(2,85)}$ = 1.517; P = 0.225	$F_{(2,85)}$ = 0.593; P = 0.555	$F_{(4,85)}$ = 0.865; P = 0.488	**$F_{(2,85)}$ = 3.206; P = 0.045***	$F_{(4,85)}$ = 0.343; P = 0.848
pH	**$F_{(2,85)}$ = 9.685; P < 0.001*****	$F_{(1,85)}$ = 0.297; P = 0.587	$F_{(2,85)}$ = 0.970; P = 0.383	$F_{(2,85)}$ = 2.366; P = 0.100	$F_{(4,85)}$ = 0.991; P = 0.417	$F_{(2,85)}$ = 1.738; P = 0.182	$F_{(4,85)}$ = 1.144; P = 0.341
***Arundo donax* Leaf Tissue**							
Total N (%)[16]	**$F_{(2,60)}$ = 6.029; P = 0.004****	$F_{(1,60)}$ = 0.862; P = 0.357	**$F_{(1,60)}$ = 5.876; P = 0.018***	$F_{(2,60)}$ = 2.572; P = 0.085	$F_{(2,60)}$ = 0.109; P = 0.897	$F_{(1,60)}$ = 0.964; P = 0.330	$F_{(2,60)}$ = 0.239; P = 0.788
Total P (%)	$F_{(2,60)}$ = 1.009; P = 0.371	$F_{(1,60)}$ = 3.015; P = 0.088	$F_{(1,60)}$ = 2.425; P = 0.125	$F_{(2,60)}$ = 1.172; P = 0.317	$F_{(2,60)}$ = 0.174; P = 0.841	$F_{(1,60)}$ = 1.481; P = 0.228	$F_{(2,60)}$ = 0.508; P = 0.604
Total K (%)	$F_{(2,60)}$ = 0.587; P = 0.559	$F_{(1,60)}$ = 1.637; P = 0.206	**$F_{(1,60)}$ = 9.909; P = 0.003****	$F_{(2,60)}$ = 2.775; P = 0.070	$F_{(2,60)}$ = 1.012; P = 0.370	$F_{(1,60)}$ = 1.198; P = 0.278	$F_{(2,60)}$ = 2.879; P = 0.064

Legend: * = $0.05 \geq P > 0.01$ = significant, ** = $0.01 \geq P > 0.001$ = highly significant*** = $P \leq 0.001$ = very highly significant

.

[14] Percent silt + clay (square root transformed) used as a covariate for all soil nutrients.
[15] Soil nutrient data and pH were $\log_{10}$ base transformed.
[16] Raw data was used for leaf tissue total N and K. Leaf tissue total P was $\log_{10}$ base transformed.

FIGURES

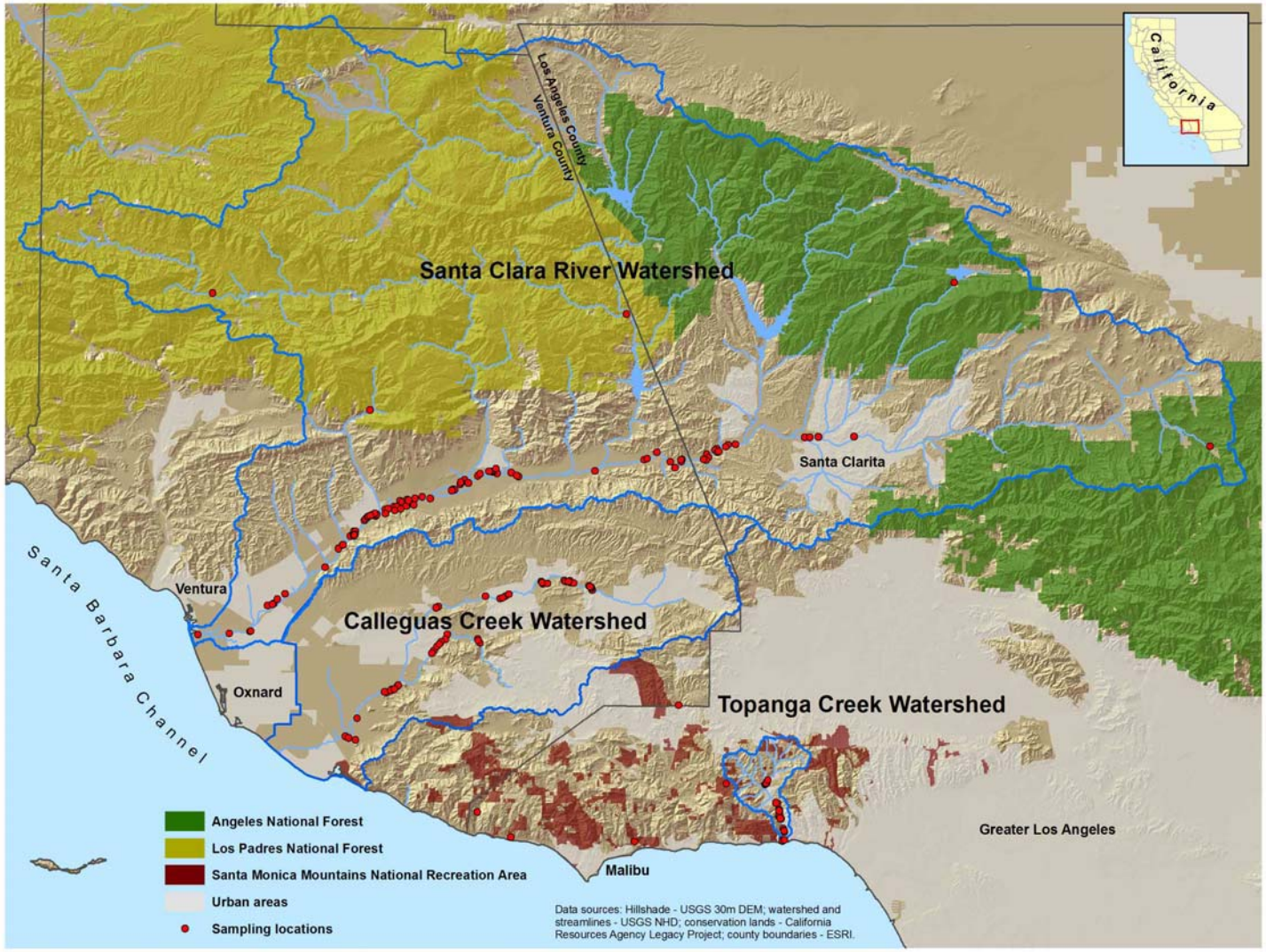

Figure 7. The three study watersheds in Ventura and Los Angeles Counties, California.

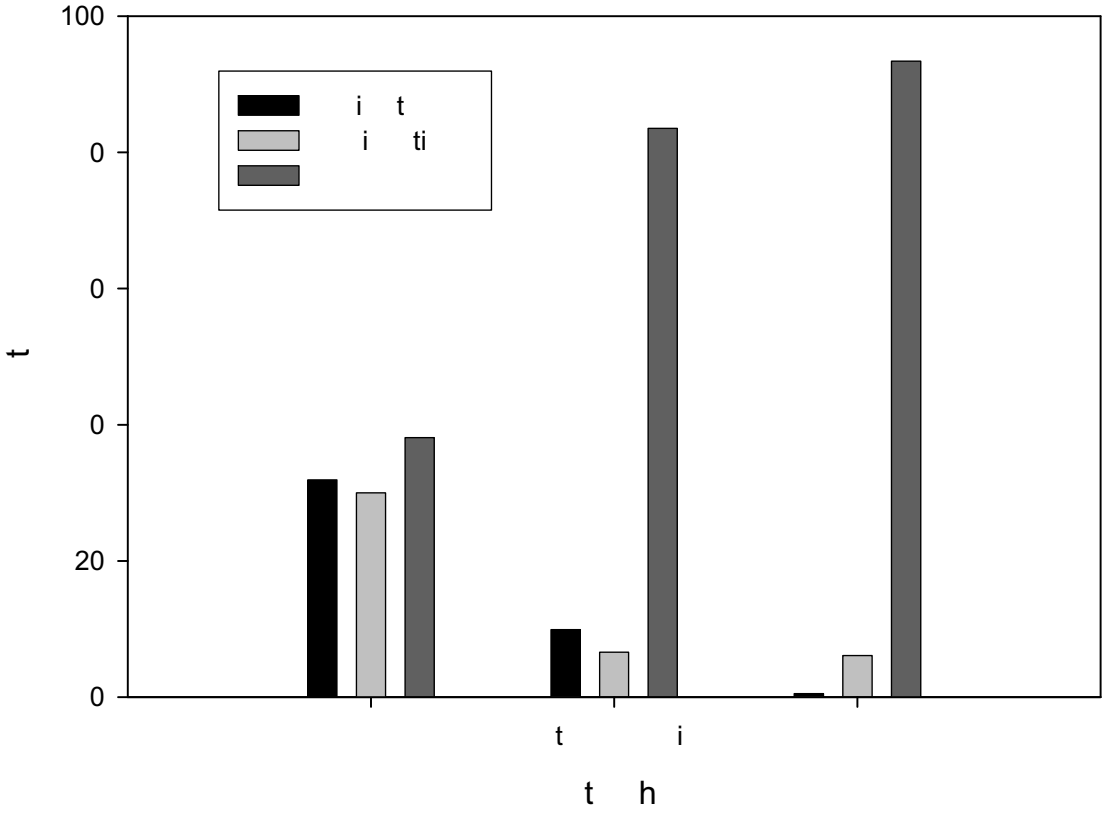

Figure 8. Distribution of land use type within the three studied watersheds.

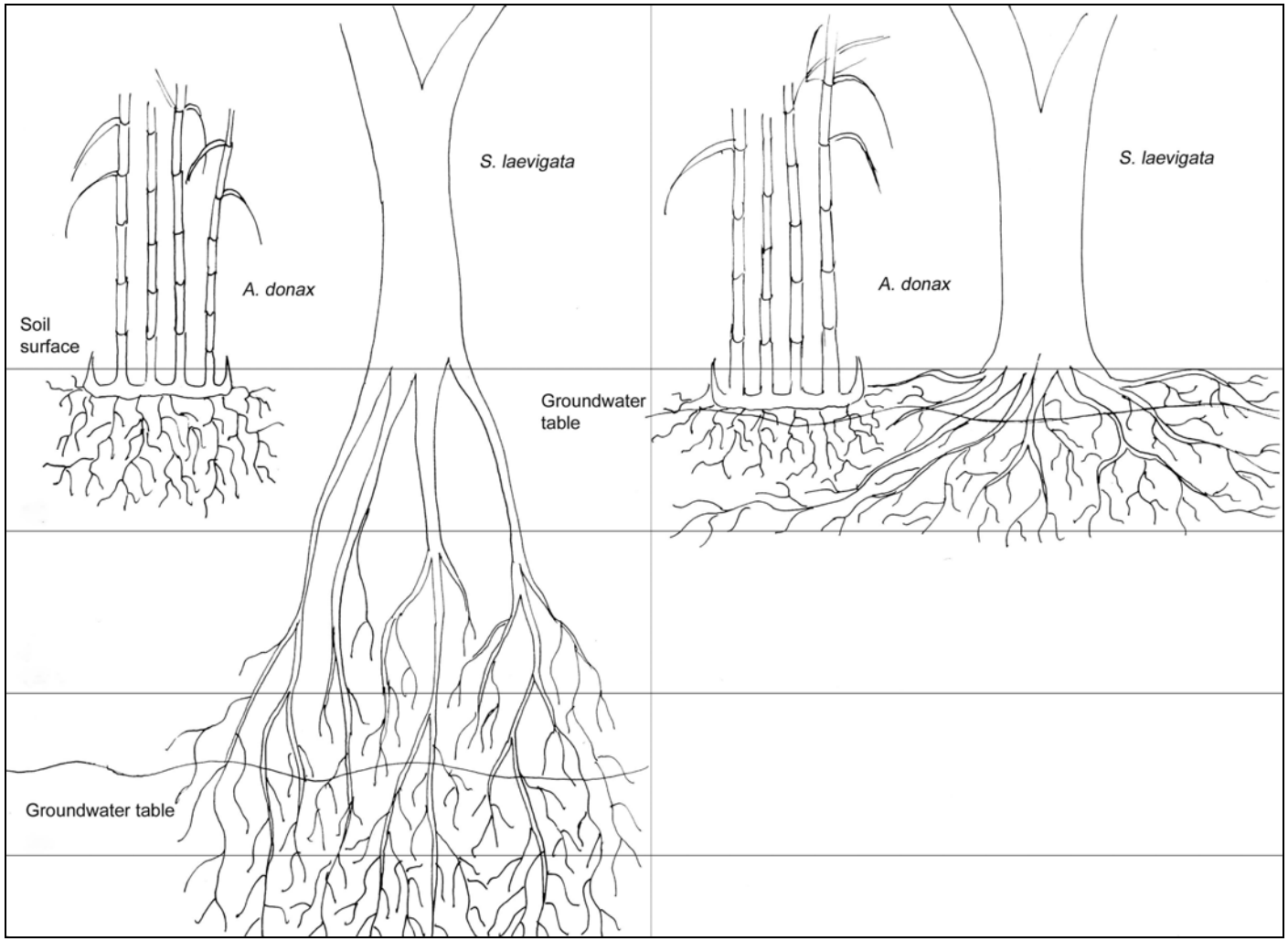

Figure 9. Diagram of *A. donax* and *S. laevigata* rooting depths and distribution in a) deep and b) shallow groundwater table conditions.

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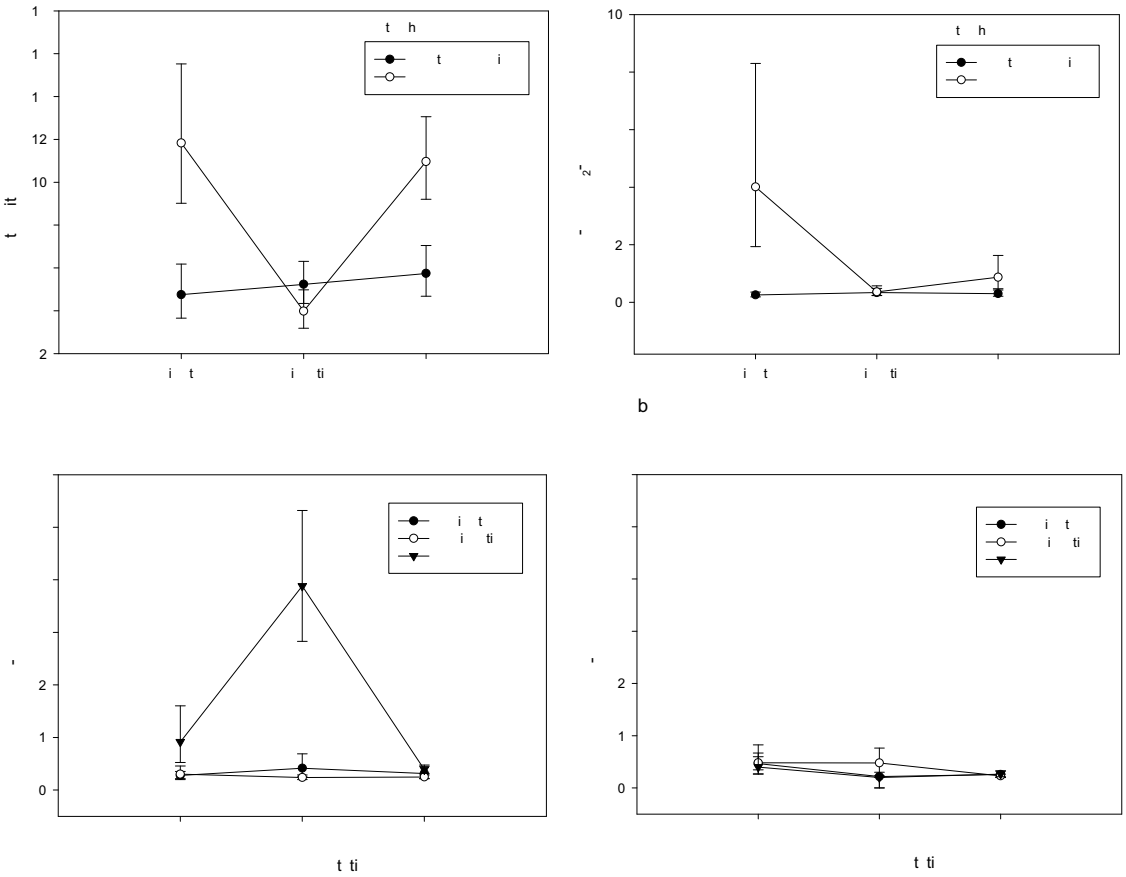

Figure 10. Interaction plots for 3-way ANOVA of shallow groundwater nutrients by watershed (Santa Clara River and Calleguas Creek only) x land use (A = agricultural, R = residential, and O = open space) x degree of infestation (N = none, S = small, and L = large). Plots include two-way interaction plots for shallow groundwater a) total N, and b) NO_3-N + NO_2-N (small infestation data removed), and three-way interaction plots for shallow groundwater NH_4-N in c) Calleguas Creek and d) Santa Clara River.

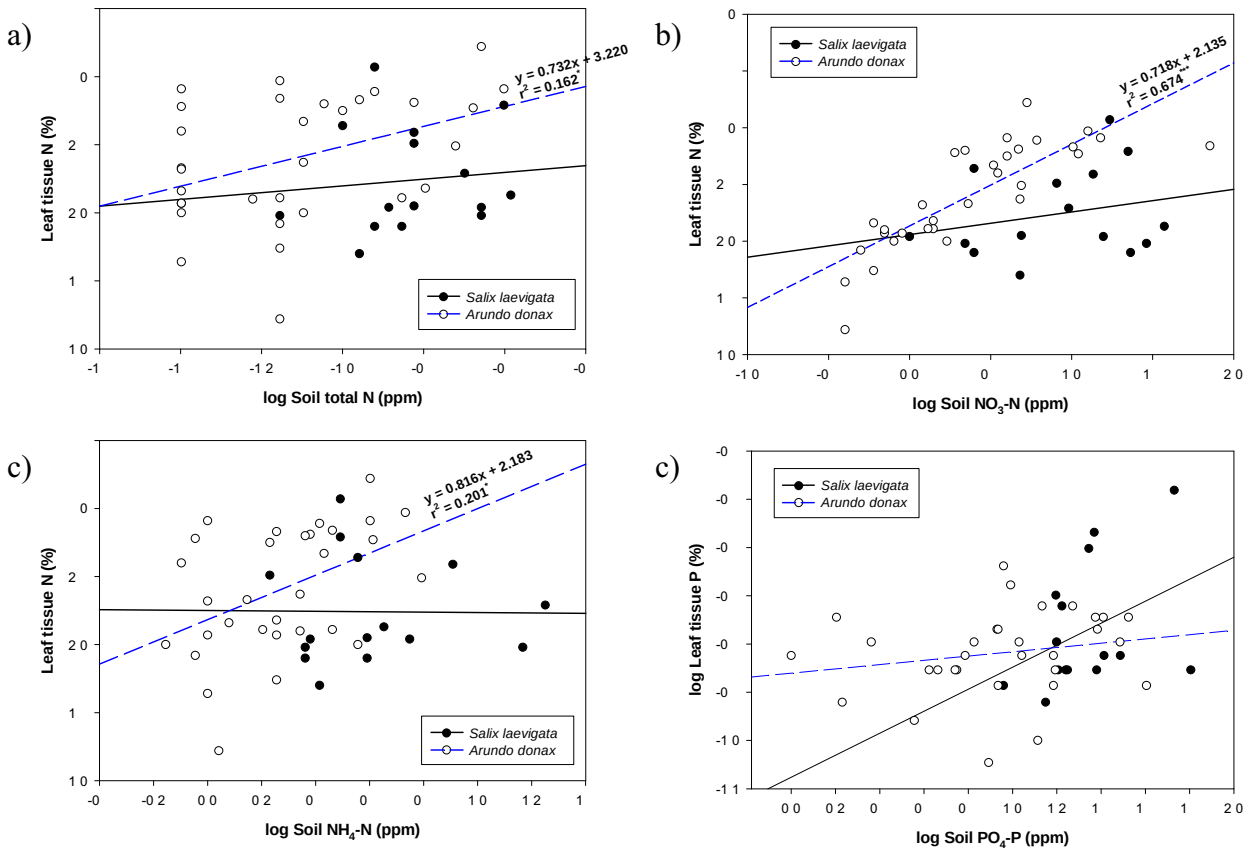

Figure 11. Linear regression relationships between shallow groundwater and soil nutrients (independent variable) found in terrace sites and associated leaf tissue nutrients (response variable) of target plants by plant species. Only Santa Clara River data was used. Equations were only included for significant relationships. Leaf tissue N/P and soil (a) total N, (b) NO_3-N, (c) NH_4-N, and (d) PO_4-P.

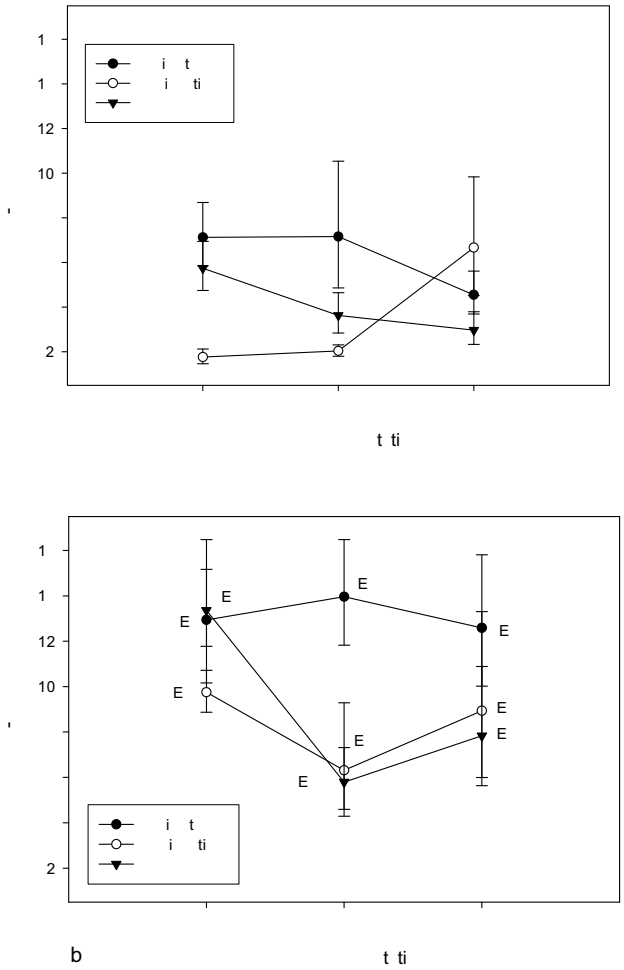

Figure 12. Interaction plots for 3-way ANOVA of soil nutrients by watershed (Santa Clara River and Calleguas Creek only) x land use (A = agricultural, R = residential and O = open space) x degree of infestation (N = none, S = small, and L = large). Plots show the three-way interaction for soil PO_4-P in a) Santa Clara River and b) Calleguas Creek.

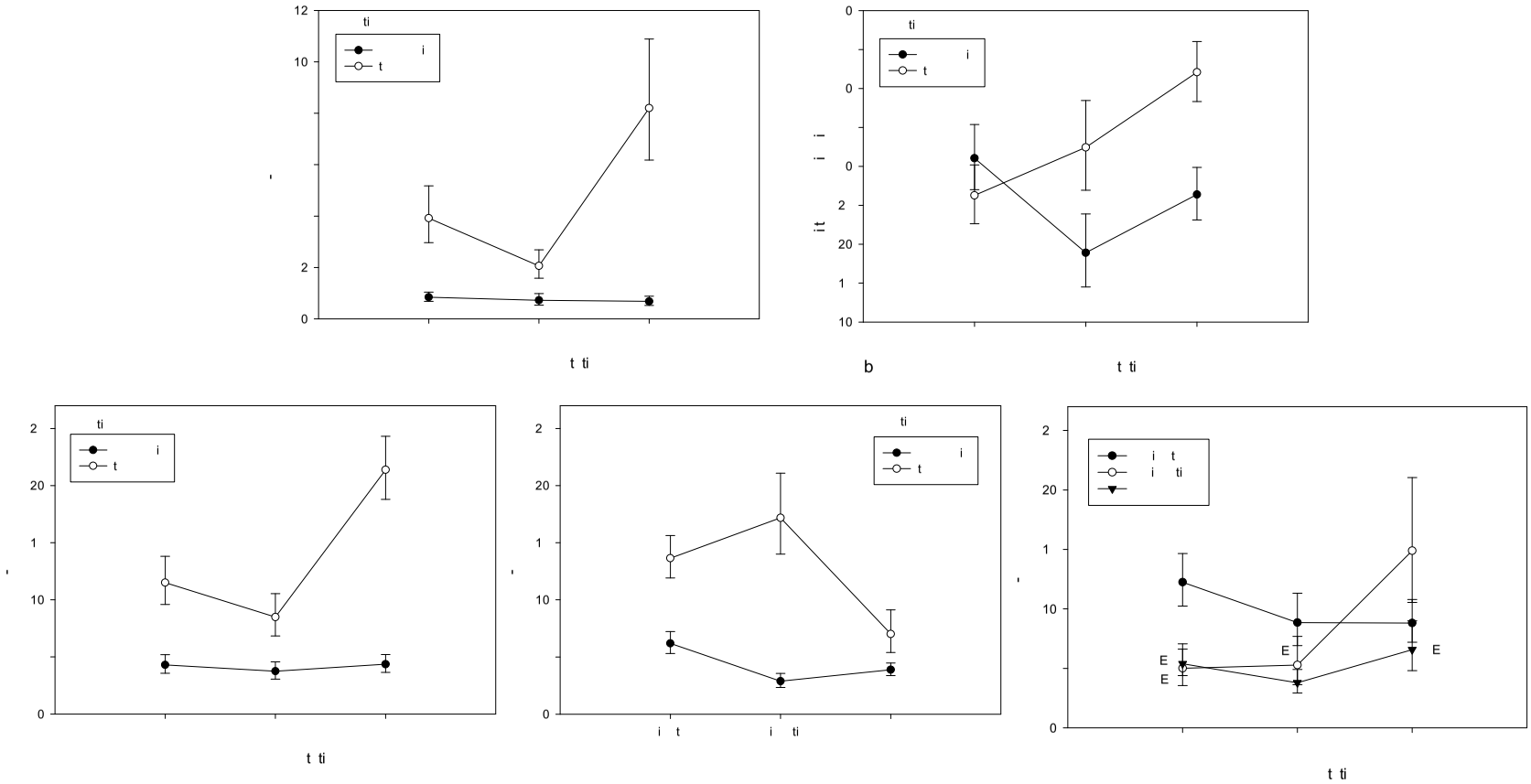

Figure 13. Interaction plots for 3-way ANOVA of soil nutrients and grain size for land use (A = agricultural, R = residential, and O = open space) x degree of infestation (N = none, S = small, and L = large) x fluvial geomorphic location (terrace and floodplain) for Santa Clara River only. Plots include 2-way interactions of a) soil NO_3-N and b) silt + clay and 3-way interaction of soil PO_4-P (c, d, and e).

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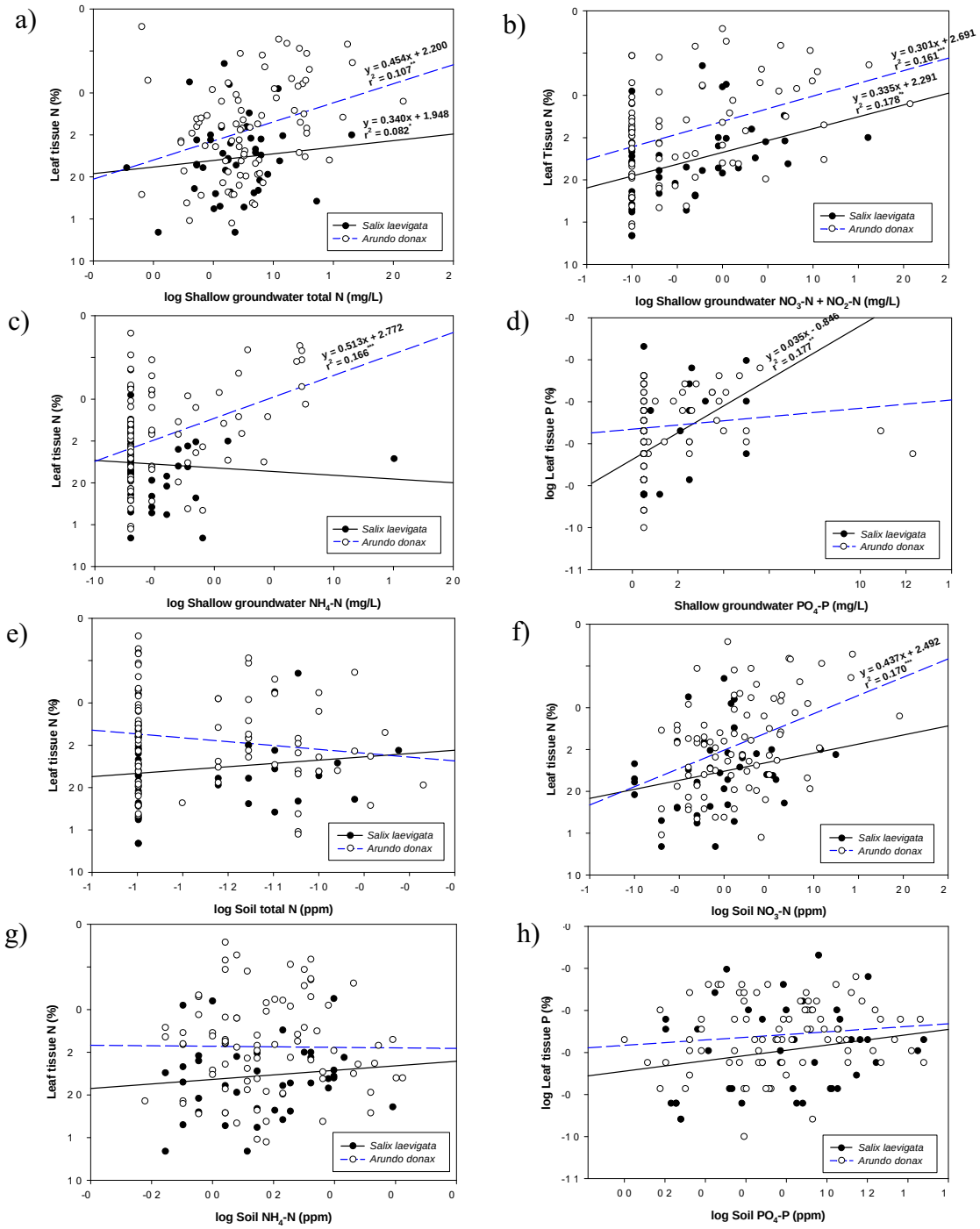

Figure 14. Linear regression relationships between shallow groundwater and soil nutrients (independent variable) found in floodplain sites and associated leaf tissue nutrients (response variable) of target plants by plant species. Equations were only included for significant relationships. Leaf tissue N/P and soil (a) total N, (b) NO_3-N, (c) NH_4-N, and (d) PO_4-P. Leaf tissue N/P and shallow groundwater (e) total N, (f) NO_3-N + NO_2-N, (g) NH_4-N, and (h) PO_4-P.

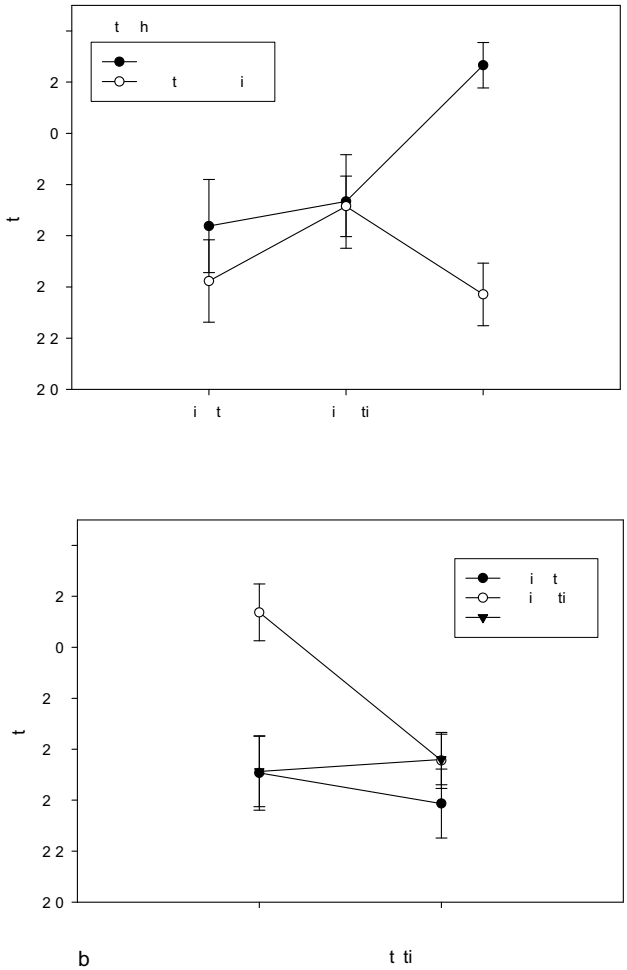

Figure 15. Interaction plots for 3-way ANOVA of *A. donax* leaf tissue nutrients by watershed (Santa Clara River and Calleguas Creek only) x land use (A = agricultural, R = residential, O = open space) x degree of infestation (S = small, L = large). Plots illustrate the two-way interaction for a) leaf tissue N and b) leaf tissue K.

APPENDIX

APPENDIX 3-1

TABLE 1. SAMPLING LOCATIONS

Site ID[17]	Latitude (degrees)	Longitude (degrees)
Calleguas Creek		
CAFL1	34.18181797	-119.03227547
CAFL2	34.18522848	-119.02564312
CAFL3	34.26126039	-118.97952396
CAFL4	34.26026671	-118.98207734
CAFL5	34.27144197	-118.92569614
CAFN1	34.13669625	-119.08521188
CAFN2	34.15400296	-119.07143463
CAFN3	34.17924422	-119.03796569
CAFN4	34.23487474	-118.96908212
CAFN5	34.18599115	-119.02471977
CAFS1	34.13507461	-119.08160741
CAFS2	34.13344902	-119.07335250
CAFS3	34.17960581	-119.04052360
CAFS4	34.21919798	-118.98473675
CAFS5	34.22309129	-118.98073481
COFL1	34.18100023	-119.03332044
COFL2	34.28386898	-118.85975520
COFL3	34.28732609	-118.83532254
COFL4	34.28502903	-118.82843195
COFL5	34.23055504	-118.93391920
COFN1	34.18210127	-119.02929805
COFN2	34.28435823	-118.85500057
COFN3	34.28635279	-118.83322028
COFN4	34.28214583	-118.80707444
COFN5	34.22688327	-118.93127832
COFS1	34.28637156	-118.83378790
COFS2	34.28705938	-118.82914742
COFS3	34.28464581	-118.82491607
COFS4	34.28645848	-118.83080796
COFS5	34.22922341	-118.93361712

[17] First character stands for watershed (S = Santa Clara River; C = Calleguas Creek; T = Topanga Cayon); Second character stands for land use (A = agricultural; O = open space; R = residential); Third character stands for fluvial geomorphic location (F = floodplain; T = terrace); Fourth character stands for degree of infestation (L = large infestation; S = small infestation; N = no infestation); and number stands for replicate.

TABLE 1 (continued). SAMPLING LOCATIONS

Site ID[18]	Latitude (degrees)	Longitude (degrees)
CRFL1	34.26952092	-118.90881867
CRFL2	34.27168974	-118.90275277
CRFL3	34.27363845	-118.89887664
CRFL4	34.28602137	-118.86197255
CRFL5	34.27015417	-118.90565316
CRFN1	34.27816652	-118.80317417
CRFN2	34.28010098	-118.80417497
CRFN3	34.28114930	-118.80471577
CRFN4	34.23009370	-118.97145169
CRFN5	34.28538610	-118.86089791
CRFS1	34.21678056	-118.98688914
CRFS2	34.22753965	-118.97609828
CRFS3	34.28504504	-118.86083965
CRFS4	34.28149489	-118.80560375
CRFS5	34.22546622	-118.97838193
Santa Clara River		
SAFL1	34.31599656	-119.09517872
SAFL2	34.38832736	-118.93290969
SAFL3	34.37853578	-118.95602329
SAFL4	34.35348068	-119.04170327
SAFL5	34.38983082	-118.89746865
SAFL6	34.40303776	-118.74487334
SAFN1	34.38109352	-118.95231379
SAFN2	34.38252431	-118.95086406
SAFN3	34.38010991	-118.95468604
SAFN4	34.38622895	-118.88881040
SAFN5	34.41809141	-118.64794627
SAFS1	34.38650915	-118.93600730
SAFS2	34.38889540	-118.91346602
SAFS3	34.37347672	-118.96392172
SAFS4	34.38713193	-118.89121969
SAFS5	34.40141788	-118.71480217
SATL1	34.37955360	-118.94674502

[18] First character stands for watershed (S = Santa Clara River; C = Calleguas Creek; T = Topanga Cayon); Second character stands for land use (A = agricultural; O = open space; R = residential); Third character stands for fluvial geomorphic location (F = floodplain; T = terrace); Fourth character stands for degree of infestation (L = large infestation; S = small infestation; N = no infestation); and number stands for replicate.

TABLE 1 (continued). SAMPLING LOCATIONS

Site ID[19]	Latitude (degrees)	Longitude (degrees)
SATL2	34.37299149	-118.96207594
SATL3	34.36193652	-119.02509629
SATL4	34.33253070	-119.07771637
SATL5	34.40404988	-118.74102739
SATLD1	34.23179138	-119.25541925
SATLD2	34.34685814	-119.05269706
SATLD3	34.36438361	-118.99051289
SATLD4	34.23333733	-119.21936131
SATLD5	34.32794371	-119.08172417
SATN1	34.41422937	-118.66145672
SATN2	34.40875657	-118.67276156
SATN3	34.36076590	-119.02292772
SATN4	34.41591941	-118.65056385
SATN5	34.40360916	-118.70071513
SATS1	34.37267943	-118.96522050
SATS2	34.38859608	-118.93302837
SATS3	34.38028551	-118.95542398
SATS4	34.40124856	-118.70185146
SATS5	34.39195890	-118.80118028
SATSD1	34.41272029	-118.66298717
SATSD2	34.37248522	-118.96579332
SATSD3	34.41051199	-118.66039256
SATSD4	34.41148815	-118.65905279
SATSD5	34.40319082	-118.70229227
SOFL1	34.35990047	-119.01475981
SOFL2	34.35719647	-119.01773538
SOFL3	34.36599487	-118.99932973
SOFL4	34.36452552	-119.00776427
SOFL5	34.39567518	-118.70910885
SOFN1	34.32881568	-119.07774386
SOFN2	34.31887373	-119.09080865
SOFN3	34.33239022	-119.07561427
SOFN4	34.35490100	-119.02514490

[19] First character stands for watershed (S = Santa Clara River; C = Calleguas Creek; T = Topanga Cayon); Second character stands for land use (A = agricultural; O = open space; R = residential); Third character stands for fluvial geomorphic location (F = floodplain; T = terrace); Fourth character stands for degree of infestation (L = large infestation; S = small infestation; N = no infestation); and number stands for replicate.

TABLE 1 (continued). SAMPLING LOCATIONS

Site ID[20]	Latitude (degrees)	Longitude (degrees)
SOFN5	34.35635107	-119.03155874
SOFN6	34.40588200	-118.67016896
SOFS1	34.31559457	-119.09520957
SOFS2	34.31924572	-119.09028830
SOFS3	34.35645919	-119.02864812
SOFS4	34.35424478	-119.03863080
SOFS5	34.35664217	-119.01821039
SOTL1	34.32809450	-119.07738880
SOTL2	34.32945983	-119.07627577
SOTL3	34.34939501	-119.04156798
SOTL4	34.35409910	-119.02377773
SOTL5	34.41041409	-118.73012722
SOTN1	34.36328583	-119.01684833
SOTN2	34.35810691	-119.00888879
SOTN3	34.41841671	-118.63987014
SOTN4	34.40295386	-118.67300430
SOTN5	34.42674807	-118.50331075
SOTS1	34.32863555	-119.07692595
SOTS2	34.35231283	-119.03071065
SOTS3	34.36246751	-119.01539817
SOTS4	34.40365333	-118.67624148
SOTS5	34.29775595	-119.11061701
SRFL1	34.34551662	-119.06320377
SRFL2	34.34638943	-119.06159009
SRFL3	34.34678681	-119.06052181
SRFL4	34.34727757	-119.05925003
SRFL5	34.34763791	-119.05837077
SRFN1	34.39021530	-118.91872273
SRFN2	34.39055946	-118.92006811
SRFN3	34.39047094	-118.92058108
SRFN4	34.34850996	-119.05502697
SRFN5	34.34279946	-119.06580761
SRFS1	34.34842966	-119.05599014

[20] First character stands for watershed (S = Santa Clara River; C = Calleguas Creek; T = Topanga Cayon); Second character stands for land use (A = agricultural; O = open space; R = residential); Third character stands for fluvial geomorphic location (F = floodplain; T = terrace); Fourth character stands for degree of infestation (L = large infestation; S = small infestation; N = no infestation); and number stands for replicate.

TABLE 1 (continued). SAMPLING LOCATIONS

Site ID[21]	Latitude (degrees)	Longitude (degrees)
SRFS2	34.34434206	-119.06444111
SRFS3	34.34619077	-119.06199317
SRFS4	34.34843880	-119.05402014
SRFS5	34.34869981	-119.05140314
SRTL1	34.34955376	-119.05358260
SRTL2	34.26270140	-119.16888054
SRTL3	34.27168856	-119.15589622
SRTL4	34.34653955	-119.06151641
SRTL5	34.23558016	-119.19549652
SRTL6	34.42552071	-118.56015748
SRTN1	34.39073430	-118.92195504
SRTN2	34.39069558	-118.92312767
SRTN3	34.26057022	-119.17577449
SRTN4	34.26676621	-119.16454090
SRTN5	34.42593033	-118.54444083
SRTS1	34.26179976	-119.17029432
SRTS2	34.34747539	-119.05919303
SRTS3	34.23591485	-119.19486805
SRTS4	34.42548039	-118.55383988
SRTS5	34.39371038	-118.91472976
Topanga Canyon		
TOFL1	34.06384511	-118.58723690
TOFL2	34.06142517	-118.58494202
TOFL3	34.05183099	-118.58190827
TOFL4	34.06960465	-118.58714193
TOFL5	34.06604201	-118.58649661
TOFN1	34.04854679	-118.58064923
TOFN2	34.06349609	-118.58599612
TOFN3	34.05022988	-118.58104510
TOFN4	34.06934339	-118.58688243
TOFN5	34.07574029	-118.58923590
TOFS1	34.04960300	-118.58127845
TOFS2	34.06511346	-118.58651371

[21] First character stands for watershed (S = Santa Clara River; C = Calleguas Creek; T = Topanga Cayon); Second character stands for land use (A = agricultural; O = open space; R = residential); Third character stands for fluvial geomorphic location (F = floodplain; T = terrace); Fourth character stands for degree of infestation (L = large infestation; S = small infestation; N = no infestation); and number stands for replicate.

TABLE 1 (continued). SAMPLING LOCATIONS

Site ID[22]	Latitude (degrees)	Longitude (degrees)
TOFS3	34.06168367	-118.58562925
TOFS4	34.06894994	-118.58698418
TOFS5	34.07637094	-118.59061053
TRFL1	34.04108514	-118.58094972
TRFL2	34.04112973	-118.58058594
TRFL3	34.04087928	-118.58260598
TRFL4	34.04068482	-118.58244010
TRFL5	34.03998594	-118.58274286
TRFN1	34.09726543	-118.60056496
TRFN2	34.09518739	-118.60157046
TRFN3	34.09382936	-118.60303125
TRFN4	34.09431375	-118.60276169
TRFN5	34.09441508	-118.60242583
TRFS1	34.09592609	-118.60095137
TRFS2	34.09501355	-118.60170339
TRFS3	34.09789693	-118.60000195
TRFS4	34.04005618	-118.58304461
TRFS5	34.04103183	-118.58065979
Reference Sites		
Agua Blanca	34.54197845	-118.76600772
Aliso Canyon	34.41807398	-118.09363894
Arroyo Sequit	34.06579390	-118.93263468
Bouquet Canyon	34.57381133	-118.38870624
Cold Creek	34.09425859	-118.64799891
Lachusa Creek	34.04172728	-118.89414808
Las Virgenes Creek	34.16885342	-118.70297916
Solstice Canyon	34.03844903	-118.75221346
Sespe Creek	34.55823516	-119.24346691
Santa Paula Creek	34.44816727	-119.06068350

[22] First character stands for watershed (S = Santa Clara River; C = Calleguas Creek; T = Topanga Cayon); Second character stands for land use (A = agricultural; O = open space; R = residential); Third character stands for fluvial geomorphic location (F = floodplain; T = terrace); Fourth character stands for degree of infestation (L = large infestation; S = small infestation; N = no infestation); and number stands for replicate.

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CHAPTER 4 -

WILDFIRE PROMOTES GIANT REED (*ARUNDO DONAX*) INVASION IN RIPARIAN ECOSYSTEMS

Abstract: Invasion of riparian ecosystems by the large bamboo-like grass species *Arundo donax* L. has caused major alterations to structure and ecosystem functions in streams of arid and Mediterranean-type climate regions. Although healthy riparian ecosystems function as natural barriers to wildfire, the extensive wildfires in southern California in October 2003 burned large expanses of riparian ecosystems along the Santa Clara River and appeared to promote *A. donax* invasion. I investigated post-fire plant colonization of riparian areas along the Santa Clara River to determine the influence of wildfire on *A. donax* invasion. Growth of *A. donax* was compared to native plants for 1 year after the fire. Pre- and post-fire plant abundance and soil nutrient concentrations were analyzed to ascertain the role of fire-derived nutrients in the invasion process. Due to its immediate re-growth after the fire and its high growth rate compared to native riparian plants, *A. donax* dominated these burned riparian ecosystems within a few months after the fire and reached 99% cover a year later. *Arundo donax* grew an average of 3–4 times faster than native woody riparian plants – up to 2.62 cm/day (average 0.72 cm/day) – and reached up to 2.3 m in height less than 3 months after the fire. One year post-fire, *A. donax* density was nearly 20 times higher and productivity was 14–24 times higher than native plants. Elevated soil NH_4-N and P levels post-fire may have stimulated the high growth rate of *A. donax*. Large quantities of *A. donax* biomass that

have replaced native woody species after wildfire have increased susceptibility of riparian ecosystems along the Santa Clara River to fire, creating an invasive plant-fire regime cycle. Wildfire not only promotes dominance of riparian ecosystems by *A. donax*, but also alters vital ecosystem processes and increases the risk of fire spreading to surrounding shrublands, towns, and agriculture.

Key Words: *Arundo donax,* wildfire, giant reed, invasive species, alien species, competition, nitrogen, riparian, Mediterranean-type climate, rivers, soil nutrients

INTRODUCTION

Historically, dense cover of chaparral biomass accumulating over a 30–50 years or more provided fuel for high-intensity wildfires in shrublands of southern California and in similar shrublands of other Mediterranean-type climate regions (Minnich 1983, Keeley et al. 1999, Keeley and Fotheringham 2001, 2005). However, riparian corridors may have acted as natural firebreaks (Dudley 1998, Rundel 2000, 2003) and refuge for wildlife in the landscape because of their low-lying topographic position and relative absence of flammable fuels. Lightning was the primary cause of wildfires, especially during dry, low humidity conditions that occur in the late summer and fall (Naveh 1975, Keeley 1982, Keeley et al. 1999). Currently, most wildfires in these areas are anthropogenic in origin (Rugen 1987, D'Antonio and Vitousek 1992, Keeley et al. 1999).

Invasion of annual grass species has been linked to altered fire regimes in rangelands, deserts, and wildlands of California and the western U.S. (Brooks and Pyke 2001, Brooks et al. 2004, Dukes and Mooney 2004). Grass/fire cycles, more recently termed invasive plant-fire regime cycles, may ensue when alien grass species colonize an area and provide fuel for fire propagation, increasing frequency, area, and intensity of fires (D'Antonio and Vitousek 1992, D'Antonio 2000, Brooks 2002, Brooks et al. 2004, Keeley 2004, Keeley and Fotheringham 2005). Rapid recovery of alien grass species compared to native species after fire leads to increased susceptibility of that ecosystem to fire.

In coastal shrubland watersheds in California, a large invasive grass species *Arundo donax* may be an even bigger problem in riparian ecosystems due to its perennial

growth form with a large volume of biomass produced, flammability compared to natives, and immediate rapid growth after fire (Rieger and Kreager 1989). *Arundo donax* was introduced from southern Eurasia into the Los Angeles region several hundred years ago for erosion control and building materials (Robbins et al. 1951, Perdue 1958, Dudley and Collins 1995), and now infests many stream and river system in coastal California (Gaffney 2002). The natural flood disturbance regime in this climate regime successfully distributes it along rivers, where it establishes readily on bare substrates (Else 1996, Else and Zedler 1996). Studies suggest that increased water and nutrient delivery to these systems have increased its invasion success (see Chapter 2 and 3), yet the influence of fire on its invasion in river systems remains relatively unexplored and undocumented. Several accounts suggest that infestations of *A. donax* have increased fuel load as well as fire frequency and intensity along riparian corridors (Robbins et al. 1951, Bell 1994, Scott 1994, D'Antonio 2000). Growing to between 4–8 m in height and as fast as 10 cm per day (Perdue 1958, Crampton 1974, Hickman 1993), it produces abundant flammable biomass that accumulates during the summer and fall months (Rundel 2000). The ability of its rhizomes to recover more rapidly than native plants after fire likely contributes to its invasion success, but no evidence exists to document this response to fire. Furthermore, increased post-fire nutrient effects may promote a positive feedback cycle (invasive plant-fire regime) in these ecosystems.

Although little research exists on the effects of fire in riparian ecosystems, several authors have suggested that fire may increase the ability of *A. donax* to invade natural riparian systems (Rieger and Kreager 1989, Scott 1994, Bell 1997). The large amount of

highly flammable biomass that *A. donax* produces and that accumulates during most of the year, as well as the ability of its rhizomes to respond quickly after fire, likely contribute to its invasion success by creating a invasive plant-fire regime cycle. DiTomaso (1998) suggests that *A. donax* invasion is changing riparian ecosystems from primarily flood-defined (Mount 1995) to fire-defined systems. The Simi/Verdale wildfire of October 2003 (Ventura County, CA) (Keeley and Fotheringham 2005) provided a unique opportunity to study the contribution of fire to invasion of riparian terrace ecosystems of the Santa Clara River by *A. donax*. In this study, I compared growth and recolonization of *A. donax* to that of native plant species in riparian ecosystems burned in a southern California wildfire. I hypothesized that high adjacent soil nutrient content, immediate post-fire resprouting phenology, and higher growth rate than native plants promote invasion of *A. donax* in riparian corridors of southern California.

METHODS

Study area

Study sites were located in the approximately 700-acres of riparian ecosystem of the Santa Clara River that was burned in the late October 2003 Simi/Verdale fire (Keeley and Fotheringham 2005) (Figure 16). The 187 km-long Santa Clara River and its tributaries drain a 4,185 km^2 watershed, the second largest coastal watershed in southern California. Hundreds of acres of *A. donax* infest floodplains and terraces along the Santa Clara River. Natural riparian vegetation on terraces consisted of large riparian trees, both black cottonwood (*Populus balsamifera* (L.) ssp. *trichocarpa* Torrey & A. Gray) and red willow (*Salix laevigata* Bebb) in the canopy layer. A mixture of smaller trees and shrubs

comprised the understory layer, including arroyo willow (*Salix lasiolepis* Benth.), sandbar willow (*Salix exigua* Nutt.), shining willow [*Salix lucida* Muhl. ssp. *lasiandra* (Benth.) E. Murray], mulefat [*Baccharis salicifolia* (Ruiz Lopez & Pavon) Pers.], and blue elderberry (*Sambucus mexicana* C. Presl.).

Study design

Six sites established in a previous study along the Santa Clara River (see Chapter 3) were burned during the 2003 wildfire. These study sites were all located on riparian terraces, and five out of six sites were adjacent to shrubland ecosystems. The wildfire crossed the river through one site located near the Los Angeles-Ventura County line and the other five sites were located near the town of Santa Paula. I compared pre-fire plant composition and soil nutrient data collected in summer 2003 at these six permanent monitoring sites to data collected in these sites during the year after the wildfire (2004). I established eight additional study sites along riparian terrace areas burned to the west of these sites in a river reach that did not contain previous study sites to make sure sites were well-distributed throughout the riparian areas burned and represented the range of environmental conditions found in the study area. I monitored recolonization of all sites from November 2003-October 2004 (Figure 16) (see Appendix 4-1 for study site locations and descriptions). The 14 study sites were approximately 600 m^2 (most sites were 30 m long x 20 m wide) and all but one was located next to open space land use types; the one exception was adjacent to a citrus orchard.

Study species

Arundo donax is a robust, perennial, bamboo-like member of the Poaceae family (grass family) that occurs throughout the floodplains and terraces of rivers in California and other warm, temperate climates worldwide (Crampton 1974, Hickman 1993). It has erect, stout yet hollow culms that are 1–4 cm in diameter and 2–8 m or more tall. Culms branch, forming ramets, typically at the end of the first year of growth or after a culm is damaged. Leaf blades are broad (2–6 cm wide), less than 1 m long, flat, clasping at the base, strongly scabrous along their margins, and evenly spaced along the culm (Faber and Holland 1992, Hickman 1993). *Arundo donax* reproduces vegetatively through a network of large thick rhizomes that grow horizontally just below the surface of the soil. Under some conditions it produces a large (3–6 dm), terminal, plume-like inflorescence (panicle) at the end of the growing season (Faber and Holland 1992, Hickman 1993); however, seeds of the inflorescence are primarily sterile in California (Johnson et al. 2006).

In addition to *A. donax*, I studied several native riparian plant species commonly found on terraces of rivers in southern California and in terraces that were burned in the fire: *Salix laevigata, S. lasiolepis*, *S. exigua*, *Populus balsamifera* ssp. *trichocarpa*, and *Baccharis salicifolia*. *Salix laevigata* is a riparian tree that reaches heights up to 15 m and is dominant in both floodplains and terraces along southern California rivers, and *Populus balsamifera* ssp. *trichocarpa* grows to a height of 30 m in alluvial plains and terraces along rivers in southern California (Faber et al. 1989, Faber and Holland 1992, Hickman 1993). *Salix lasiolepis* is a widely distributed plant that occurs as a small tree

in wetter areas and a spreading shrub in drier locations (Faber et al. 1989). *Salix exigua* is a shrub-sized willow that commonly grows on sandy substrates along active floodplains (Faber et al. 1989). *Baccharis salicifolia* is one of the most dominant shrubs found throughout floodplains and terraces of streams and rivers of southern California. A member of the Asteraceae, it usually grows to a height of less than 4 m.

Sampling methods

I took plant measurements monthly from November 2003 to October 2004 in all 14 study sites to examine the effects of fire on recolonization of riparian terraces. I determined change in plant abundance in burned areas by comparing pre- and post-fire (summer 2003 and July 2004) percent cover of *A. donax* and native woody plant species in the six long-term study locations. Ocular estimates of percent cover by species were taken within 1 m^2 quadrants place randomly throughout six permanent study sites during summer 2003 and all 14 study sites during each post-fire sampling period. Post-fire mean shoot density (stems m^{-2}) of *A. donax* and all native species were sampled monthly within six $1m^2$ quadrants (placed randomly each time) within all 14 study sites. I measured mean shoot length (cm) and basal diameter (mm) of 20 randomly selected *A. donax* and 20 native individuals of each dominant native woody species at each study site and post-fire sampling period. In addition, I measured shoot height and basal diameter for three permanently marked *A. donax* and native plant shoots (three of each species) at each sampling period. Basal diameter measurements were taken 10 cm above the surface of the soil. I calculated mean shoot elongation rate (cm d^{-1}) for each species using data from the permanently marked individuals.

I calculated the aboveground biomass, relative growth rates (RGRs), and productivity of plants within the study sites using the plant dimension data collected during the study. Non-destructive dimensional analyses were used to estimate aboveground biomass dry weight of plants in study sites with minimal interference to plant growth (Whittaker 1961, 1965, Whittaker and Marks 1975, Sharifi et al. 1982, Spencer et al. 2006). I created regression models for each species using basal diameter, shoot length, and aboveground biomass of culm/branch samples measured in the field experiment to predict biomass of each individual plant sampled in the study sites. Regression models for aboveground biomass were very highly significant for all species ($r^2 = 0.971$ to 0.990, $P < 0.001$) (see Chapter 2 for study design and Appendix 2-1 for equations). *Arundo donax* biomass was estimated based on both basal diameter and shoot length measurements taken at all study sites, and native species biomass estimates were based on basal stem diameter. All data were log transformed in regression models.

I calculated RGRs for all permanently marked individuals using the following differential equation, where W is the total aboveground biomass dry weight (g) of each shoot and t is time (day^{-1} post-fire).

$$\mathrm{RGR} = \frac{dW}{dt}\frac{1}{W} = \frac{d(\ln W)}{dt}$$

Mean productivity (kg m^{-2} year^{-1}) for each species was calculated at approximately 1 year post-fire. I estimated biomass (kg) for the 20 randomly sampled culms/stems for each species measured during September 2004. For each species, mean biomass per shoot (kg shoot^{-1}) was multiplied by mean density (shoots m^{-2}) at each study

site and then divided by time (year). I averaged productivity calculations for each species across study sites.

Five soil subsamples were collected at each study site adjacent to *A. donax* and each native woody plant species immediately after fire (November through January). Subsamples were collected in the upper 20 cm of the soil where nutrient concentrations are greatest (Day 1983). For each species, soil samples were combined into a composite sample by thorough mixing in a stainless steel bowl. Each soil subsample was collected with an 8-cm diameter bucket auger. Soil samples taken before the fire (summer 2003) were taken adjacent to *A. donax* and *S. laevigata* according to the same sampling protocol.

Soil samples were air-dried and ground to a powder in preparation for nutrient content analyses at the DANR Analytical Laboratory in Davis, California. Soil samples were analyzed for total N (%), nitrate-N (NO_3-N - ppm), ammonia-N (NH_4-N - ppm), and orthophosphate (PO_4-P - ppm). Total N in the soil was determined by the combustion gas analyzer method (Method 972.43) (Hofer 2003, Knepel 2003). Concentrations of NO_3-N and NH_4-N in the soil were determined by equilibrium extraction of soil with potassium chloride and a flow-injection analyzer (Olsen and Sommers 1982, Prokopy 1995). Because the soils studied were neutral to alkaline, the Olsen-P method was used to estimate the relative availability of inorganic PO_4-P in the samples. Soil grain size was analyzed using a hydrometer to determine the particle size distribution of sand, silt, and clay in soil suspension (Sheldrick and Wang 1993).

Statistical analyses

One-way and two-way analysis of variance (ANOVA) tests were used to analyze effects of various combinations of factors (plant type and time) on plant performance and growth data (dependent or response variables) (Systat Statistical Program [Version 10]). Factors tested include plant type (*A. donax* and native plant species) and time (pre-fire vs. post-fire or months post-fire). Dependent variables included plant abundance (percent cover), density (stem m^{-2}), shoot length (cm), shoot elongation rate (cm d^{-1}), RGR (g $g^{-1}day^{-1}$), productivity (kg m^{-2} yr^{-1}), and soil nutrient concentrations (NH_4-N, NO_3-N, and phosphate in ppm).

I conducted a one-way ANOVA of productivity by species (*A. donax*, *B. salicifolia*, and *S. laevigata*) and two way-ANOVAs for all plant performance metrics by factors of plant type and time to determine differences in plant growth by species over time post-fire. Tukey's post-hoc test was used for pairwise comparisons of means in the one-way ANOVA. I performed ANOVA hypothesis tests to evaluate contrasts between means of grouping variables and levels in two-way ANOVA results. Probability plots were examined to test for normality of data and to identify any data that required transformation. All biomass, soil NH_4-N, and NO_3-N data were ln transformed. When means and standard errors were used to describe or present statistical differences, data were back-transformed and reported in original units.

RESULTS

Pre- versus post-fire plant abundance

In the two-way ANOVA (plant type x time period) of plant abundance, both main effects were significant (Table 12). Percent cover of *A. donax* was much higher than native plant cover both before and after the study sites were burned (Figure 17). Although both *A. donax* (65.0 ± SE 6.7% cover) and the native plants (21.7 ± SE 6.0% cover) were in greater abundance before the fire, less than a year after the fire *A. donax* (42.8 ± SE 4.3% cover) was the dominant plant species in these riparian ecosystems (Figure 17). Native species comprised 25.0% of the total vegetation before the fire and less than 1% (0.4 ± SE 0.2% cover) of the vegetation in burned riparian terraces only 9 months after the fire.

Post-fire density

The two-way ANOVA (plant type x time period) of plant density revealed a significant two-way interaction (Table 12). The mean density of *A. donax* (stems m^{-2}) was much greater than that of native plant species for all months sampled (March–September 2004) (Figure 18). Mean density of native plant species declined somewhat over time during the first year after the fire, although differences between sampling periods were not significant. However, mean density of *A. donax* shoots increased significantly over time. A year after the wildfire, *A. donax* density (26.3 ± SE 3.2 stems m^{-2}) was an order of magnitude greater than that of native species (1.4 ± SE 0.4 stems m^{-2}) within the burned riparian ecosystems sampled.

Post-fire shoot length

Post-fire resprout timing and shoot length over time differed significantly between *A. donax* and the native plants studied (Figure 19). *Arundo donax* began growing within days after being burned to the ground, whereas native plants did not start to appear (a few seedlings/resprouts at eight sites) sites until January (over two months after they burned). The two-way ANOVA of shoot length by plant type and time period resulted in a very highly significant two-way interaction (Table 12). Shoot length was 1.7–5.2 times greater (over 2.5 times greater on average) for *A. donax* than for natives during all months sampled (Figure 19).

Post-fire shoot elongation rate and RGR

Arundo donax shoots grew at a much faster rate than the native riparian plant species within the first year after fire (Figure 20 and Figure 21). The two-way ANOVA (plant type x month post-fire) for the shoot elongation rate revealed a significant two-way interaction due to variation in rate between species for each time period (Table 13). The highest *A. donax* shoot elongation rates were observed immediately post-fire (first two months) and in April 2004 at the beginning of the growing season. During the first 3 months post-fire, *A. donax* exhibited very high shoot elongation rates. Native plant species did not emerge until January 2004 and grew much more slowly than *A. donax*. Mean shoot elongation rates of *A. donax* were significantly higher than those of native plant species except during the winter (between January and March) when rates did not differ significantly. A series of heavy frosts occurred in late February 2004 (4 months post-fire), and they appeared to have lowered *A. donax* shoot elongation rates

substantially. In April, shoot elongation rates for both *A. donax* and native plant species increased from winter levels, corresponding with warmer spring growing conditions. From April 2004 until the end of the year, elongation rates decreased for all plants, with *A. donax* maintaining higher rates (up to two times higher) than native species until December 2004.

In the two-way ANOVA (plant type x month post-fire) of RGR, the two-way interaction was very highly significant (Table 13). The mean RGR of *A. donax* was much greater initially (first three months) than that of the native plant species (Figure 21). *Arundo donax* mean RGR was extremely high (0.094 ± SE 0.005 g $g^{-1}day^{-1}$) immediately after being burned, whereas the native plants did not emerge until the third month after the fire and then grew at a much more moderate rate. Mean RGR of native plants was highest five months after the fire and significantly higher than *A. donax* during the spring. As mentioned above, a series of very heavy frosts in February 2004 appeared to curtail *A. donax* growth but had little effect on the RGR of native plants. The mean RGR of both *A. donax* and native plants was very low at the end of the growing season, from mid-summer (July) to late fall (November).

Post-fire productivity

Approximately one year after the fire, *A. donax* productivity was much higher than that of any of the native species ($F_{(2,295)} = 43.291$; $P < 0.001$) (Figure 22). Productivity of *A. donax* was 14 times higher than that of *B. salicifolia* and 24 times higher than that of *S. laevigata* in burned areas. Due to initial low abundance and significant mortality during the year, *S. exigua*, *S. lasiolepis*, and *P. balsamifera* ssp.

trichocarpa were at such a low density in burned sites that their productivity was undetectable one year after the fire.

Soil nutrients

Mean pre- and post-fire soil nutrient levels surrounding *A. donax* compared to native plants differed significantly (Figure 23; Table 14). Mean soil nutrient levels (NH_4-N, NO_3-N, and PO_4-P) adjacent to *A. donax* plants increased substantially after the study sites burned. However, no significant differences in nutrient concentrations were observed between pre- and post-fire soil adjacent to native plant species. After the study sites burned, both NH_4-N and PO_4-P concentrations were more than twice as high in the soil adjacent to *A. donax* plants compared to native plant species.

DISCUSSION

In this study, I explored the role of fire in the *A. donax* invasion process in riparian ecosystems of southern California where wildfire is naturally prevalent in adjacent shrubland ecosystems. Burning through nearly 300 ha of *A. donax* infested riparian terraces, the October 2003 Verdale-Simi fire provided an opportunity to examine ecosystem-level effects of wildfire, namely the change in native versus invasive plant composition, and mechanisms responsible for invasion by *A. donax*. Comparisons of post-fire *A. donax* and native plant performance demonstrate several physiological and morphological characteristics that give *A. donax* an advantage over native species after fire. Elevated nutrient levels found surrounding *A. donax* compared to native plants, likely resulting from greater pre-fire biomass, may have maintain its immediate post-fire

growth. These findings indicate how fire promotes invasion of *A. donax* in riparian terraces adjacent to shrubland ecosystems and may help in establishing an invasive plant-fire regime cycle (Brooks et al. 2004).

Change in Plant Composition and Structure

Results of this study indicate a strong and potentially lasting effect of fire on plant composition in riparian areas burned along the Santa Clara River study area. Less than a year after the fire, *A. donax* was clearly increasing its dominance in these ecosystems. *Arundo donax* increased in abundance by almost 25% and comprised more than 99% of the vegetative cover in study sites a year after fire. The much higher biomass or productivity of *A. donax* a year after the fire compared to the two most abundant native species, *S. laevigata* and *B. salicifolia*, suggests that native riparian trees and shrubs might eventually be excluded by *A. donax* in fire-prone riparian ecosystems. Similar examples of post-fire competitive exclusion of native plant species by invasive grasses have been documented in many ecosystems in which fire is an unnatural or altered process (i.e., enhanced frequency) (D'Antonio and Vitousek 1992, D'Antonio 2000). Although smaller in stature, the invasive annual grass *Bromus tectorum* L. (cheatgrass) has caused an increase in wildfire occurrence followed by a decrease in native species abundance in sagebrush shrublands of the western United States (Whisenant 1990, Brooks and Pyke 2001). The dominant species in sagebrush shrublands, *Artemesia tridentata* (sagebrush), does not resprout after fire (Booth et al. 2003), whereas *B. tectorum* successfully germinates from seed and grows in harsh conditions in interspaces

between shrubs after fire (Brooks et al. 2004). Successive fire cycles and increased fire return intervals have lead to dominance by the invader.

Soil Nutrients Stimulate Growth

Elevated nutrient levels in surface soil provide high nutrient levels that increase or maintain plant growth immediately after fire in shrubland ecosystems (Rundel and Parsons 1980, Boerner 1982). Wildfires are known to alter nutrient budgets and cycling by volatilizing some nutrients and mobilizing the levels of others (Boerner 1982, D'Antonio and Vitousek 1992, D'Antonio 2000). Volatilization of nutrients depends on fire temperature but is thought to be high for nitrogen, carbon, and sulfur because of the low temperatures at which they become volatile (Rundel et al. 1983). Ammonium and phosphate levels in surface soils may increase rapidly after fire in shrubland ecosystems due to mineralization (Christensen 1973, Debano and Dunn 1982, Rundel et al. 1983), but post-fire nitrate levels are highly dependent on vegetation type and quantity (Romanya et al. 2001). Nitrogen losses in shrubland ecosystems may occur after fire due to leaching by rainfall and soil erosion (Debano and Conrad 1978, Romanya et al. 2001). Because of the low-lying nature of riparian ecosystems in the landscape, nutrient-rich ash may collect in these areas or nutrients in the ash may run off into these systems from surface erosion and soil leaching (Boerner 1982).

Mechanisms contributing to increased abundance of *A. donax* compared to native plant species in burned areas a year after fire were examined, including response to elevated nutrient levels, differing phenology, and high growth rates. A positive feedback cycle was observed, whereby *A. donax* contributes higher nutrient levels to soil post-fire

and these high levels promote rapid growth compared to native riparian species. Evidence suggests that large differences in pre- and post-fire soil nutrient levels may have stimulated and/or helped maintain high growth rates of *A. donax* following fire. Levels of ammonia, nitrate and phosphate in the soil surrounding *A. donax* were much higher in riparian study sites after the fire, whereas soil nutrient levels adjacent to the native plants species did not change. Higher soil nutrient levels found next to *A. donax* versus native plants were likely due to quality and quantity of fuel (vegetation) burned, fire intensity, and resulting ash deposited (Debano and Conrad 1978). Although not measured, these high post-fire levels were likely indicative of nutrient content contained in the pre-fire aboveground biomass of varying species, influencing nutrient content of ash (Christensen and Muller 1975, Debano and Conrad 1978). Variation in fire intensity between patches of *A. donax* (Bell 1997, D'Antonio 2000) and native plants mixed with *A. donax* observed may have also influenced nutrient content. In mature California chaparral, elevated post-fire soil nitrogen levels from addition of ammonium and phosphorus-rich ash (Christensen 1973) provide favorable nutrient conditions for plant growth (Christensen and Muller 1975, Rundel and Parsons 1980). The high proportion of nutrients, such as ammonium, in the ash remaining after fire is thought to mineralize rapidly, especially after the first rainfall, and become available to plants (Rundel and Parsons 1984), and be readily available to plants, if not lost from the system (Rundel et al. 1983). Higher soil ammonium and phosphate concentrations associated with *A. donax* compared to native plants post-fire may help explain higher initial growth rate of *A.*

donax compared to native species immediately after fire, but causation cannot be definitively determined from these results.

Mechanisms of Invasion

I found clear evidence of three mechanisms, response to nutrients, fire-adapted phenology, and high growth rate of *A. donax*, that promote its preemption of natives after fire. Fire appears to stimulate *A. donax* growth immediately, whereas native plant species recover much slower after burned. Native species did not begin resprouting or germinating until several months after the October 2003 wildfire. In areas containing high nitrogen levels, Decruyenaere & Holt (2005) found that *A. donax* exhibited no dormancy during the year, although recruitment of new shoots (from rhizomes) was higher in the summer than in winter months. Accordingly, high nutrient levels in soils surrounding *A. donax* post-fire may have led to high growth rates and maintenance of shoot growth after rhizomes burned. Conversely, native woody riparian species, such as *S. laevigata*, *P. balsamifera* spp. *trichocarpa* and *B. salicifolia*, are dormant in the winter months and are leafless (G. Coffman personal observation). Resprouting and germination of these species in southern California occurs between late winter and early spring, corresponding with declining river flows (Braatne et al. 1996, Stella et al. 2006). Resprouting and germination of native species after fire appeared similar to the natural phenology (no burn effect) of these species and nutrient levels did not appear to effect regrowth. In chaparral ecosystems, several sprouter non-seeder species (clonal growth form similar to *A. donax*) appear within weeks after fire (Hanes 1971, Naveh 1975, Zedler et al. 1983, Thomas and Davis 1989).

Growth rates and other measures of plant performance of *A. donax* were much higher than native species during the first year after fire, resulting in a higher aboveground biomass a year later. Mean monthly growth rates of *A. donax* were up to three times higher than native riparian plant species in the winter and twice as high in spring through summer. Most native species growth occurred in the spring and early summer and corresponds to phenology under non-burned conditions (Braatne et al. 1996). The pattern and mean RGRs of *A. donax* were similar to those measured for recruits that emerged in April in a Northern California study (Spencer et al. 2005) (see Chapter 3).

Riparian ecosystems infested by *A. donax* adjacent to fire-prone shrublands in southern California appear to be on a trajectory to an invasive plant-fire regime cycle (Brooks et al. 2004). Introduction the unique habit of *A. donax*, a clonal tall grass species, into an ecosystem naturally dominated by woody trees and shrubs has altered fuel types, layers, and loads (Scott 1994, DiTomaso 1998, Brooks et al. 2004). Decreased moisture content and increased surface to volume ratio of *A. donax* versus native vegetation may lead to an altered or increased length of fire susceptibility or increased probability of ignition in these systems, although no data currently exists to document this assertion. Addition of this novel fuel characteristic to the riparian ecosystem has increased vertical continuity (structure of fuel allows fire to spread from surface to crowns of shrubs and trees), which can in turn increase the frequency and extent of fires (Brooks et al. 2004). Due to its tall growth form, infestations of *A. donax* mixed with native species may spread fire vertically into the canopy of riparian trees

instead of mainly burning trunks of riparian species near the ground surface. As *A. donax* abundance increases in fire-prone areas due to increased nutrient levels, fire-adapted phenology and high growth rate of *A. donax*, increased fire return intervals may eventually lead to exclusion of native species in riparian ecosystems. Evidence of this positive-feedback cycle suggests that *A. donax* may create an invasive plant-fire regime cycle in streams and rivers of Mediterranean-type climates similar to this southern California example.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

That fire promotes invasion of riparian ecosystems by the large alien grass species, *Arundo donax* L., has long been speculated, but no data existed to support this premise. Although fire was once a natural part of shrubland ecosystems that characterize the coastal southern California landscape, large riparian ecosystems provided natural firebreaks because native vegetation retains foliar water that resists ignition (Hanes 1971, Naveh 1975, Bell 1997, Rundel 1998, Keeley and Fotheringham 2001). In October 2003, however, a wildfire burned more than 700 acres of vegetation on riparian terraces along the Santa Clara River. One year after the fire, *A. donax* dominated the vegetation in burned areas. This study illustrates how wildfire promotes invasion of this large alien grass species in riparian ecosystems of southern California.

Removal of *A. donax* from riparian ecosystems adjacent to fire-prone shrublands in Mediterreanean-type climates should be a key management priority. Negative effects on other ecosystem functions, such as wildlife habitat reduction (Knick et al. 2005), follow fire regime changes (Brooks et al. 2004) and associated plant invasions (Herrera

and Dudley 2003, Kisner 2004). Infestations of *A. donax* located on riparian terraces adjacent to towns or agricultural practices pose an increased risk of fire to people and property. Immediate post-fire removal of *A. donax* reduces future fire risk and greatly reduced the amount of biomass removal necessary. However, time of year is critical to selection and success of appropriate removal techniques. Active planting of removal areas with a diverse composition of native species may be required to prevent reinvasion by *A. donax* or other exotic species due to enhanced nutrient levels in these burned riparian ecosystems (Chapter 2).

TABLES

Table 12. Two-way ANOVA of plant abundance (% cover), density (stems m^{-2}), and shoot height (cm) by factors of plant type (*A. donax* and native plant species) and pre- and post-fire time periods.

Factors and interactions	Plant abundance	Density	Height (shoot elongation)
Plant type	$F_{(1,80)} = 59.123$; $P < 0.001$***	$F_{(1,852)} = 322.769$; $P < 0.001$***	$F_{(1,3231)} = 819.299$; $P < 0.001$***
Time period	$F_{(1,80)} = 15.166$; $P < 0.001$***	$F_{(5,852)} = 1.700$; $P = 0.132$	$F_{(8,3231)} = 442.074$; $P < 0.001$***
Plant type x time period	$F_{(1,80)} = 0.006$; $P = 0.937$	$F_{(5,852)} = 2.850$; $P = 0.015$*	$F_{(8,3231)} = 21.295$; $P < 0.001$***
r^2	0.626	0.287	0.591

* = $0.05 \geq P > 0.01$ = significant; ** = $0.01 \geq P > 0.001$ = highly significant; *** = $P \leq 0.001$ = very highly significant

Table 13. Two-way ANOVA of shoot elongation rate (cm d^{-1}) and relative growth rate (RGR; g $g^{-1}day^{-1}$) by factors of plant type (*A. donax* and native plant species) and month post-fire (12 months).

Factors and interactions	Shoot elongation rate	RGR
Plant type	$F_{(9,319)} = 16.178$; $P < 0.001$***	$F_{(9,315)} = 44.146$; $P < 0.001$***
Month post-fire	$F_{(1,319)} = 76.481$; $P < 0.001$***	$F_{(1,315)} = 81.154$; $P < 0.001$***
Plant type x month post-fire	$F_{(9,319)} = 6.845$; $P < 0.001$***	$F_{(9,315)} = 55.397$; $P < 0.001$***
r^2	0.556	0.762

Table 14. Two-way ANOVA of soil nutrients (NH_4-N, NO_3-N, and P) by factors of plant type (*A. donax* and native plant species) and pre- and post-fire time periods. Soil grain size (% silt + clay) was used as a covariate. NH_4-N and NO_3-N were ln transformed.

Factors and interactions	**NH_4-N (ppm)**	**NO_3-N (ppm)**	**P (ppm)**
Plant type	$F_{(2,44)} = 2.002$; $P = 0.164$	$F_{(2,44)} = 0.612$; $P = 0.438$	$F_{(2,44)} = 3.021$; $P = 0.089$
Time period	$F_{(1,44)} = 8.125$; $P = 0.001$***	$F_{(1,44)} = 2.670$; $P = 0.080$	$F_{(1,44)} = 6.002$; $P = 0.005$**
Plant type x time period	$F_{(2,44)} = 5.459$; $P = 0.008$**	$F_{(2,44)} = 2.268$; $P = 0.115$	$F_{(2,44)} = 2.224$; $P = 0.120$
Silt + clay	$F_{(1,44)} = 11.737$; $P = 0.001$***	$F_{(1,44)} = 2.710$; $P = 0.107$	$F_{(1,44)} = 5.803$; $P = 0.020$*
r^2	0.555	0.255	0.394

FIGURES

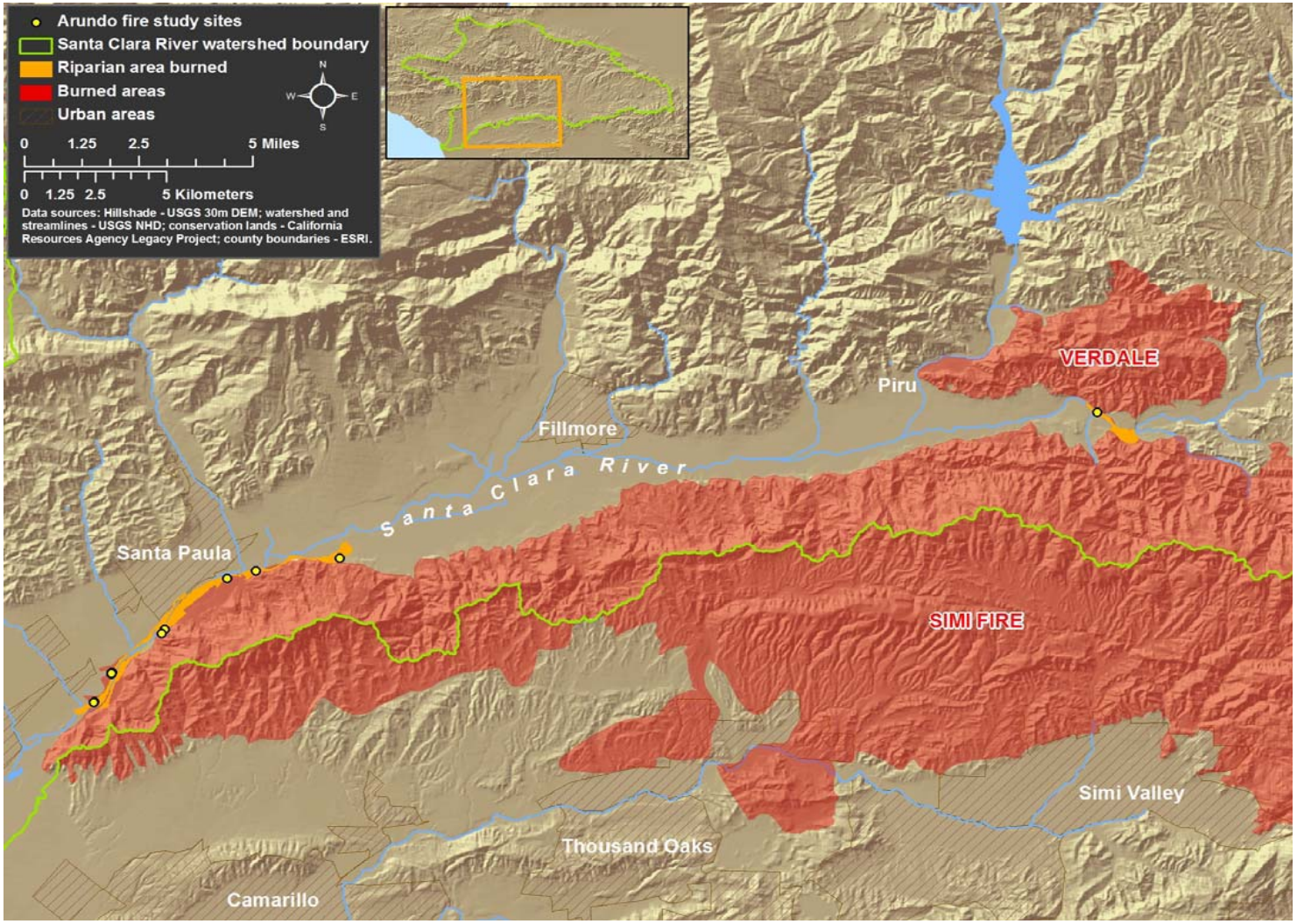

Figure 16. Location of study sites in riparian terraces of the Santa Clara River, Ventura County, California.

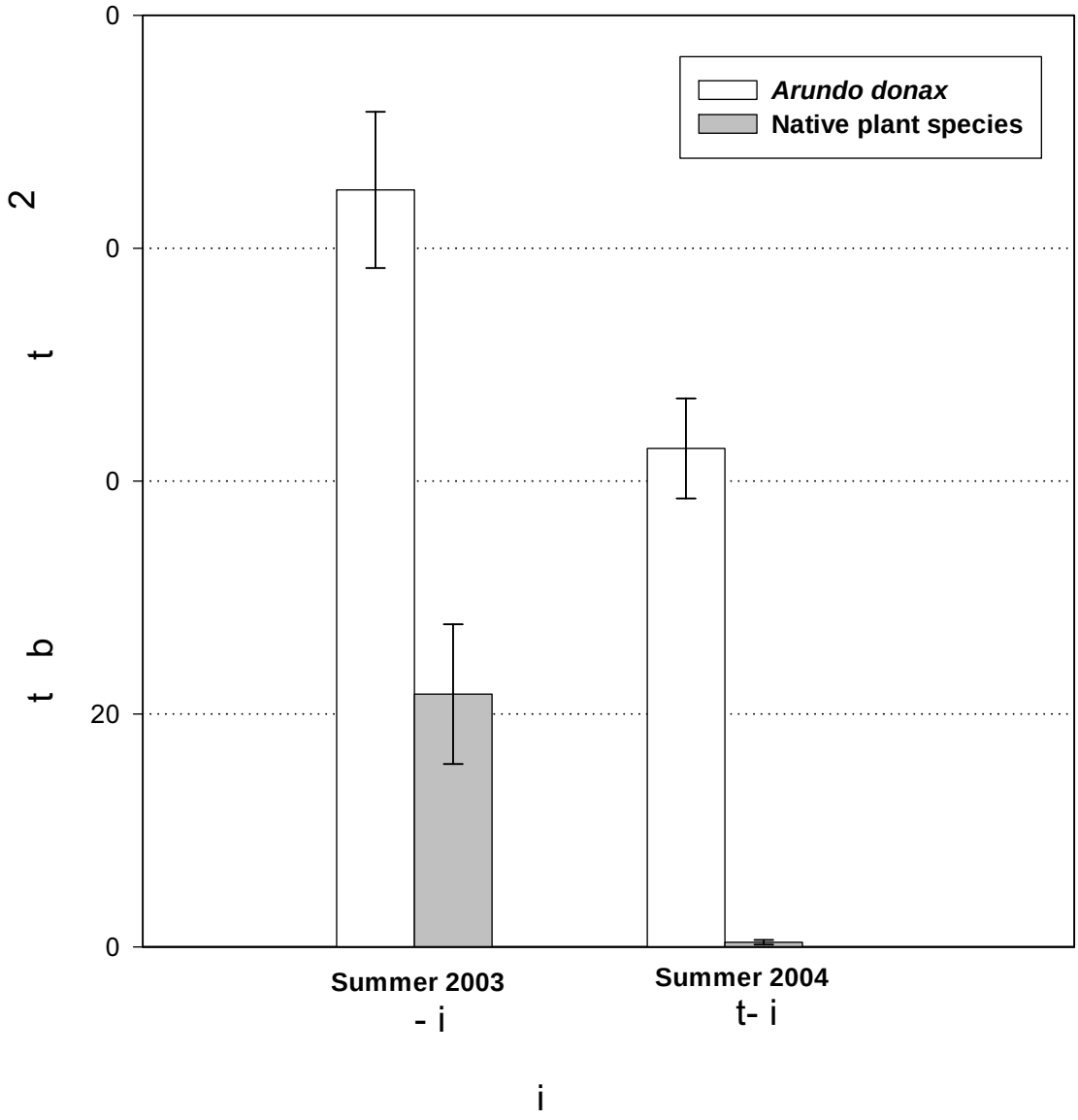

Figure 17. Abundance of *A. donax* compared to native riparian plant species before the October 2003 wildfire (summer 2003) and a year later. Letters denote results of post-hoc hypothesis tests (comparison of means) with significance recognized at $\alpha < 0.05$.

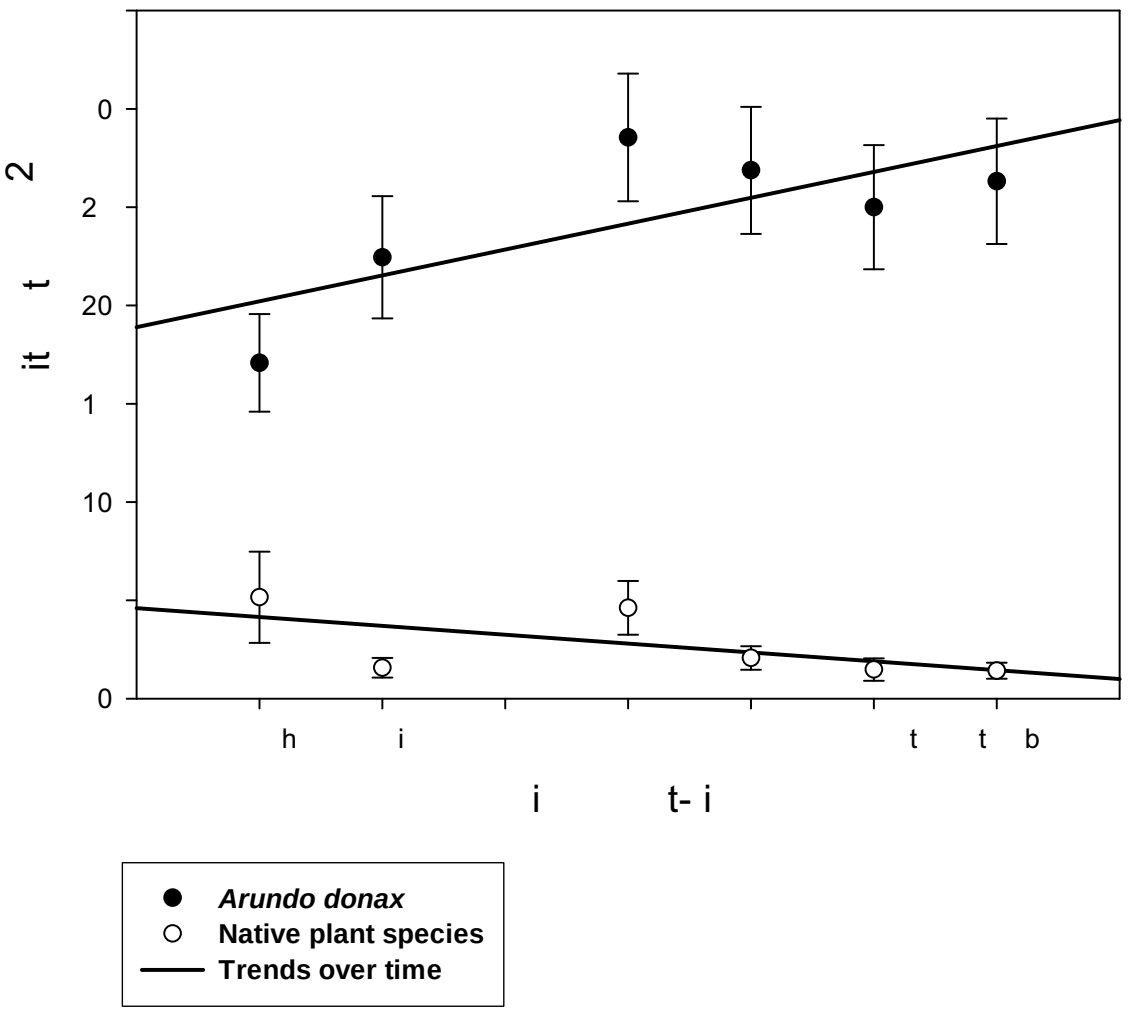

Figure 18. Mean density of *A. donax* versus native plants after the October 2003 wildfire. Regression lines illustrate trends over time. Letters denote results of post-hoc hypothesis tests (comparison of means) with significance recognized at $\alpha < 0.05$.

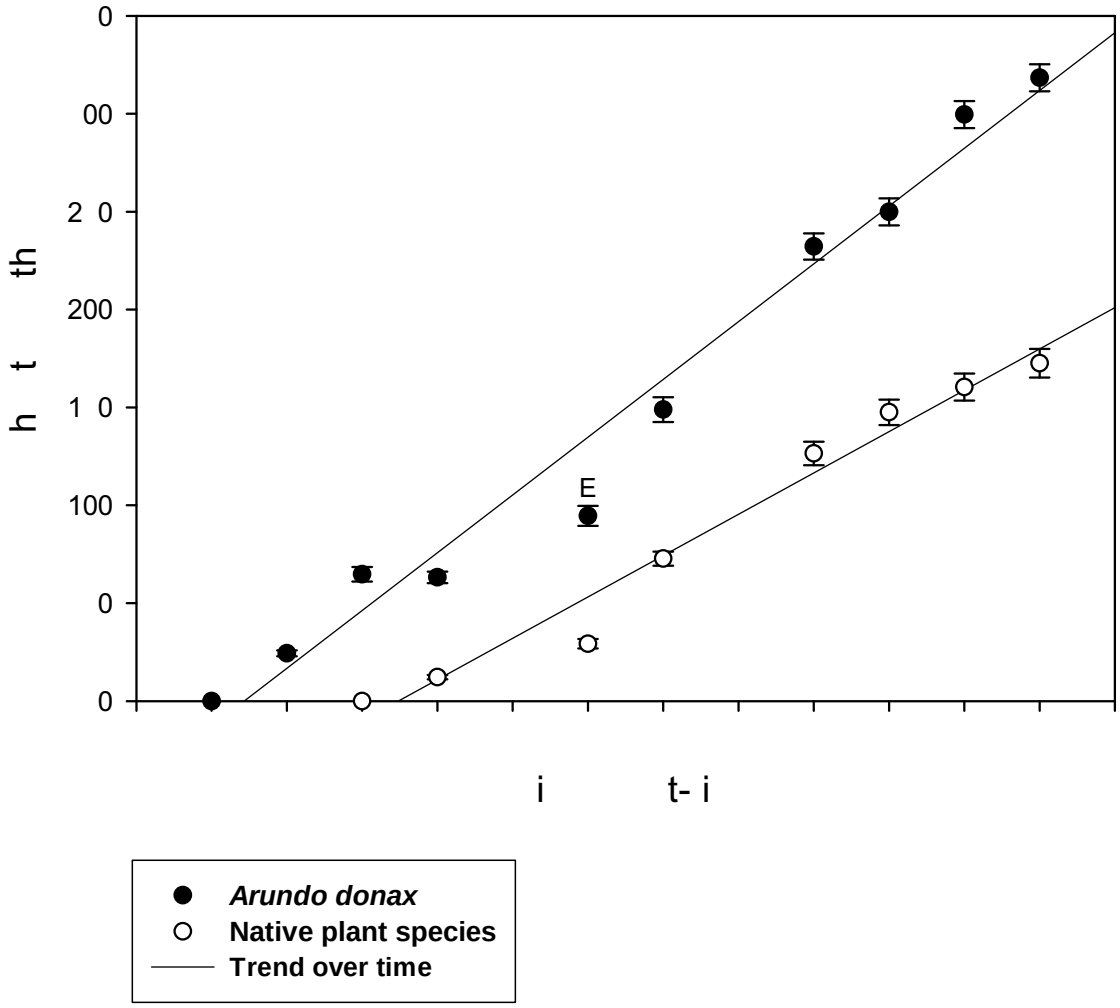

Figure 19. Monthly mean shoot length of *A. donax* compared to native plant species for a year following the October 2003 wildfires. Regression lines illustrate trends over time. Letters denote results of post-hoc hypothesis tests (comparison of means) with significance recognized at $\alpha < 0.05$.

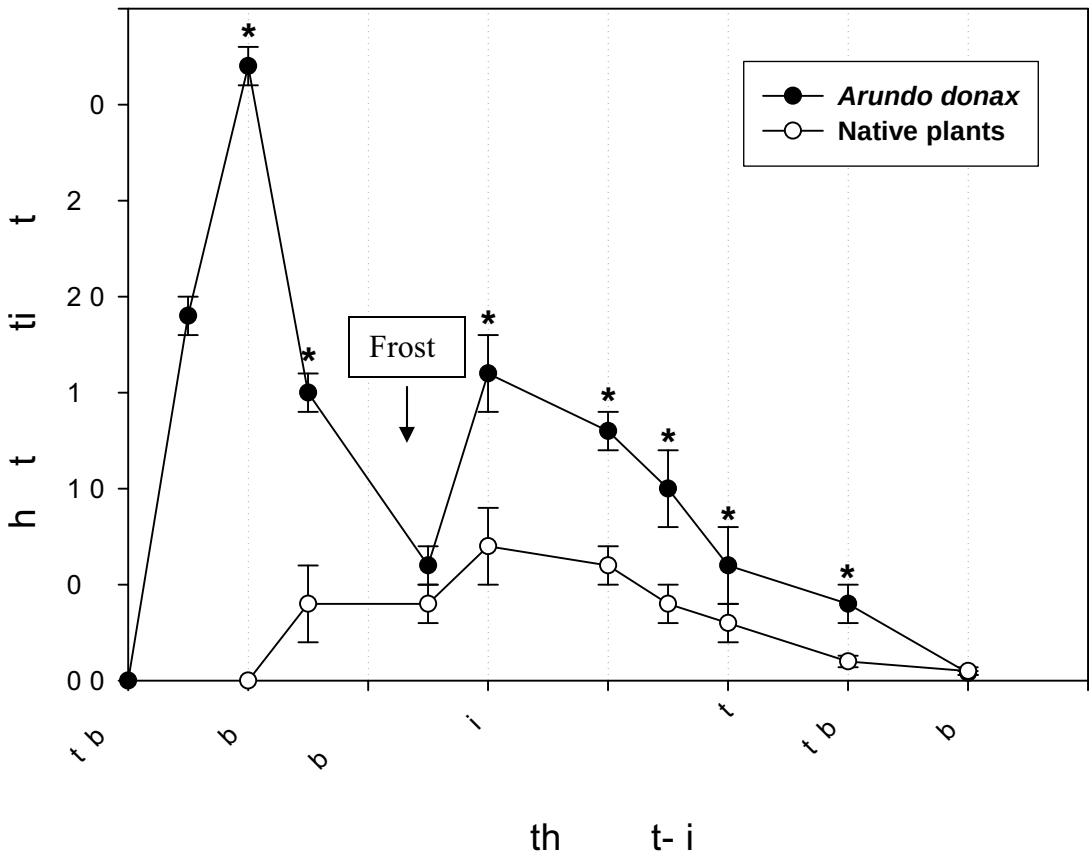

Figure 20. Mean monthly shoot elongation rates of *A. donax* compared to native plants after being burned in the October 25, 2003 wildfire. Asterisks denote significant differences in means between *A. donax* and native plants at each time period based on results of post-hoc hypothesis tests (comparison of means) with significance recognized at $\alpha < 0.05$.

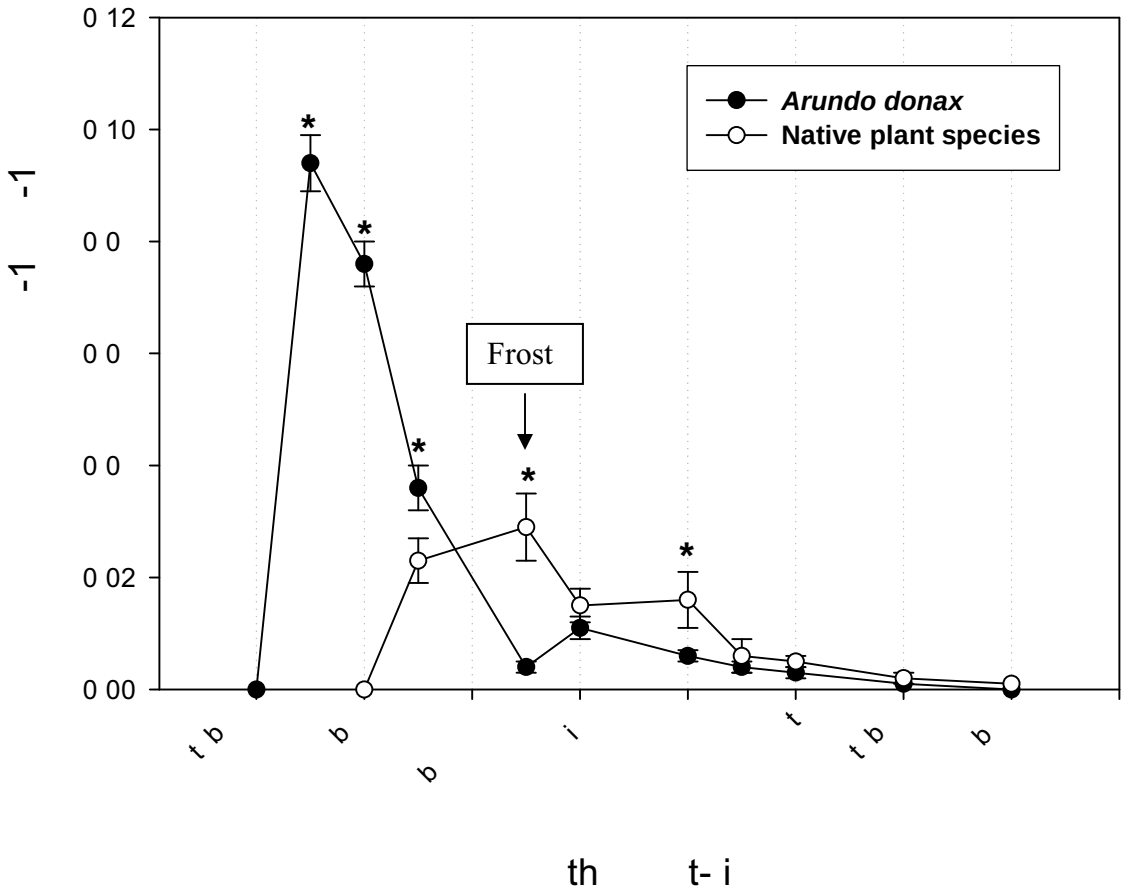

Figure 21. Relative growth rate of *A. donax* compared to native plant species. Asterisks denote significant differences in means between A. donax and native plants at each time period based on results of post-hoc hypothesis tests (comparison of means) with significance recognized at $\alpha < 0.05$.

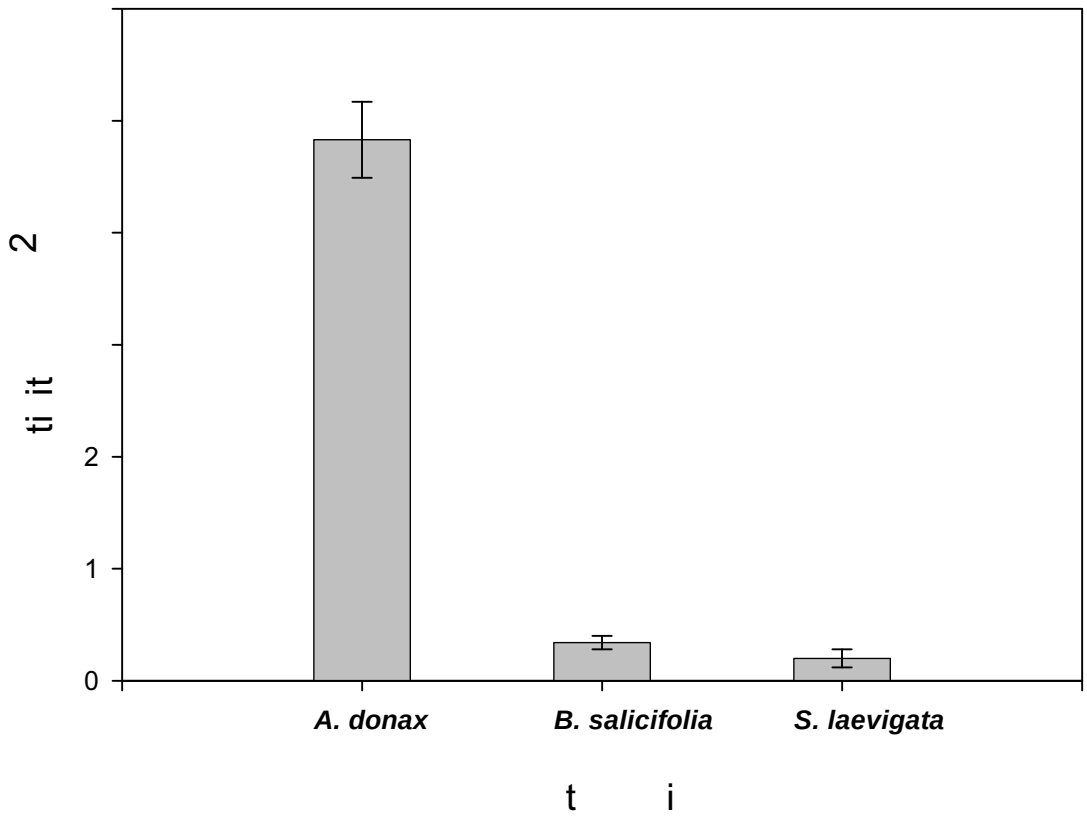

Figure 22. Mean productivity (kg/m^2/year) of *A. donax* compared to native plant species in burned sites. Letters denote results of post-hoc hypothesis tests (comparison of means) with significance recognized at $\alpha < 0.05$.

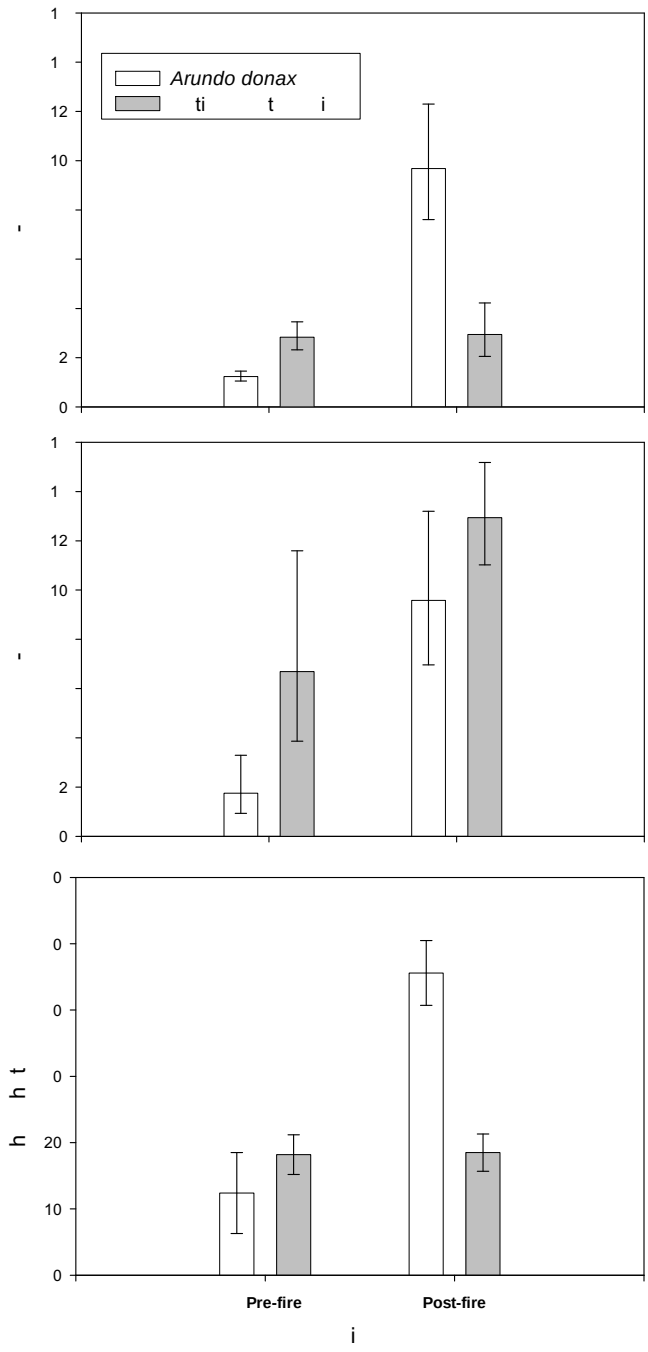

Figure 23. Pre- and post-fire mean nutrient levels of soil adjacent to *A. donax* compared to soil next to native plants. Letters denote results of post-hoc hypothesis tests (comparison of means) with significance recognized at $\alpha < 0.05$.

APPENDIX

APPENDIX 4-1

SAMPLING LOCATIONS

Site No.	Location Description	Latitude	Longitude	Pre-Fire Data Available
1	Near Piru, along Hwy 126 where fire spread to riparian corridor, on right bank of river terrace	34.41°	118.73°	Yes
2	East of Santa Paula and off of Peck Road, on left bank of river terrace	34.33°	119.08°	Yes
3	East of Santa Paula and off of Peck Road, on left bank of high river terrace	34.33°	119.08°	Yes
4	Just Downstream of 12th Street Bridge in Santa Paula, on left bank of river terrace under large coastal live oaks	34.35°	119.05°	Yes
5	Approximately 2 miles east of Santa Paula along South Mountain Road, on left bank of river terrace	34.35°	119.02°	Yes
6	Approximately 1 mile east of Santa Paula along South Mountain Road, on left bank of river terrace under mature willow trees	34.35°	119.04°	Yes
7	Southwest of Santa Paula, east of Mission Rock Road, on right bank of river terrace	34.31°	119.10°	No
8	Southwest of Santa Paula, east of Mission Rock Road, on right bank of river terrace	34.31°	119.10°	No
9	Southwest of Santa Paula, east of Mission Rock Road, on right bank of river terrace	34.31°	119.10°	No
10	Southwest of Santa Paula, east of Mission Rock Road, on right bank of river terrace	34.31°	119.10°	No
11	Southwest of Santa Paula, west of Mission Rock Road, on right bank of river terrace	34.30°	119.10°	No
12	Southwest of Santa Paula, west of Mission Rock Road, on right bank of river terrace	34.30°	119.10°	No
13	Southwest of Santa Paula, west of Mission Rock Road, on right bank of river terrace	34.30°	119.10°	No
14	Southwest of Santa Paula, west of Mission Rock Road, on right bank of river terrace	34.30°	119.10°	No

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CHAPTER 5 -

CONCLUSIONS

FACTORS INFLUENCING *ARUNDO DONAX* INVASION

I found that the role of all four factors that I investigated in my dissertation were critical to the *A. donax* invasion process, but varied in importance based on quantity and availability to plants. My results show that nutrient enrichment in riparian ecosystems due to increased urban and agricultural land use development plays an important role in *A. donax* expansion in the past half century. *Arundo donax* dominated experimental high soil moisture and nutrient treatments in full sun, indicating that the combination of elevated water quantity, decreased quality and light is key to its invasion success especially where disturbance levels are high. Fire appeared to have the greatest effect on *A. donax* invasion; it promotes rapid expansion of *A. donax* infestations near fire-prone shrublands and dominates the vegetation only months after burned.

Nutrient Availability

Anthropogenic nutrient enrichment has been linked to invasion of natural ecosystems worldwide (Kolb et al. 2002, Booth et al. 2003, Brooks 2003, Kolb and Alpert 2003, Suding et al. 2004), but little is known about the role of nutrients in promoting invasion in riparian ecosystems in Mediterranean-type climates (Wang 1998). I explored the influence of anthropogenic nutrient enrichment on the invasion of riparian ecosystems by *A. donax* in southern California. My field study results suggest that N

(nitrogen) limiting conditions may occur naturally in riparian ecosystems in this geologically young landscape but that anthropogenic nutrient inputs have elevated groundwater N:P ratios and may provide invasive species with an advantage where N enrichment of soils and groundwater occurs. In my study area, elevated levels of N in shallow groundwater and soils of floodplains were associated with adjacent land use and with watersheds with higher anthropogenic nutrient inputs. Floodplains with both large and small *A. donax* infestations contained higher soil NO_3-N concentrations than did non-infested areas. Higher N and K (potassium) leaf tissue content of *A. donax* in large and small infestations compared to those of native red willow (*Salix laevigata* Bebb.) collected from non-infested and reference sites suggests that these nutrients may be more available to *A. donax*. Unlike *S. laevigata*, *A. donax* may take advantage of anthropogenically enriched N levels in riparian ecosystems, as illustrated by its positive response to all forms of shallow groundwater N in floodplains and soil N on riparian terraces.

Interspecific competition between native and introduced species for nutrients, water, and light availability plays a critical role in plant invasion in many terrestrial ecosystems worldwide (D'Antonio and Vitousek 1992, Gordon and Rice 2000, Booth et al. 2003, Suding et al. 2004, White and Holt 2005, Richardson 2006). Experimental studies in river and wetland ecosystems have demonstrated superior resource competition by invasive plants for nutrients (Green and Galatowitsch 2002, Minchinton and Bertness 2003). My experimental findings suggest that higher nutrient levels may benefit *A. donax* more than native species, although response to competition for nutrients varies by

species groupings. *Arundo donax* exhibited a positive response to high nutrient additions, but primarily under high soil moisture and light levels, and these effects were much greater in monocultures of *A. donax* (see Chapter 2, Figure 6). Both *S. laevigata* and *B. salicifolia* responded positively to high nutrient treatments under similar conditions, but the effects were of much lower magnitude than those of *A. donax*. When *A. donax* was grown in competition with *P. balsamifera* spp. *trichocarpa*, responses to high nutrient treatments were greater for both species compared to the effects when they were grown in monoculture. However, when grown in competition with either *S. laevigata* and *B. salicifolia* effects of nutrient addition on *A. donax* were decreased; thus, competition from *B. salicifolia* and *S. laevigata* had a strong negative effect on *A. donax* biomass under high soil moisture, light, and nutrient conditions.

Water Availability

In this dissertation, I hypothesized that high soil moisture levels may promote invasion by *A. donax*. Although *A. donax* tolerates a wide variety of ecological conditions, it reportedly thrives in areas with high soil moisture, such as along canals, ditches, and stream banks (Perdue 1958, Rezk and Edany 1979). Preliminary data analyses (Stillwater Sciences, unpublished spatial data) indicate that a higher percentage of *A. donax* is associated with areas of rising groundwater, compared to other drier areas in riparian ecosystems along the Santa Clara River. In addition, increased water quantity in stream systems of Mediterranean-type climates caused by anthropogenic inputs may contribute to higher than natural soil moisture availability. My field experiment showed that *A. donax* produced the highest biomass under high soil moisture conditions,

especially when light and nutrient levels were also high (see Chapter 2; Figure 5). Although competition with *A. donax* did not suppress native plant species aboveground biomass under these high resource conditions during the time frame of the study, its biomass was much higher than those of all three native plant species studied.

Along naturally loosing stream reaches (i.e., river reaches that contribute water to the groundwater supply) in southern California or in riparian ecosystems with water tables lowered by groundwater extraction, invasion by *A. donax* appears to be diminished by lower water availability. However, growth of all native riparian species as well as *A. donax* appears to be lower than under higher water availability; all four species exhibited much lower biomass under low soil moisture versus high soil moisture conditions in my field experiment (see Chapter 2). The presence of sustained high soil moisture or near-surface shallow groundwater during the growing season may important for establishment of most riparian species (especially *Populus* spp. seedlings) (Braatne et al. 1996, Stella et al. 2006), although *A. donax* is known to establish under very low soil moisture conditions (Perdue 1958) and *B. salicifolia* grown from cuttings also had a high rate of survival in low soil moisture conditions in my field experiment (See Appendix 2-2). However, in years with prolonged wet winters all species may establish successfully, even in areas where soil type does not normally sustain high moisture levels. Once established, rooting depth, distribution, and structure relative to soil moisture and depth to groundwater likely play a larger role in growth of and competition between *A. donax* and native species (see Chapter 2, Figure 9). *Salix* spp., *Populus* spp., *B. salicifolia*, and other woody riparian species are phreatophytes with adaptations to low soil moisture

conditions; their roots follow the receding soil moisture during establishment and can use water from depths of up to 30 m (Robinson 1958). In contrast, *A. donax* is a perennial grass with roots that can only reach ~3 m below the soil surface based on my field observations. Evidence from my field experiment indicates that all plants grow much more slowly under low compared to high soil moisture conditions, but the higher biomass of *A. donax* under all conditions may only decrease the rate of expansion in drier riparian ecosystems.

Light Availability

Light availability influences plant invasion in many ecosystems, due to both vegetation removal and direct effects of shading by invasive species (Crawley 1987, D'Antonio and Vitousek 1992, Yamashita et al. 2000, Meekins and McCarthy 2001, Fargione and Tilman 2002). Reduction in light availability may act as a barrier to invasion in both disturbed and natural habitats (Richardson et al. 2000), because plant species vary greatly in the amount of light they require for colonization and optimal growth (Treshow 1970, Menges and Waller 1983). Light availability varies greatly according to time and space along rivers in Mediterranean-type climates; the natural dynamic disturbance regime within these rivers creates large open areas after flooding and mature riparian forests create light limiting environments on high terraces. I experimentally investigated the effects of varying light levels on *A. donax* growth (in combination with nutrients and soil moisture factors) and competition with three native plant species. Light availability did not affect initial plant establishment of woody species (or *A. donax*) in this experiment, as was documented by D'Antonio and Vitousek

(1992) for other invasive grass species (see Appendix 2-2). In general, biomass of *A. donax* and native plant species was lower under low light conditions when soil moisture was not limiting (see Chapter 3, Figure 5). However, *A. donax* biomass was much higher than that of native species in low light and low soil moisture conditions but similar in high soil moisture conditions. Only one negative effect of competition was observed under conditions of low light (and high soil moisture): *A. donax* biomass was significantly lower when grown with *P. balsamifera* spp. *trichocarpa* compared to monoculture. Thus, light reduction does not appear to be an effective barrier to initial *A. donax* invasion in riparian ecosystems in Mediterranean-type climates. Dudley (1998) suggested that monotypic stands of *A. donax* limit native riparian plant recruitment through light reduction. Further investigation is needed to determine the effects of *A. donax* infestations on recruitment of native plant species in later stages of the invasion process.

Occurrence of Fire

Although healthy riparian ecosystems function as natural barriers to wildfire (Radtke et al. 1981, Dudley 1998, Rundel 2000, 2003), the extensive wildfires in southern California in October 2003 burned large expanses of riparian ecosystems along the Santa Clara River and appeared to promote *A. donax* invasion. Due to its immediate regrowth after the fire and its high growth rate compared to that of native riparian plants, *A. donax* dominated these burned riparian ecosystems within a few months after the fire and comprised 99% of the vegetative cover a year later. *Arundo donax* grew an average of 3–4 times faster than native woody riparian plants – up to 2.62 cm/day (average 0.72

cm/day) – and reached up to 2.3 m in height less than 3 months after the fire. One year post-fire, *A. donax* density was nearly 20 times greater and productivity was 14–24 times higher than density and productivity of native plants. Elevated soil nutrient levels post-fire may have contributed to *A. donax*'s high post-fire growth rate, which was similar to post-fire growth observed for chaparral resprouters after fire (Zedler et al. 1983). The large amounts of *A. donax* biomass that replaced native woody species after the wildfire have increased the susceptibility of riparian ecosystems along the Santa Clara River to fire, creating an invasive plant-fire regime cycle similar to those described by D'Antonio and Vitousek (1992) and Brooks et al. (2004). Wildfire not only promotes dominance of *A. donax* in riparian ecosystems but also alters vital ecosystem processes and increases the risk that fire will spread to surrounding shrublands, towns, and agricultural areas.

***ARUNDO DONAX* INVASION ECOLOGY**

Based on my research findings and available literature, I propose three *A. donax* invasion scenarios and associated conceptual invasion trajectories. I extrapolated invasion scenarios and trajectories from my two-year field experiment based on results of my two field studies, other *A. donax* invasion research, and my personal field observations. Proposed conceptual invasion trajectories represent general degree of infestation (abundance of *A. donax*) over time depending on variation in amount and timing in factors (and levels) investigated in my research: water, nutrient, light, and fire. Invasion scenarios include: *A. donax* growing alone in monocultures (scenario1), *A. donax* growing with native plants from the onset of establishment (scenario 2), and *A. donax* growing under a mature riparian forest canopy (scenario 3).

Invasion Scenario 1

According to experimental results and field observations, *A. donax* expansion is most rapid where it grows alone in large monotypic stands (Figure 24). Results of my field experiment show that after two years, *A. donax* biomass was highest when it was grown by itself in monoculture then when grown with any other species (see Chapter 3, Figure 4). *Arundo donax* (and native riparian plant) biomass was relatively low under the low resource conditions (low water and nutrient availability) that naturally exist in the riparian ecosystems found in many floodplains as well as high terraces in Mediterranean-type climates (Figure 24). However, I predict that a rapid *A. donax* invasion trajectory will occur where naturally high soil moisture, nutrient, and light conditions prevail or are added to the system, such as in floodplains in highly urbanized watersheds or high terraces next to agricultural areas (see Chapters 2 and 3). Several studies have shown a similar increased response of invasive, clonal plant species to addition of nutrients and light in a variety of ecosystems (Aerts and Berendese 1988, Bobbink et al. 1988, Green and Galatowitsch 2002, Maurer and Zedler 2002). Maurer and Zedler (2002) reported that rapid expansion of *Phalaris arundinacea*, another clonal grass species, into wetlands throughout North America was likely due to clonal subsidy, morphological plasticity, and high nutrient availability. When fire burns through large, continuous *A. donax* infestations on riparian terraces where high resource conditions are prevalent, *A. donax* reinvades on an even steeper trajectory (Figure 24; also Coffman unpublished data and Chapter 4). Results of my fire study showed that *A. donax* dominated burned riparian ecosystems (i.e., via high regrowth from rhizomes) within a few months after a large fire

and reached 99% in aerial cover one year later (see Chapter 4). Regardless of resource level or combination of resources added, *A. donax* expansion is most rapid when it grows alone in monotypic stands.

Invasion Scenario 2

Where *A. donax* begins (at time 0) to grow with native plants on bare substrates after a large disturbance, a more gradual but similar invasion trajectory to Scenario 1 may be found regardless of resources added (Figure 24). Results of my field experiment show that in low resource conditions *A. donax* aboveground biomass was slightly lower when grown with *B. salicifolia* compared to in monoculture, possibly due to early shading by this native species (see Chapter 2; Figure 5). Although *A. donax* only suppressed one native species (*P. balsamifera* ssp. *trichocarpa*) under naturally low resource conditions, its biomass was 2–3 times higher than that of either native tree. Under high soil moisture, nutrient, and light conditions, competition from *B. salicifolia* and *S. laevigata* had negative effects on *A. donax* biomass. Despite some suppression by these native species, however, *A. donax* had a higher biomass than that of all native plant species examined. In a similar field competition experiment, Booth et al. (2003) showed that a native clonal perennial grass (*Elymus elymoides*) suppressed an annual invasive grass (*Bromus tectorum*) in high soil moisture and nutrient conditions, thereby facilitating recruitment of a native shrub (*Artemesia tridentata*). When fire is introduced to riparian terraces infested with *A. donax* and a mix of native riparian plants, fire intensity is likely decreased due to higher leaf water content of natives (Brooks et al. 2004). However, the invasion trajectory in this type of mixed community is probably only slightly lower than

that of large *A. donax* infestations (Scenario 1) due to immediate resprouting and much higher growth rates of *A. donax* compared to native plants after fire (Figure 24). However, this invasion trajectory will vary between Scenario 1 and 3 depending on length of time from establishment to fire.

Invasion Scenario 3

An invasion trajectory similar to Scenario 2 (low water and nutrient availability) occurs when *A. donax* establishes under a mature riparian canopy regardless of soil moisture or nutrient levels (Figure 24). In my field experiment, under low light but high water and nutrient availability conditions *A. donax* biomass was slightly lower than it was where all resource conditions were low, but the biomass of native plant species was slightly higher. Competition with *Populus balsamifera* ssp. *trichocarpa* saplings that establish concurrently may suppress *A. donax* growth, but only under high soil moisture and nutrient levels. Thus, the incline of the trajectory may be slightly lower when water and nutrients are added due to the different responses of *A. donax* and native plant species found under these experimental conditions. When fire enters riparian ecosystems containing a mature riparian canopy infested by an understory of *A. donax*, a crown fire may spread through these areas due to an unnatural ladder effect: *A. donax* provides a large quantity of flammable material that transfers fire vertically to large riparian trees under which it grows (Brooks et al. 2004). The post-fire invasion trajectory is initially gradual due to competition from resprouts, but most of these resprouts will eventually die (according to field observations; Coffman unpublished data), and the trajectory then increases in steepness.

MANAGEMENT IMPLICATIONS

Arundo donax ***removal effort priorities***

Millions of dollars have been spent to remove *A. donax* infestations of riparian ecosystems throughout California (Katagi et al. 2002). Due to the lack of understanding of *A. donax* ecology, however, decisions regarding prioritization of removal areas and removal techniques often have to be made in the absence of sufficient scientific information. After analyzing my own research results and the current body of literature available on *A. donax*, I propose the following management strategies, which incorporate the most current understanding of the *A. donax* invasion process, to most effectively and efficiently address this problem. I recommend that *A. donax* control efforts should be placed where ecological benefits are the greatest and associated removal effort the lowest.

1. Remove *A. donax* under mature riparian forests, especially adjacent to fire-prone shrublands. The highest priority location for *A. donax* control is within mature riparian forests adjacent to shrublands. My research suggests that removal in these areas creates the greatest environmental benefit, because these areas have the highest risk of further damage if removal is conducted and threat of reinfestation is lowest (i.e., where removal effort is long-lasting). *Arundo donax* may reinfest areas that are flooded occasionally but not completely scoured (e.g., higher terraces), especially where water and nutrient levels are high. In these locations, mature riparian forests may facilitate invasion by physically trapping propagules after flooding (Dudley pers. comm.). Although my research shows that *A. donax* does not grow as rapidly in low light

conditions compared to high light conditions when high levels of water and nutrients are present (see Chapter 2), my field observations suggest that the understory of mature riparian forests can be invaded by *A. donax* after large floods; the invasion trajectory just may be more protracted. When these mature riparian forests become heavily invaded, areas near fire-prone shrublands are highly susceptible to fire. The large, dry biomass produced by *A. donax* in these areas carries fires (i.e., ladder effect) through canopies of these once-natural firebreaks, burning across and along river systems. These areas should be targeted for high priority removal due to the subsequent threat of an invasive plant-fire cycle and the lasting damage caused, the complete loss of mature riparian forests.

2. Remove the largest *A. donax* propagule source. Another *A. donax* removal priority should be to target areas containing the largest source of propagules to curtail the distribution of *A. donax*, thereby working to control it in the initial phase of the invasion process. Due to its clonal growth form, dominant asexual reproduction, and flood-driven dispersal mechanisms, the largest *A. donax* infestations will produce the highest quantity of vegetative propagules. My research suggests that the largest infestations are most prevalent in riparian ecosystems that are within highly urbanized watersheds, located adjacent to agricultural and residential land uses, and in areas that have burned in both southern California and the Western Cape region of South Africa. Large infestations in areas most frequently scoured by winter flooding contain the largest potential source of propagules.

Prioritization of removal in riparian ecosystems with the lowest likelihood of reinfestation has been suggested (i.e., areas outside the flood zone) (Coffman et al. 2004).

In general, my research findings suggest that *A. donax* is least likely to invade open substrates or recently scoured areas in which resources levels are low (i.e., low soil moisture and nutrient availability) and where native plants have established at the same time. Further investigation of the relationship between frequency of rhizome establishment and *A. donax* abundance in various locations after flood events is necessary to validate this recommendation. Riparian ecosystems downstream of large propagule sources along active floodplains are most likely to be reinfested and removal in these areas should be given lowest priority. Results of my studies suggest that *A. donax* is most likely to invade open (i.e., very low native vegetation cover) or recently scoured areas in which resources levels area high (i.e., high soil moisture and nutrient availability). These areas often are found next to agricultural land uses and areas exposed to wastewater treatment discharge from residential land use (see Chapter 3) (Neely and Baker 1989).

I recommend that more effort should be placed where ecological benefits are the greatest and associated removal costs the lowest. Natural biological and physical processes in riparian ecosystems that are heavily invaded by *A. donax* are usually already degraded. Although removal efforts may slightly reduce propagule abundance, net ecological benefits from removing *A. donax* in these areas may be much lower than in areas less invaded. My research suggests that removal of *A. donax* in locations within riparian forests adjacent to fire-prone shrublands, watersheds with low nutrient inputs, and watersheds with little *A. donax* abundance will result in the greatest ecological benefit. Furthermore, a considerable amount of money and effort is involved in removal of large infestations.

3. Control *A. donax* on a watershed scale. Here I suggest several watershed-scale *A. donax* control strategies given the natural dynamic flood regime in streams of Mediterranean-type climate regions and the widespread anthropogenic resource inputs that are not easily altered. *Arundo donax* should be removed from low nutrient input watersheds where infestations are small or area of infestation is localized; the highest probability of eradication success at the lowest cost is possible in these locations. However, watershed-scale long-term control of *A. donax* in natural riparian ecosystems may require management of resource levels that promote invasion to reduce growth and competition. Manipulation of resource availability in favor of a given native (desired) species has been proposed to create a competitive advantage and a barrier to reinvasion (Blumenthal et al. 2003, Corbin and D'Antonio 2004, Suding et al. 2004, Prober et al. 2005, Perry and Galatowitsch 2006). Results of my studies suggest that reduction of nutrient inputs in urbanized watersheds may slow invasion of *A. donax* but likely will not alone prevent its eventual spread.

Several researchers suggest that *A. donax* should be removed from the most frequently inundated floodplains only using a top-down directional approach (Bell 1997, Coffman et al. 2004). Removal of *A. donax* on higher terraces may not necessarily need to proceed in this downstream manner because reinfestation is much less likely. However, one study suggests that layering (i.e., rooting from nodes) is an important *A. donax* invasion mechanism in streams of southern California and, thus, an inside-out approach is required (Boland 2006). I suggest that both approaches are necessary depending on the flooding dynamics of the stream, infestation size and distribution, and

fluvial geomorphic location of the infestation. Because removal of large areas of *A. donax* is very costly, the ideal time to remove it from a heavily infested watershed may be immediately after a very large flood event (i.e., 100-year flood) that removes most of the vegetation, resulting in much easier access to much reduced quantities of *A. donax* biomass.

4. Revegetation after removal may not help resist or suppress *A. donax*. The management literature recommends revegetation of riparian systems with native species after removal of invasive species, including *A. donax*, to resist further invasion (Sonoma Ecology Center 1999, County of Ventura Planning Division 2006). Resistance to invasion may be achieved if natives obtain a much higher biomass than *A. donax* and suppress it when competing for resources. However, results of my two-year competition field experiment suggest that this is rarely the case; *A. donax* had a significantly higher biomass than almost all native plant species under all resource levels and only minimal suppression by native plants was documented under a few conditions tested (see Chapter 2). Results of my competition field experiment indicate that *B. salicifolia* may increase in biomass when grown with *A. donax*, although it never obtained a significantly higher biomass than *A. donax* under any condition. Longer studies are needed to validate these findings, although it appears that revegetation will not resist reinvasion without implementation of appropriate *A. donax* maintenance. However, active revegetation after *A. donax* removal should help initiate restoration of riparian ecosystem functioning if *A. donax* removal is conducted in the appropriate location and diligent maintenance is implemented.

FIGURES

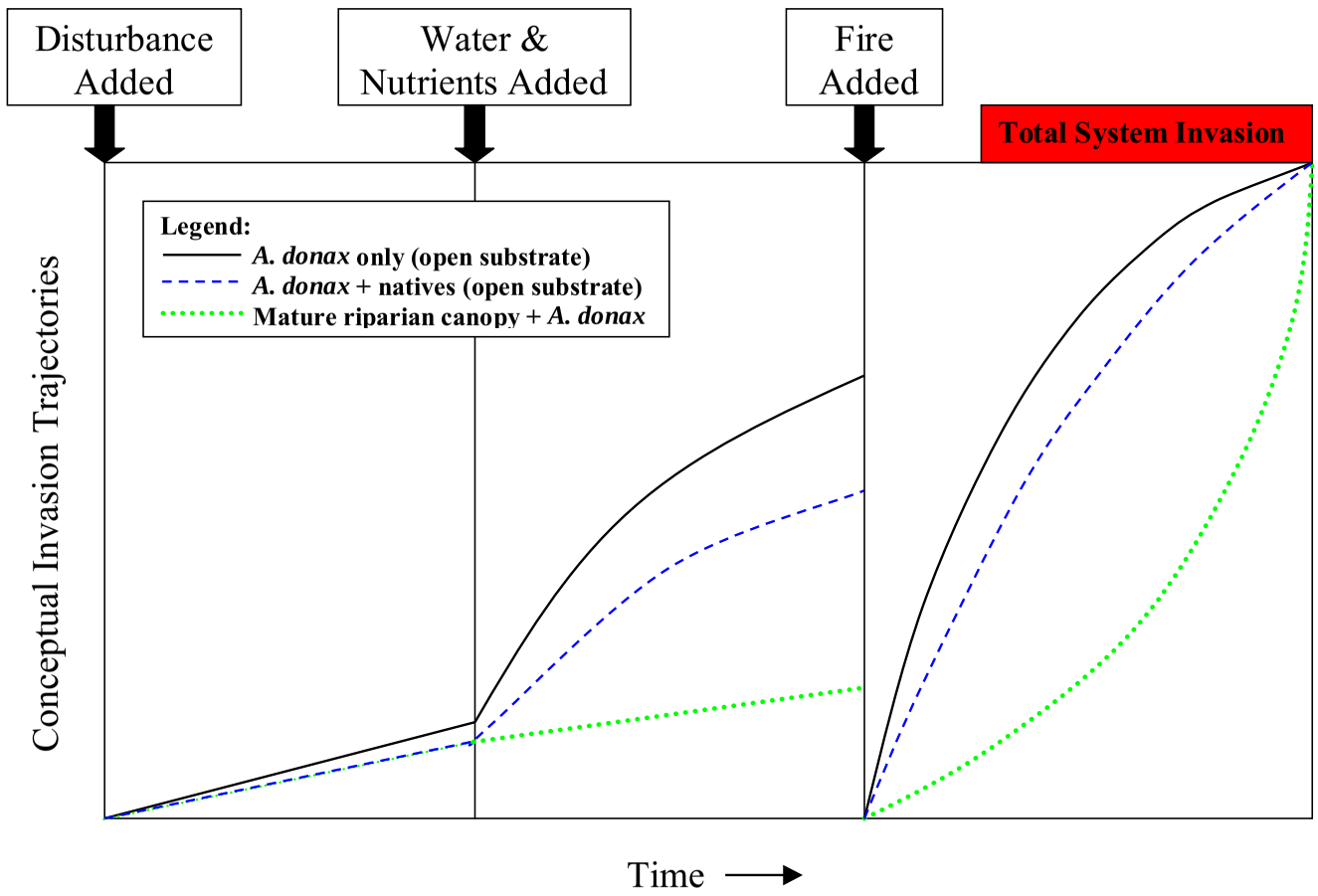

Figure 24. Conceptual *Arundo donax* invasion trajectories over time. Trajectories represent three invasion trends beginning after a large disturbance, including invasion where *A. donax* grows in monotypic stands, where it begins to grow at the same time as native riparian plants, and where it grows underneath a mature riparian forest canopy. The first panel shows invasion under low resource levels, conditions found throughout natural riparian ecosystems in California. When water and nutrients are added to riparian ecosystems, trajectories increase (panel 2). Panel 3 illustrates the steep invasion trajectories that occur when fire is introduced to riparian ecosystems where *A. donax* is already present.

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State Coastal Conservancy (January 2005)

Santa Clara River

Riparian Revegetation and Monitoring Handbook

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July 2011

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Cover Photograph:

Oblique air photo looking east upstream along the Santa Clara River after a large flood event in January 2005 showing riparian vegetation along the floodplain. Photo taken for the California State Coastal Conservancy.

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EXECUTIVE SUMMARY

The Santa Clara River Riparian Revegetation and Monitoring handbook was developed as a guide to provide science-based strategies for organizations involved with riparian ecosystem restoration on the river. The primary goals of this handbook was to: (1) provide guidelines which will assist the Trustee Council, agencies, and non-governmental organizations (NGOs) in selecting restoration sites, monitoring invasive plant removal, evaluating the success of riparian revegetation projects after *Arundo donax* (*Arundo*) removal along the Santa Clara River, and integrating such efforts into an appropriate adaptive management program; and (2) create conceptual strategies for riparian restoration monitoring based on ecological data.

We attempted to apply results of our research on riparian plant species survivorship and growth at the UCLA Riparian Field Experiment to develop various aspects of this handbook. In particular, we developed four strategies for prioritization of *Arundo* removal and revegetation after removal (Chapter 4) and discuss development of success criteria using data collected on heights of four native riparian plant species sampled at the end of the first and second growing seasons after planted (Chapter 3). We recommend that other success criteria and trajectories for associated performance metrics be refined by studying an array of reference sites, establishing a field experiment, and/or sampling riparian plant species on the Santa Clara River for at least ten years.

It is our hope that this handbook will be a starting point for a unified approach to scientifically driven riparian restoration on the Santa Clara River, led by the newly developing UC Research Station and Conservation Center. One of the main objectives of the UC Research Station and Conservation Center, which is being funded by the Trustee Council, is to provide assistance in planning and monitoring restoration projects. A Strategic Plan for *Arundo* control and restoration is currently under development for the Santa Clara River (Stillwater Science and UCSB in preparation). Information from this handbook is being used in developing the Strategic Plan.

The scope of this handbook entails conceptual prioritization of *Arundo* removal strategies and monitoring of revegetation after *Arundo* removal. Several other restoration actions have been proposed for the river, although the activities we concentrated on should generally be implemented first and may possibly be the largest components of restoration of this braided sand-bed river. We present a conceptual monitoring program, and emphasize the need for development of a more detailed monitoring plan for the entire watershed.

We acknowledge that information in this handbook is not complete and advise that no portion of the conceptual monitoring program presented should be used as a final detailed monitoring plan. The proposed success criteria were not all developed based on scientific data, but should eventually be informed and refined using local or regional scientific data. If you would like to use portions of the conceptual monitoring plan for your restoration efforts, please contact the authors or the UC Research Station and Conservation Center staff for advice on developing a detailed monitoring plan suitable for your project.

Chapter 1 introduces the roles and projects of the main organizations conducting restoration on the Santa Clara River, including the Trustee Council, State Coastal Conservancy, The Nature Conservancy, and Friends of the Santa Clara River. The goals and objectives of this handbook development are stated at the end of the first Chapter. In Chapter 2, we present opportunities and constraints for riparian ecosystem restoration along the Santa Clara River, focusing on non-native invasive species removal and both active and passive revegetation after removal.

Results of our UCLA Riparian Field Experiment are presented in Chapter 3, followed by a discussion of how our results can inform success criteria targets (i.e., California Department of Fish and Game's performance criteria for riparian tree and shrub height after 3 and 5 years). Our research on riparian plant species survivorship shows that native trees and shrubs need not be artificially irrigated if planted during the appropriate time of year, under high-moderate soil moisture conditions, and using the appropriate plant installation specifications. Out of the 1,152 individuals planted in November of 2002, total riparian plant cutting survivorship in spring 2003 was 97.7%. Total plant survivorship at the end of 2003 and 2004 was 98.4% and 97.8%, respectively. Also, our first two years of growth data indicate that average height of all four riparian tree and shrub species varies significantly under varying soil moisture and light treatments. Based on these results, we suggest that success and performance criteria must be multifactorial in nature. Targets for success criteria and metric trajectories must be developed for the Santa Clara River based on long-term ecological data from this experiment and sampling at a suite of reference sites throughout the river.

Chapter 4 outlines conceptual timing and duration of each task involved in invasive plant removal and revegetation actions. Strategies and a conceptual framework for monitoring these restoration actions are presented in Chapter 5. Finally, Chapter 6 lists the next steps in planning and implementation of these restoration actions. Three appendices include: photos of the UCLA Riparian Field Experiment, Long-term photo monitoring points established around HRNA (comparing 2003 pre-restoration to 2008 five years during restoration), and an Annotated Bibliography for the Santa Clara River we developed (August 11, 2009).

CHAPTER 1
INTRODUCTION

This Santa Clara River Riparian Revegetation and Monitoring Handbook is an attempt to link research on ecology of invasive species, mainly *Arundo*, and native riparian species revegetation with management activities to help guide future riparian restoration efforts along the Santa Clara River. We met with the Trustee Council several times during the course of conducting this research and writing this handbook to more carefully guide its development and align it with the goals of the Trustee Council. Most data in the handbook were collected (Chapter 3) at the UCLA Riparian Field Experiment located immediately adjacent to Hedrick Ranch Nature Area (HRNA) on the Valley View Ranch (**Error! Reference source not found.**).

The following is a brief background of riparian restoration planning, studies and implementation along the Santa Clara River supported by the Trustee Council and conducted by other major stakeholders to date.

History of the Trustee Council

In 1994, a pipeline ruptured during the Northridge earthquake spilling 190,000 gallons of oil into the Santa Clara River, one of the last free-flowing rivers in Southern California. The 187 km long Santa Clara River and its tributaries drain a 4,185 km^2 watershed, the second largest coastal watershed in southern California. To mitigate for impacts to the river ecosystem, a settlement was reached between ARCO and regulatory authorities in 1997.

The Santa Clara River Trustee Council (Trustee Council) was formed to manage and distribute funds from the settlement of claims for natural resource damages resulting from an ARCO pipeline oil spill into the Santa Clara River which occurred in January 1994. The overall goal of the Trustee Council is to restore riparian habitat along the Santa Clara River for use by migratory bird species, provide shade and passage for native fish, control erosion, encourage recovery of native plant communities following removal of invasive plants, and improve habitat for other riparian dependent wildlife species. Wildlife species affected by the ARCO oil spill, such as the least Bell's vireo and the unarmoured three-spine stickleback, are the focus of the riparian habitat restoration. The Trustee Council consists of representatives from the U.S. Fish and Wildlife Service USFWS and the California Department of Fish and Game - Office of Spill Prevention and Response (CDFG). Representatives from the USFWS currently include: Denise Steurer (trustee) and Jenny Marek (alternate) Representatives from CDFG are Dan Blankenship (trustee) and Ken Wilson (alternate).

The Santa Clara River Trustee Council developed the Restoration Plan and Environmental Assessment (RPEA) for the Santa Clara River ARCO Oil Spill which was finalized in October 2002 (The Santa Clara River Trustee Council 2002). This document provided a framework to examine and present restoration alternatives to restore, rehabilitate and replace or acquire the equivalent of the natural resources impacted by the ARCO oil spill. The Trustee Council has the responsibility and legal authority to plan, develop, and implement restoration projects within the entire 1,600 square-mile Santa Clara River watershed. Restoration projects that have been funded by the spill settlement include land acquisition, invasive plant control, habitat enhancement, education, and watershed monitoring and research projects. Development of this Santa Clara River Riparian Revegetation and Monitoring Handbook was funded by the ARCO settlement.

In 2000, the California State Coastal Conservancy proposed the establishment of the Santa Clara River Parkway after discussions with river corridor landowners and local governments. As currently envisioned, the Parkway project will result in the acquisition and restoration of a 40 mile-long (6,000-acre) corridor from the mouth of the Santa Clara River to the Los Angeles County Boundary. Governor Gray Davis provided initial funding of $9.2 million, as appropriated by the legislature, to the Coastal Conservancy for land acquisition and planning. Land acquisition is being conducted on a willing seller basis, with the initial focus of the project on the lower river.

Early in restoration planning, the Trustee Council was approached by California State Coastal Conservancy (Coastal Conservancy) to gain funding for a planned Santa Clara River Parkway project. At the same time, the Nature Conservancy (TNC) selected the Santa Clara River as one of its priorities for land protection and conservation. A partnership was formed between the Trustee Council, the Coastal Conservancy, and TNC to restore wetland and riparian ecosystem processes and functions along the Santa Clara River, and protect these ecosystems for future generations. The Trustee Council has funded acquisition of several properties along the Parkway, totalling more than $4 million. The acquisition of land was an important step in protecting and restoring the natural riparian corridor along the Santa Clara River and in providing habitat for a multitude of wildlife and aquatic species, including a number of Threatened/ Endangered species and species of special concern. In particular, healthy riparian ecosystems along the Santa Clara River will provide vital habitat for two federally endangered species that were impacted by the oil spill, the unarmoured three-spine stickleback and Least Bell's Vireo.

The Trustee Council has funded several other grants to TNC and Coastal Conservancy including a steelhead assessment study, the development of an upper and

lower watershed habitat protection plan, a vegetation classification and mapping study of the river, and a series of Watershed U science workshops (UC Cooperative Extension) to promote stakeholder understanding of the Santa Clara River Watershed. The Coastal Conservancy sponsored a science workshop on February 16, 2007 and developed a Santa Clara River Parkway website (http://www.santaclarariverparkway.org/) that facilitates the sharing of information among various stakeholders and the public.

The Trustee Council, Coastal Conservancy and TNC have been supporting the establishment of a University of California Reserve along the Santa Clara River that will serve as the headquarters of research and study, along with providing educational opportunities and support for on-the-ground habitat restoration. Also, the Trustee Council is involved with Coastal Conservancy, TNC and other stakeholders in the development of an upper Santa Clara River watershed land trust, in order for a local conservancy to take on the responsibilities and stewardship of lands acquired for restoration and long-term protection. Finally, there will be future acquisitions using Council funds that remain from the existing grant agreement with TNC.

The Trustee Council has funded many studies and pilot projects related to riparian habitat restoration on the Santa Clara River since their EA and Management Plan was finalized in 2004. Studies and project focused on riparian habitat improvement and restoration, educational efforts that focus on riparian habitat restoration, planning and watershed evaluation and assessment.

Organizations Conducting Riparian Restoration

Several organizations other than the Coastal Conservancy and TNC have been working on planning, permitting, and implementing of invasive plant removal and riparian habitat restoration projects throughout the Santa Clara River watershed. These organizations include Friends of the Santa Clara River, Natural Resources Conservation Service (NRCS), Ventura County Resource Conservation District, County of Ventura - Planning Department, Caltrans, Los Angeles and Ventura County Agricultural Commissioners, Ventura County Weed Management Area, City of Santa Clarita, UC Davis Cooperation Extension, and others.

Santa Clara River Parkway

As envisioned by the Coastal Conservancy, the Santa Clara River Parkway Project will consist of a continuous protected corridor of coastal river, riparian habitat and estuary along 40 miles of the River from the Pacific Ocean inland to the Los Angeles County line (http://www.santaclarariverparkway.org/parkwayplanning). This Santa Clara River Parkway will serve as a park and wildlife preserve; allow for ecosystem

restoration along the River; provide for better flood management along the River; promote public enjoyment and environmental education; and allow for restoration of natural river processes which will in turn help prevent losses of habitat, farmland and public facilities due to flooding. The Coastal Conservancy has partnered with The Nature Conservancy's LA-Ventura Project to acquire, manage, and restore Parkway lands. Currently, a number of parcels of river corridor within the Parkway have already been acquired, totalling 3,060 acres over 14.7 miles along the river. Future management of Parkway lands is expected to be carried out under a joint powers agreement between the Coastal Conservancy, Ventura County and the cities of Oxnard and Ventura.

Friends of the Santa Clara River

In September 2001, the Coastal Conservancy purchased a 223.11-acre property, consisting of two parcels once part of the Valley View Ranch (**Error! Reference source ot found.** and **Error! Reference source not found.**). This property was one of the first properties acquired by the Coastal Conservancy as part of their Santa Clara River Parkway project. On October 9, 2001, the Coastal Conservancy granted Friends of the Santa Clara River (FSCR) this property and they officially named it the Hedrick Ranch Nature Area (HRNA). As part of the grant agreement with the Coastal Conservancy, FSCR developed a management plan for the HRNA property (URS Corporation 2003). The HRNA property is located along the Santa Clara River between Santa Paula and Fillmore, in Ventura County, California. The property contains both wetlands and riparian habitat along the southern side of the Santa Clara River that the FSCR is managing and restoring over time. As of September 2010, the riparian and wetland ecosystems on the HRNA property have been fully restored by both passive and active habitat restoration efforts over the past ten years. Lessons learned from habitat restoration actions on HRAN are discussed in Chapter 3 of this handbook.

UCLA Riparian Field Experiment

The UCLA riparian field experiment is located on a parcel of land adjacent to HRNA formerly owned by Mr. Sanger Hedrick (Valley View Ranch) and now owned by Underwood Family Farms (http://www.underwoodfamilyfarms.com/) (**Error! eference source not found.** and **Error! Reference source not found.**). This 0.5-hectare field experiment was established in October 2002 in a riparian ecosystem of a floodplain terrace along the south side of the Santa Clara River formerly infested with a monoculture of *Arundo*. The main research goal was to investigate survivorship and growth of three native riparian plant species in competition with the invasive non-native *Arundo* grown under various soil moisture, nutrient and light treatments and levels. We

planted 288 groups of 4 plants in a square configuration consisting of three competition groupings (four-species, two-species and one-species groupings) in the study to compare interspecific versus intraspecific competitive interactions between *Arundo*, *S. laevigata*, *P. balsamifera* ssp*. trichocarpa*, and *B. salicifolia.* The field experiment was conducted through two growing seasons, from December 2002 to December 2004. Results of this study related to management/control of *Arundo* and revegetation of removal areas with native riparian plants is presented in Chapter 3 of this handbook.

Handbook Goals and Objectives

The primary goals of this Riparian Revegetation and Monitoring Handbook are to:

1. Provide guidelines which will assist the Trustee Council, agencies, and non-governmental organizations (NGOs) in selecting restoration sites, monitoring invasive plant removal, evaluating the success of riparian revegetation projects after *Arundo* removal along the Santa Clara River, and integrating such efforts into an appropriate adaptive management program; and
2. Create conceptual strategies for riparian restoration monitoring based on ecological data.

Objectives of this Handbook are:

1. Present results of the UCLA riparian field experiment related to revegetation and monitoring
2. Summarize the most effective techniques and timing for invasive plant removal and riparian revegetation
3. Review and comment upon the DFG's standardized protocols for monitoring the success of riparian revegetation projects along the Santa Clara River, consistent with Southern CA efforts (SCCWRP, http://www.sccwrp.org)
4. Integrate riparian ecosystem monitoring protocols, techniques, and methods used statewide that are relevant to southern California into development of this handbook

CHAPTER 2
RIPARIAN ECOSYSTEM RESTORATION OPPORTUNITIES AND CONSTRAINTS ON THE SANTA CLARA RIVER

Introduction

The Santa Clara River is a large, ecologically diverse, and regionally important river system for many plant and animal species due to a combination of the regions' characteristic Mediterranean-type climate and its dynamic hydrology and geomorphology. The 187km long Santa Clara River and its tributaries drain a 4,185 km^2 watershed, the second largest coastal watershed in southern California. The River supports a diversity of riparian vegetation types from its arid headwaters in Los Angeles County to the estuary where the river joins the Pacific Ocean just south of Ventura, CA. Many natural vegetation types have been identified within the 500-year floodplain of the Santa Clara River including: herbaceous, mixed riparian forest, mixed riparian scrub, freshwater wetland, desert riparian scrub, sand dune/beach, coastal sage scrub, and tidal marsh (Ventura County Resource Conservation District 2006, Stillwater Sciences and URS Corporation 2007). Although much of the vegetation within the 500-year floodplain of the Santa Clara River is dominated by native plants, five non-native invasive plant species were found to be widespread along the river and threaten the quality and extent of native riparian vegetation (Table 1)(Stillwater Sciences and URS Corporation 2007). Many riparian ecosystem restoration opportunities have been identified along the Santa Clara River as it is one of the largest and least regulated and human altered river systems in southern California (The Nature Conservancy 2006, Ventura County Resource Conservation District 2006, Coffman 2007, Stillwater Sciences 2008). Chapter 2 of this handbook describes the opportunities and constraints associated with non-native invasive plant removal and revegetation of these removal areas.

Riparian Vegetation Extent, Dynamics, and Condition

Vegetation types, extent and distribution along the Santa Clara River are shaped by their position in the landscape and physical habitat conditions associated with their location. Elevation relative to flooding and time since the last flood were two strong factors found to contribute to distribution of vegetation types located along the Santa Clara River (Stillwater Sciences 2008). Also, wildfire occurrence and intensity were found to affect the age, distribution, and quantity of native riparian vegetation and non-

native *Arundo* (Coffman 2007, Coffman et al. 2010). Riparian vegetation and wildlife habitat types located along the Santa Clara River are described in detail in several recent reports (Stillwater Sciences and URS Corporation 2007, Stillwater Sciences 2008, Orr et al. 2011). In 2005, 7,214 acres (2,919 hectares) of riparian vegetation were mapped along the 500-year floodplain of the Lower Santa Clara River within Ventura County. The most extensive vegetation types found on the river included: herbaceous floodplain (27%), mixed riparian forest (23%), mixed riparian scrub (15%), and riparian vegetation dominated by non-native, invasive *Arundo* (12%). Only four riparian vegetation types found on the river were dominated by non-native, invasive plants: herbaceous floodplain (27%), *Arundo donax* (12%), mixed non-native trees (2%), and disturbed (1%)(percentages indicate relative extent of each type found along the river).

Opportunities for Riparian Ecosystem Restoration

Six restoration strategies were recommended for riparian ecosystem restoration along the Santa Clara River in 2008, including: (1) parcel acquisition from willing sellers of threatened and/or high value habitat that is currently prone to regular flooding; (2) levee setback and removal, floodplain recontouring, and floodplain infrastructure modification; (3) non-native invasive species removal; (4) active and passive revegetation; (5) creation of a network of water quality treatment wetlands, and (6) aquatic habitat enhancements (Stillwater Sciences 2008). This handbook focuses on two of the six restoration strategies recommended for riparian ecosystems of the Santa Clara River, non-native invasive species removal and both active and passive revegetation. These two restoration activities are high priority strategies due to the urgency of several invasive plant species threats to the riparian ecosystem functioning, condition, and associated wildlife use; relatively low level of effort and cost involved; and resulting cost compared to ecological benefit associated with these activities.

Removal of non-native invasive plant species would greatly improve riparian vegetation quality for native plant recolonization, wildlife habitat, and some riparian dependent special status species (i.e. Least Bell's Vireo). Currently, *Arundo* is by far the most abundant and invasive of the non-native plant species distributed throughout the 500-year floodplain of the Santa Clara River. It may be found as a component within almost all vegetation types as well as growing by itself in monoculture. Although widely distributed within the river, *Arundo* is commonly found at low to moderate densities throughout the river (1-50% cover)(Stillwater Sciences and URS Corporation 2007, Orr et al. 2011). Several other common but less widespread invasive, non-native

plants were found to be associated with riparian vegetation in the 500-year floodplain of the Santa Clara River including: tamarisk (*Tamarix ramosissima*), iceplant (*Carpobrotus edulis*, *C. chilensis* and *Mesembryanthemum crystallinum*), eucalyptus (*Eucalyptus* spp.), Peruvian peppertree (*Schinus molle*), castor bean (*Ricinus communis*), myoporum (*Myoporum laetum*), shortpod mustard (*Hirschfeldia incana*), tocolote (*Centaurea melitensis*), white sweetclover (*Melilotus alba*), and non-native bromes (*Bromus* spp.) (Table 1) (Stillwater Sciences 2008). Active revegetation after removal of non-native plants will accelerate recovery of native riparian vegetation in targeted areas where invasive non-native plants are abundant and where native seed sources or propagules are distant.

Prioritization of Invasive and Non-native Plant Species Removal

This handbook focuses on selection of target invasive and non-native plant species for prioritized removal, control, and revegetation. The California Invasive Pest Council's (CalIPC) Invasive Plant Inventory rates non-native invasive plants that threaten the State's wildlands (http://www.cal-ipc.org/ip/inventory/weedlist.php?region=SW). Categories of high, moderate and limited ratings are based on an assessment of the ecological impacts of each species on wildlands. The Inventory represents the best available knowledge of invasive plant experts in the state of California. We categorized target invasive non-native plant species in this handbook into: (1) priority removal and (2) watch list.

The priority removal list we developed consists of five species that have both 'high' ratings on the CalIPC Invasive Plant Inventory and are known to occur throughout the Santa Clara River watershed. The most widespread of these species, *Arundo* is emphasized in this handbook because of its serious known impacts to riparian ecosystems (see section below on The *Arundo* Problem)(Giessow et al. 2011). *Arundo* removal along the Santa Clara River is thought to be the highest priority restoration action due to its widespread distribution, known impacts, and relatively minimal permit requirements for removal (if removal is non-mechanized). Also, the large effect of *Arundo* removal and short amount of time required for ecosystem recovery relative to other restoration actions (i.e., levee setbacks) is a strong incentive for prioritizing this action. Removal and revegetation strategies for these five species are discussed briefly in this handbook, including: *Arundo* (*Arundo donax)* perennial pepperweed (*Lepidium latifolium*), creeping water primrose (*Ludwigia peploides* ssp. *montevidensis*), smallflower tamarisk (*Tamarix parviflora*), and salt cedar (*Tamarix ramosissima*).

Other non-native invasive species with CalIPC high ratings were found in more limited distribution within the Santa Clara River 500-year floodplain (Table 1). Thirteen other high rated non-native invasive species have not been found along the Santa Clara River but have the potential to invade riparian and/or aquatic vegetation on the river due to their known occurrence in other semi-arid systems of California. These species are presented on the Watch List (Table 1)(Vaghti and Greco 2007). We recommend that their presence/distribution on the River be surveyed every 5 years (Table 1). Occurrences and distribution of eighteen non-native invasive species with moderate and limited ratings were included on the Watch List and should be surveyed every 5 years as well. Identification and immediate eradication of all species on the Watch List is critical to riparian vegetation quality and river ecosystem health.

The *Arundo* Problem

Infestations of *Arundo* have created serious physical and biological impacts along rivers in southern California. Where it grows extensively along floodplains, *Arundo* acts as a transformer species; it causes physical obstructions to natural water flow, thereby increasing the risk of flooding to adjacent lands. During large floods *Arundo* increases stream roughness, creates debris dams at bridge crossings, and causes bank erosion and instability (DiTomaso 1998). As the aboveground biomass dries in the hot, dry summer months that characterize Mediterranean-type climates, *Arundo* creates an unnatural fire hazard where moisture-rich riparian corridors used to form natural barriers to fire (Scott 1994, Rundel and Gustafson 2005, Giessow et al. 2011). Water loss due to high evapotranspiration (ET) of *A. donax* reduces already scarce water resources in Mediterranean-type climate regions. Based on transpiration rates of rice (another C3 species thought to have similar transpiration rates), Iverson (1994) estimated that *Arundo* uses three times more water than native riparian species. Studies using a variety of methods indicate that ET of *Arundo* (1.2–7.5 m/year) may be much higher than that of native riparian vegetation such as *Salix* spp., *Populus* spp. (1.0–3.3 m/year) and mixed riparian communities of arid and Mediterranean-type climates (0.11–1.6 m/year) (Zimmerman 1999, Hendrickson and McGaugh 2005, Shafroth et al. 2005, Abichandani 2007). Abichandani (2007) showed that *Arundo* infestations may transpire 6 to 110 times more (up to 18,206 kg m^{-2} $year^{-1}$) than native vegetation.

Arundo has very little known habitat value for wildlife in California (Bell 1997, Kisner 2004) compared to the dominant native vegetation (Bell 1994, Herrera and Dudley 2003). Its stems and leaves contain an array of inorganic noxious chemicals (Jackson and Nunez 1964) that reduce herbivory by most native insects and grazers.

Due to its dense clonal growth form, it physically restricts indigenous wildlife passage, yet many animals depend on the riparian corridor and river floodplain for foraging, nesting, and cover (Kisner 2004). Like other invasive plants, *Arundo* appears to have negative impacts on indigenous plant and animal biodiversity through the loss of suitable habitat and competition with indigenous species (Czech and Krausman 1997). In addition, *Arundo* threatens river ecosystem sustainability via its impacts on natural river processes, such as lowering of the groundwater table, decreased surface water levels in streams, creating the potential for unnatural and extremely hot fires, and loss of plant and animal biodiversity.

Passive and Active Revegetation of Removal Areas

A combination of passive and active revegetation strategies should be used when restoring the native riparian vegetation after invasive plant removal along the Santa Clara River (The Federal Interagency Stream Restoration Working Group 1998, Coffman 2007). Passive revegetation or process-based revegetation focuses on restoring rates and magnitudes of biological processes that recreate sustainable habitat quality, productivity, and a diverse assemblage of native species (Stillwater Sciences 2008). Passive riparian revegetation occurs naturally during flooding along streams and rivers, but is not predictable and typically not frequent except when adjacent to the low flow channels. Levee removal and setbacks are proposed to increase the area of potential passive revegetation on the lower Santa Clara River; their removal will increasing the available floodplain area and facilitate inundation of floodplains by slow-moving floodwaters during high flow events. Physical processes and constraints may limit full recovery of natural riparian vegetation and must be considered carefully when relying solely on passive revegetation.

Active revegetation entails planting species by hand as either containerized plants grown in a nursery, direct installation of pole cuttings, or seeding/hydroseeding. In some areas, active revegetation may involve installing and maintaining an irrigation system to ensure adequate soil moisture in areas that do not exhibit a high groundwater table throughout the growing season. Hydrology, substrate, human activities, reference conditions within a watershed, and local and seed source location and composition (upstream native and non-native plant species) must be considered when developing revegetation plans for any particular site.

In general, using passive revegetation is most appropriate when (Katagi et al. 2002 , Team Arundo del Norte 2004):

- A diverse composition of native riparian plants are well established either on-site or in close upstream proximity of the site that provide seeds and/or vegetative propagules,
- Very small areas of invasive, non-native plants are removed,
- The site contains low density of any other non-native plant species population onsite or upstream of the site,
- The site contains little disturbed, unvegetated, open ground,
- The soils are stable and at low risk of erosion, and/or
- The site floods at least once a year, allowing for nearby native plant seeds or vegetative propagules to reach the site.

The passive revegetation method requires the least effort, cost, and expertise to restore native riparian vegetation. We recommend relying primarily on passive revegetation in the channel bed (flood reset zone) of the Santa Clara River. Wind, rain, and high flows carry seeds, plants, and sediment downstream, where they will settle on the floodplains and grow. This process is periodic and may take several to many years for native plant species to become successfully established. Passive revegetation requires a lower level of soil disturbance after invasive plant removal, resulting in potentially lower soil compaction and less erosion. In addition, this revegetation method ensures the introduction of local genetic plant material. However, if non-native invasive plants dominate adjacent areas, the removal site is at risk of being repopulated by such plants if not revegetated actively with native plant species.

Using active revegetation methods is more appropriate than passive revegetation when:

- The site is located downstream from or near a population of the non-native invasive plant species that was removed or in close proximity to any other non-native invasive species population that may rapidly invade this site (Table 1). Immediate revegetation with native plant species may be necessary to prevent invasion of the removal site.
- The soil or stream bank is unstable and at high risk of erosion. Immediate revegetation will help to reduce the threat of erosion by providing bioengineered bank stabilization.
- A landowner strongly desires a privacy screen or is concerned about erosion of their property following invasive plant removal, and/or

- The site is being restored to replace habitat removed by human activities and is required by special status wildlife species known to have occurred in the area and when timely restoration of vegetation structure is important for replacement habitat.
- Many times pioneer species (initial volunteers) in passive revegetation are restricted to common species such as willows and/or mulefat. Active revegetation would enhance species diversity and vegetation structure of a site and should be used where appropriate.

Restoration of native riparian vegetation types within invasive species removal areas on the higher terraces not frequently flooded will often require active revegetation of diverse array of desirable native species. In general, active revegetation should not be initiated until most target non-native invasive plant removal is under control, since it may be difficult to avoid harming desirable plants during follow-up herbicide treatments. However, it can often take more than one season to adequately remove a well-established invasive plant population. When a removal site is located in a vulnerable area such as a steep bank, passive and/or active revegetation will likely not provide adequate soil or bank stabilization. If this is the case, bioengineered bank stabilization efforts (consult with a professional engineer or the NRCS) should be incorporated into the revegetation plan. A combination of erosion control fabric, willow wattles, deeply planted live cuttings, large logs, and engineered (man-made) stabilizing structures may be needed to adequately prevent erosion and bank failure.

Hedrick Ranch Nature Area (HRNA) – Example of both Passive and Active Revegetation

The Hedrick Ranch Nature Area provides two of the best examples of successful passive revegetation, as well as several examples of active revegetation conducted after *Arundo* removal in the Santa Clara River Watershed. The wildfire on October 25-26, 2003 burned a small portion of the grassland area in the southwest corner of the HRNA property and was stopped by a bulldozer firebreak (see Appendix A). Some of the dominant native riparian plant species that colonized passively after the wildfire included: yerba mansa (*Anemopsis californica*), creeping wild rye (*Leymus triticoides*), and Western ragweed (*Ambrosia psilostachya*). The second example of passive revegetation occurred during the extensive flooding in January and February 2005. The northern pasture (area E) of HRNA was completely transformed within a year from non-native grasslands infested with thistles and annual non-native Mediterranean grasses to mixed willow forest and scrub (mulefat alliance) vegetation (Figure 3).

Dominant plants that colonized the restored mixed willow forest included willow species (*Salix* spp.) in the tree and shrub layer and mugwort (*Artemisia douglasiana*) and stinging nettle (*Urtica dioica*) in the herbaceous layer.

The Trustee Council and State Water Resource Control Board funded several large active restoration activities described in the HRNA Management Plan. The Friends of the Santa Clara River removed many non-native invasive plants and began to actively revegetated the eastern side of the northern pasture of the HRNA (area E) with a diversity of native riparian plants prior the winter floods of 2004-2005. These initial efforts entailed broad-scale invasive non-native plant removal, including mowing and herbicide application and planting of a diversity of native riparian plants. However, not all areas needed to be actively restored, because of passive recovery of native riparian plant communities after winter 2004-2005 flooding. Work crews opportunistically removed *Arundo* by hand immediately after 2005 flooding on the northern portion of HRNA in the active floodway (flood reset zone) scoured by the floods (see Appendix A). Removing *Arundo* reduced the likelihood that this invasive plant could successfully reinvade the active floodplain on HRNA. In 2008, follow-up maintenance was performed by several contractors to remove all *Arundo* from this area using the cut stump method. Due to high soil moisture in the removal area, treatments were applied from October-November when *Arundo* culms were senescing.

After the success of the passive revegetation of the northern pasture (area E), only minimal supplemental native plantings to enhance species diversity and structure and weed control continued on these sites to increase diversity and enhance wildlife use of these riparian ecosystems. Riparian tree and shrub species were planted using 3 foot (3/4 inch – 1inch in diameter) pole cuttings. In harder soil, a battery powered drill with an auger bit was used to drill holes 2 feet deep to plant pole cuttings.

An on-site native plant nursery (solar powered) was established on HRNA to grow riparian plants from seeds and cuttings collected around HRNA. Plants grown at this nursery were installed throughout HRNA, primarily on the northern and southern pastures (areas E and F) (Figure 3 and Appendix A). Two types of planting effort occurred: intense work where non-natives originally covered 100% of the area, and invasive species control in areas dominated by natives. Active weed removal and revegetation was conducted on the south side of area F where non-native tall fescue (*Festuca arundinacea*) dominated the area. Less than five years after restoration activities, an herbaceous wetland plant community was established including:

California blackberry (*Rubus ursinus*), salt grass (*Disticlus spicata*), creeping wild rye (*Leymus triticoides*), and spike rush (*Eleocharis machrostachya*).

On-going removal of non-native plants continues to date, using both restoration professionals and volunteers. However, active revegetation of native riparian plant communities has stopped in 2011 now that riparian vegetation appears to have been successfully reestablished (Sanger Hedrick, Jackie Worden, and David Hubbard, pers. comm.).

Wildlife surveys conducted periodically on HRNA by specialists and volunteers for over ten years during restoration activities have resulted in increasing trends in abundance and diversity of riparian bird species and special status bird species (FSCR in preparation – funded by the Trustee Council). Bird surveys were completed in 2010 to evaluate the quality and extent of riparian revegetation efforts on HRNA (Western Foundation of Vertebrate Zoology 2010). Seventy bird species were observed on the HRNA between 25 April, 25 and June 24, 2010. The Western Foundation of Vertebrate Zoology (WFVF) conducted a 10 point count around the HRNA property during the breeding season and found 20 pairs of the Federally endangered Least Bell's Vireo (*Vireo bellii pusillus*). A focused survey conducted during the 2010 breeding season found 70 pairs of Least Bell's Vireo on HRNA and surrounding areas (Sandy Hedrick, pers. comm.). Bird, butterfly and other wildlife were surveyed in 2011 by the Western Foundation of Vertebrate Zoology and others. Preliminary results of 2011 surveys report that on two occasions during the 2011 breading season, the Federally Endangered Southwestern Willow Flycatchers (*Empidonax traillii extimus*) were observed. Occurrences during the breading season are a good indication that these species are nesting in or near HRNA. The first occurrence on HRNA of a Yellow-billed Cuckoo (*Coccyzus americanus*), a Federal Candidate Species, was observed early July 2011 by the Western Foundation of Vertebrate Zoology.

Trends in bird species composition and special status bird species observations indicate over time restoration activities have encouraged a healthy mix of riparian and wetland habitats on HRNA. Bird species composition, diversity, and densities are dynamic and will change with vegetation succession due to varying plant species and structural composition. Restoration activities have created a mix of vegetation types with differing age classes depending on location relative to the low-flow channel and channel bed. The restoration of natural, dynamic physical and biological processes should provide more opportunities for birds and other wildlife to benefit, if not directly, at least indirectly from restoration projects.

Other factors in combination with habitat restoration may contribute to recovery and expansion of some bird species. For example, the main reason for recovery of Least Bell's Vireo (*Vireo bellii pusillus*) on Santa Clara River (among several rivers) is thought to be the continual removal of the brood parasitic Brown-headed Cowbirds (*Molothrus ater*) (Jim Greaves, pers. comm.). Actions of Brown-headed Cowbirds (tossing eggs and/or chicks of hosts, and laying their own eggs in host nests) have contributed over many decades to low productivity among dozens of riparian and other bird species, resulting in significant population declines. Since instituting control of these bird species in 1990, seems to have reversed some of those declines. This reversal due to cowbird control, combined with restoration of riparian habitats conducive to sensitive and common species, has led to incremental increases of varying amounts for a couple dozen cowbird host species. Managers are gradually reducing period of trapping each year and carefully monitoring populations (i.e., this year only 2 months of trapping on HRNA). Only time will tell if habitat restoration alone (i.e., without active management of Brown-headed Cowbirds) can maintain sustainable populations of special status bird species like the Least Bell's Vireo.

Planting techniques for herbaceous plants and grasses installed around HRNA included the following (David Hubbard pers. comm. - http://coastalrestorationconsultants.com/):

- **Propagation of sedges, rushes and rhizomatous grasses:** Plastic kiddie pools (4 foot diameter x 1 foot deep) were filled with weed-free potting soil and rhizomes of the following species were collected on HRNA and planted in these (i.e., *Juncus mexicanus*, *Carex praegracilis*, *Distichlis spicata*, *Leymus triticoides*, etc...). These rhizomes were harvested from kiddie pools after a few months and transplanted to plug trays (50 or 72 plugs per tray). Plugs were ready to plant in 3 to 8 weeks depending on species and season.
- **Propagation of herbaceous plants and grasses from seed:** Seeds were sown in sterile soil in flats (18 inches x 18 inches). Seedlings (typically with four or more leaves) were transplanted into plug trays after 2 or 3 months. Plant plugs were ready to plant in 8 to 12 weeks depending on the species and season.
- **Planting techniques:** Careful weed control was done before planting any area. In moist soil, holes were created using a 6-foot bar with a conical end for before planting the native plant plugs. Plant plugs were installed by pushing them firmly into the planting holes and refilling the remainder of the

holes. Spacing between plants was approximately 18 to 24 inches. Two workers could plant 1,000 plants in a morning. All plants were planted in the morning when temperatures were coolest.

- **Irrigation:** Irrigation was not used for most of the wetland plantings.
- **Timing of planting:**
  - Non-native tall fescue and Bermuda grass (*Cynodon dactylon*) were left in place after herbicide treatment was completed. Native plants installed appeared to benefit from the dead organic matter creating a thatch to reduce weed recruitment and maintain higher soil moisture.
  - Planting occurred year-round in areas with good soil moisture. The driest areas were planted in winter and the wettest areas in the fall.

Riparian Revegetation Constraints

There are several physical and biological constraints that must be considered when planning and siting riparian revegetation efforts. Although revegetation of natural riparian habitat will improve ecological conditions, we must recognize that watershed-wide impacts (such as infrastructure, surface and groundwater regulation for urban and agricultural uses, in-stream mining, and grazing) will preclude a complete return to pre-European conditions. Both geomorphology landform location and hydrology of a site may limit the possible invasive plant species removal and associated revegetation activities. Location relative to the food reset zone (channel bed and low-flow channel) should be considered. Due to large flood events that occur on the Santa Clara River every 5-10 years that are known to transport invasive non-native riparian plant species such as *Arundo*, a watershed removal approach is highly recommended. Local access to an infested site is another important criterion to assess in removal of invasive non-native plant populations. Site access by equipment and work crews as well as distance to water source for irrigation of planted native species may limit the type of removal and or revegetation that may be performed. In general, sites that are easier to access should be targeted first unless invasive non-native plant infestations are small and revegetation is either not necessary or can be implemented successfully without additional irrigation.

Regulatory Constraints

If the proposed restoration action (removal of invasive weeds and/or revegetation project) involves any mechanized earthwork or is part of a larger project, you must first apply for permits through the USACE, RWQCB, and CDFG. Compensatory mitigation (and 5 years of monitoring) is required to offset any impacts to USACE jurisdictional wetland and/or CDFG riparian habitat due to the proposed project. Refer to the following documents for information on regulatory permits and CEQA compliance required on a project by project basis (Ventura County Planning Division 2006b, Ventura County Resource Conservation District 2006, Stillwater Sciences 2008). Programmatic permits for these activities are not available yet. However, it is the intent of the Trustee Council to support efforts to develop these.

CHAPTER 3
RESULTS OF UCLA RIPARIAN FIELD EXPERIMENT
AND
HRNA REVEGETATION

Introduction

We established a field experiment in a riparian ecosystem of a floodplain terrace along the Santa Clara River to investigate survivorship, growth, and competition of three common native riparian plant species and the invasive non-native *Arundo*. Native riparian tree species studied included two trees, red willow (*Salix laevigata* - Bebb) and black cottonwood (*Populus* (L.) *balsamifera* ssp*. trichocarpa* - Torrey & A. Gray) and the shrub coyote brush (*Baccharis salicifolia* - Ruiz Lopez & Pavon). Data were collected on survivorship and growth metrics under various soil moisture, nutrient and light conditions of three native plant species commonly used for revegetation of riparian habitat in southern California. Chapter 3 presents experimental methods, results, discussion related to development of criteria for monitoring success of riparian revegetation projects along this River and other similar systems throughout southern California. The California Department of Fish and Game's standard Stream Alteration Agreement Conditions were reviewed and recommendations made for updating success criteria for growth (height) of these three species after 1 and 2 years under various environmental conditions. Additionally, this chapter reviews methods and results of sampling riparian tree seedling cohorts from the 2005 flood events conducted by restoration staff on the adjacent HRNA property.

Study Site Description

The UCLA Riparian Field Experiment was located on a private ranch on the south side of the Santa Clara River between Santa Paula and Fillmore, Ventura County, California (34.363635, -118.991171) (Figure 2)(Appendix A). Large riparian trees such as black cottonwood (*Populus balsamifera* ssp*. trichocarpa*) and red willow (*Salix laevigata*) once dominated the terrace in which the field experiment was established prior to its clearing for agriculture. A mixture of smaller trees and shrubs likely comprised the understory layer, including arroyo willow (*Salix lasiolepis* Benth.), mulefat (*Baccharis salicifolia*) and blue elderberry (*Sambucus mexicana* C. Presl.).

We collected data from the field experiment for two growing seasons, from December 2002 to December 2004. In October 2002, we began construction of the 0.5-hectare field experiment on a riparian terrace between agricultural fields and the river. Based on measurements of groundwater depth taken from a grid of borings throughout the experimental area, we found that shallow groundwater flowed in a southeast to northwest direction from the agricultural fields through the experiment toward the river. Rows (or blocks) of plant groupings within the field experiment were located roughly perpendicular to the direction of shallow groundwater flow to accommodate variance due to differing hydrology throughout the area (Figure 4).

Baseline soil grain size (soil texture) and nutrient status were determined in summer 2002, before construction of the experiment began, to help in final placement of experimental groupings and treatments. The western side of the experimental area was primarily composed of two horizons: a shallow horizon of sandy loam, silt loam, and loam (soil surface to 26–66 cm) and a deep horizon of fine sand and coarser sand below the top horizon (to 171–199 cm and deeper). The eastern side of the experiment contained mostly loam (and silt loam) in the top horizon (soil surface to 44–102 cm), loam and silt loam in a middle horizon (between 44–216 cm), and sand in the lowest horizon (below 138–216 cm). Soil moisture was consistently higher on the eastern versus the western side of the experiment due to soil grain size composition and microtopography (Figure 5).

We conducted baseline soil nutrient analyses on 18 soil samples collected systematically throughout the experiment from average plant rooting depth (0–30 cm). In spring 2003, pre-fertilization soil nutrient levels in the experimental study area [mean soil nitrate (5.2 ± 1.7 ppm) and phosphate (11.1 ± 1.1 ppm) levels] were comparable to concentrations found in soil along similar terrace landforms along the Santa Clara River. Average soil pH (7.69 ± 0.02) did not differ markedly throughout the experimental site and was similar to other terrace landforms along the River.

Study Species

We selected three native riparian plant species commonly found on terraces of rivers in southern California to use in the experiment: *Salix laevigata* (red willow) *Populus balsamifera* (black cottonwood) ssp*. trichocarpa*, and *Baccharis salicifolia* (mulefat). Additionally, three individuals of *Salix lasiolepis* (arroyo willow) were planted in the experiment accidentally and we opportunistically followed these as well. *Salix laevigata* is a riparian tree that can grow as tall as 15 m and is a member of the

Salicaceae. Dominant in both floodplains and terraces along rivers in southern California, *S. laevigata* can be identified by its dark, deeply furrowed bark on mature trees and lanceolate leaves, which are shiny on the top and glaucous beneath. Also a member of Salicaceae, *P. balsamifera* ssp*. trichocarpa* grows to a height of 30 m in alluvial plains along rivers in southern California. *Populus balsamifera* ssp*. trichocarpa* trees can be identified by their broad crown and bicolored ovate leaves with acute tips, which are dark green on the top and glaucous underneath (Faber and Holland 1992, Hickman 1993). *Baccharis salicifolia* is the dominant shrub found throughout floodplains and terraces of streams and rivers in southern California. A member of the Asteraceae, *B. salicifolia* usually grows to a height of less than 4 m. Its long linear to lanceolate leaves resemble willow leaves, but they typically have three principal veins that extend the entire length of the leaf and are coarsely serrated (Faber and Holland 1992, Hickman 1993). In addition, *B. salicifolia* shrubs produce a rounded panicle of white simple compound dioecious flowers.

Arundo donax is a robust, perennial, bamboo-like member of the Poaceae (grass) family that was introduced and is now widespread throughout the floodplains and terraces of rivers in California and other warm, temperate climates worldwide (Perdue 1958, Crampton 1974). It has erect stout (yet hollow) culms that are 1–4 cm thick and 2–8 m in height. Culms branch to form ramets, typically at the end of the first year of growth or after a culm is damaged. Leaf blades are broad (2–6 cm wide), less than 1 m long, flat, clasping at the base, strongly scabrous along their margins, and evenly spaced along the culm (Crampton 1974, Hickman 1993). *Arundo* reproduces vegetatively through a network of large, thick rhizomes that grow horizontally just below the ground surface. Under some conditions it produces a large (3–6 dm) terminal plume-like inflorescence (panicles) at the end of the growing season (Faber et al. 1989, Faber and Holland 1992, Hickman 1993).

Field Experiment Design

This field experiment was organized as a full factorial randomized block design to minimize variation due to heterogeneous soil and shallow groundwater conditions found within the site. A total of 288 plant groupings (four plants per square grouping) were organized in 12 blocks (rows) of 24 groupings each perpendicular to the general flow of shallow groundwater hydrology (Figure 4). Blocks of plant groupings were placed 4 m apart and plant groupings within blocks were placed 3 m apart. A total of 756 cuttings of riparian trees/shrub species (1 m long by approximately 2–3 cm in diameter) and 396 rhizomes of *Arundo* (200–400 g) were planted approximately 0.75 m

apart in square configured groupings. Native riparian species cuttings were planted throughout the experimental area in December 2002, and *Arundo* rhizomes were planted in March 2003. Both native riparian plant cuttings and *Arundo* rhizomes were installed directly into the ground in designated groupings. Multiple levels of three resource treatments (and a competition treatment grouping) were applied randomly to plant groupings along rows before planting, including soil moisture (high and low), light (high and low), and nutrient additions (high, low, and none).

Cuttings of two native riparian tree species (red willow, *S. laevigata* and black cottonwood, *P. balsamifera* ssp*. trichocarpa*) and one native riparian shrub (mulefat, *Baccharis salicifolia*) were collected from riparian habitat adjacent to the field experiment. 1 m long cuttings were taken from only young branches or from younger trees/shrubs with buds to create poles approximately 1 m long by approximately 2–3 cm in diameter. All branches and leaves were clipped from the pole plant cuttings. Pole cuttings were soaked in water and rooting hormone for overnight. We created small holes for each riparian pole cutting at each of the experimental groupings using a T-bar. Before installation at experimental groupings, we removed buds from the top 1/3 of the pole cutting and left buds from the bottom 2/3 on the cutting to form roots in the ground. Removing buds from the above ground portion of the cutting was thought to encourage growth of a root system during the wet winter months and not expend energy on aboveground biomass production. Specifications for riparian plant cuttings described above were developed based on interviews with several native plant nurseries in southern California.

We planted species in three competition groupings (four-species, two-species and one-species monoculture groupings) in the experiment to compare interspecific versus intraspecific competitive interactions between *Arundo*, red willow, black cottonwood, and mulefat (Table 2). Four-species groupings consisted of one individual of each species placed at random within the square configuration. The two-species groupings consisted of two *Arundo* plants and two plants of a single native species. Like species were planted diagonally across from each other in the two-species groupings. One species-groupings, or monocultures, contained four plants of only one species per grouping.

In this experiment, the criterion for existence of an interspecific competitive interaction was evidence of significantly different biomass or height in four-species or two-species plant groupings compared to monocultures. If mean biomass or height of a species was lower when grown with another species compared to when grown in

monoculture, an interspecific competitive interaction was considered present. An interspecific interaction was deemed positive (facilitation) when the mean biomass or height of a species was higher in either mixed species groupings compared to its biomass when grown in monoculture. A comparison of mean height between species and groupings is briefly presented in the results section below. Competition results for biomass are presented in Coffman (2007).

Two soil moisture treatments occurred naturally (Figure 5). The western half of the experiment had soils that contained more coarse grain soil and were better drained (referred to as low soil moisture). The eastern half of the experiment retained higher soil moisture throughout the year (high soil moisture). To simulate natural establishment conditions, we did not apply artificial irrigation and analysed data according to the two soil moisture treatments.

In spring 2003, we built shade structures over half of the experiment to simulate shading by a mature riparian canopy and test the effects of light availability. The two light treatments consisted of 80% shade (referred to as low light) and full sun with no shade structures (referred to as high light). We used 80% black shade cloth on six shade structures (total dimensions were 200 feet x 10 feet x 15 feet high) that were erected along rows in two large sections of the experiment to minimize the shade effect onto non-shaded rows. One section (three rows) was placed over the high soil moisture portion (northeast quadrant) and one section (three rows) was placed over the low soil moisture portion (southwest quadrant) (Figure 4).

We applied nutrient treatments to designated plant groupings twice a year: fertilized "high N" and "low N" treatments "no N" treatment control in which only water was added. Granular ammonium-nitrate fertilizer (N-P-K, 34-0-0) was used as the source of added nitrogen and was mixed with 2 gallons of water before application. High nitrogen treatments (100 g N/m^2/year or 56 g N/plant/year or 2 oz. N/plant/year) were added to one-third of the plant groupings to simulate row crop fertilization levels adjacent to riparian areas. Low nitrogen treatments (40 g N/m^2/year or 23 g N/plant/year or 0.8 oz. N/plant/year) were added to one-third of the plant groupings to simulate orchard fertilization levels adjacent to riparian areas. We applied half of the nutrient treatments at the beginning of the growing season and the remainder at the peak of the growing season. According to interviews with local ranchers, quantities and timing of fertilization application was similar to that used in agricultural practices in the area. Each plant in the no fertilizer treatment received 2 gallons of water at each of the two application periods.

Sampling Methods

We monitored soil moisture to characterize the soil water content throughout the experimental site using 14 soil moisture probes (20 cm ECH_2O Dielectric Aquameter sensors by Decagon Devices, Inc.), which were installed systematically throughout the experiment in the summer of 2004 (Figure 4). We placed 10 soil moisture probes in a soil horizon approximately 60–80 cm from the soil surface, a depth which is roughly in the middle of the root system for most plants. The other four probes were placed in a shallower soil horizon (from 30–50 cm) to measure soil moisture in the area in which the cuttings were initially planted. We measured soil moisture content of these probes weekly from July 2004 to September 2005 to understand variability within the experiment and establish the two soil moisture treatments.

Annual mean soil moisture content at 60–80 cm below ground surface on the eastern side (mean ± SE = 38.5% ± 0.5) of the experiment was significantly higher than on the western side (33.2% ± 1.0) during the 2004–2005 water year (one-way analysis of variance results: $F_{(1,383)} = 23.583$; $P < 0.001$). The shallower soil horizon (30–50 cm below the ground surface), in which cuttings were established, exhibited a similar trend; soil moisture was 42.1% ± 0.4 on the eastern side and 37.8% ± 0.5 on the western side (one-way analysis of variance results: $F_{(1,166)} = 47.686$; $P < 0.001$). Mean soil moisture content fluctuated throughout the year but was consistently higher on the eastern side than the western side (Figure 5). Although soil moisture probes were not installed until the end of the second growing season (Summer 2004), trends observed during 2004-2005 were likely similar or more pronounced in 2003-2004 due to lower total annual precipitation in this water year. Thus, the eastern side was designated as the high soil moisture treatment and the western side as the low soil moisture treatment.

Survivorship

We measured plant survivorship at three time periods: 1) survivorship of planted cuttings in March 2003, 2) plant survivorship at the end of 2003 growing season (September-November), and 3) plant survivorship at the end of 2004 (September-November). A few cuttings (14) and rhizomes (9) that did not emerge initially during March 2003 surveys were replanted in April 2003. Percent survivorship results reported for end of growing season 2003 and 2004 represent the establishment success for all initial and replacement cuttings.

Growth

Growth characteristics were measured for all four species during both the 2003 and 2004 growing seasons (beginning and end of each growing season – March and September-November). Growth metrics included: maximum height of plant, average width of aboveground biomass of individual plants (based on two measurements), marked branch elongation (3 marked branches per individual plant), number of branches/*Arundo* culms, riparian plant cutting height, and average riparian plant cutting diameter (based on 3 measurements). Cutting diameters were measured at 10cm from the ground surface, middle of the cutting and 3cm from the top of the cutting. In addition, the basal area of *Arundo* at each planting was measured by taking an average of two perpendicular widths. We present only the total height metric in this chapter since it compares directly with success criteria established by the CDFG.

Biomass

The aboveground biomass of all plants in the field experiment was estimated over the two-year study period (2003 to 2004). We used non-destructive dimensional analyses to estimate aboveground biomass dry weight of plants in the experiment so that we would interfere as little as possible with plant growth and other measurements taken throughout the course of the study period (Whittaker 1961, 1965, Whittaker and Marks 1975, Sharifi et al. 1982, Spencer et al. 2006).
Refer to Coffman (2007) for detailed methods for biomass sampling and analyses.

Statistical Analyses

Descriptive statistics (mean ± SE) were performed on soil moisture, plant survivorship, and height measurements (Systat Statistical Program [Version 15]). We conducted one-way ANOVAs on soil moisture content to validate high and low soil moisture treatments and establishment of plant species between the first and second growing season, with Tukey's post-hoc test for pair-wise comparisons of means.

The experiment was organized in a full multifactorial design in which combinations of four fixed factors (Model 1) were crossed with each other. Four-way analysis of variance (ANOVA) tests were used to analyze effects of various combinations of four factors (independent variables) on height data collected in March 2003 and at the end of the each growing season (dependent or response variables) (Systat Statistical Program [Version 13]). The four independent variables analysed were plant species, soil moisture, light, and nutrient addition treatments. Data were analyzed for

main effects of individual factors and interactions between factors. ANOVA F-tests were performed to evaluate a priori contrasts between means of grouping variables and levels in multifactor ANOVA results. Probability plots were examined to test for normality of data and to identify any data that required transformation. Because soil moisture, percent survivorship, and height data were normally distributed, data transformation was unnecessary.

Percent survivorship measured at the end of 2003 and 2004 was compared in a two-way ANOVA (year x plant species) since this was the only significant effect found in the four-way ANOVA performed. In addition, we conducted a two-way ANOVA (year x plant species) on mean heights of three native riparian plants and *Arundo* for both year 1 (2003) and year 2 (2004) to understand general differences in height among species and between years after planting. Three-way ANOVAs (year x soil moisture x light) were performed on plant height data for all individuals grown in the experiment to determine treatment effects of each factor over time. A three-way ANOVA (year x competition grouping x species) was performed on plant height data to analyze treatment effects of the three competition treatments for between species and between the end of the first (year 1 = 2003) and second (year 2 = 2004) growing seasons. Graphs were created of the most significant findings for ease of interpretation. Tables are included to present statistical findings of ANOVAs.

UCLA Riparian Field Experiment Results

Survivorship by species grown under various environmental conditions

Plant establishment success between installation in winter 2002–2003 and the end of the growing season in 2004 was very high for all species. Cutting survivorship in spring 2003 was 97.7% for all individuals planted. Total plant survivorship at the end of 2003 and 2004 was 98.4% and 97.8%, respectively.

The four-way ANOVA (species x soil moisture x nutrients x light) for percent survivorship yielded no significant main effects or interactions for cuttings and plants at the end of the 2004 growing season (Table 3). Only one significant interaction was found between species and soil moisture for plant survivorship at the end of 2003 growing season. Soil moisture, nutrient, and light treatments had no significant effect by themselves on *Arundo*, *S. laevigata*, or *B. salicifolia* survivorship (Table 3). However, establishment success of *P. balsamifera* ssp. *trichocarpa* at the end of the first growing season (2003) was significantly lower within the high soil moisture treatment than in any other species and soil moisture treatment combination (Figure 6).

Percent survivorship did not decrease significantly during the two-year establishment period ($F_{(1,158)} = 0.485$; $P = 0.487$). Therefore, we considered plants fully established by the end of the first growing season (2003). Only five plants (0.8% of plants in groupings analyzed) did not survive the second growing season.

Growth metrics by species grown under various environmental conditions

Mean height was the only growth metric analysed and presented in this handbook due to timing and funding limitations. We recommend analysing mean cutting diameter and volume for all three riparian plant species in the experiment in the same manner to inform development of success criteria. Results of the three-way ANOVA (year x competition grouping x species) performed on plant height data were not significant for the three way interaction. Therefore, we did not use competition as a factor in our presentation of data.

The two-way ANOVA (species x year) for plant height resulted in very highly significant main effects (species - $F_{(3,2250)} = 379.709$); $P \leq 0.001$; year - $F_{(1,2250)} = 917.356$; $P < 0.001$) and two-way interaction ($F_{(3,2250)} = 16.839$; $P \leq 0.001$). Mean height of all species was significantly greater after the second growing season than the first for black cottonwood (45%), red willow (46%), mulefat (32%), and *Arundo* (43%) (Figure 7 and Table 5). After the first growing season, mean height of mulefat was significantly greater than both black cottonwood and red willow (the height of the latter two did not differ significantly). At the end of the second growing season, riparian plant species did not differ significantly in mean height. However, *Arundo* was significantly taller than all native plant species at the end of year 1 and 2.

The three-way ANOVAs (light x soil moisture x year) for cottonwood ($F_{(1,472)} = 20.135$; $P \leq 0.001$) and willow ($F_{(1,489)} = 15.672$; $P \leq 0.001$) were significant. Four bar graphs (Figures 8 – 11) present a comparison of mean heights of each species (1 graph per species) grown in various combinations of soil moisture and light levels at the end of year 1 and 2 growing seasons. Letters above bars indicated results of post-hoc comparison of means tests between all treatments (with significance recognized at $\alpha < 0.05$).

HRNA Passive Riparian Revegetation Monitoring Methods & Results

In January and February 2005, floods overtopped the banks of the Santa Clara River and nearby Balcom Canyon Ditch and deposited soil on top of HRNA areas E and F. When floodwaters receded they left not only soil but seeds and vegetative

propagules in these areas. HRNA restoration staff measured height and dbh of riparian tree and shrub seedling cohorts in March 2007 (2 years later) and November 2010 (5 ½ years later) (Coastal Restoration Consultants 2010). Height was recorded to the nearest meter and dbh to the nearest mm. Five line intercept transects were laid from north to south across the Area E and F to sampling vegetation throughout the area. The closest riparian tree or shrub found within the nearest meter was sampled at each five meter point along all transects.

Total number of individuals measured included: 17 black cottonwood, 4 sandbar willow (*Salix exigua*), 155 arroyo willow (*Salix lasiolepis*), 5 red willow, and 11 shining willow (*Salix lucida*) in March 2007; and 141 arroyo willow, 38 red willow, and 17 shining willow in November 2011. All species had a similar mean height after 2 years, but shining willow mean height was greater than either arroyo willow or red willow (Figure 12a). Mean height ranged between 10.8 – 13.8 feet in year 2 and 19.4 and 24.9 feet in year 5 ½. Diameter breast height was similar for all five species after 2 years (0.6 – 0.9 inch) (Figure 12b). However, shining willow (5.3 inches) had a much larger dbh than arroyo willow (3.1 inches) or red willow (4.7 inches) after 5 ½ years.

Discussion

Results of these our field experiment and monitoring of HRNA riparian tree seedling cohorts can provide valuable ecological data on riparian species survivorship and growth related to revegetation. Observations of revegetation techniques and monitoring of passive and active restoration activities on HRNA (Chapter 3) can provide valuable insight into future restoration actions on the Santa Clara River. The following are our recommendations for use of these data and observations:

UCLA Riparian Field Experiment – Survivorship and Growth

- Year 1 and 2 data collected at the UCLA Riparian Field Experiment can be used to improving success criteria for growth metrics for riparian plant species used in revegetation (Success Criterion D presented in Chapter 5). Also, these data can help inform minimum height requirements for the CDFG Stream Alteration Agreements for the Santa Clara River and similar rivers in southern California (Table 4). Figure 7 presents mean height (in feet) data for black cottonwood, red willow, and mulefat after the first and second growing seasons. Mean heights were pretty similar for all species within years and do not reflect the true variability found when grown in differing soil moisture and light conditions. Mean heights ranged from 7.26 to 8.32 ft

after the first growing season and from 10.54 to 10.97 after the second growing season.

- Environmental site conditions, especially soil moisture and light availability greatly affect height of native riparian species and likely other growth metrics. A more detailed analysis of each native riparian species shows that a wide range of heights is attained under varying soil moisture and light conditions at the field experiment, especially after the second growing season (Figures 7 – 10 and Table 5). For example, black cottonwood mean height is significantly lower (6.0 ft ± 0.2) in low light and low soil moisture than the average (7.26 ft ± 0.12) after one year, yet significantly higher when grown under high light and soil moisture conditions (13.7 ft ± 0.5) than the average (10.54 ft ± 0.21) after two years. If black cottonwood cuttings are planted on a terrace landform within an already established forest along the Santa Clara River with low soil moisture, they will most likely not attain the minimum mean height success criteria if set using an average. We suggest that minimum heights for riparian tree and shrub success criteria must be set for all four conditions, not just an overall average. Creating detailed success criteria for many conditions can be done by establishing and sampling a field experiment like the UCLA Riparian Field Experiment and/or reference sites throughout the Santa Clara River exhibiting the variety of soil moisture and light conditions found.
- Data collection in summer 2012 at the UCLA Riparian Field Experiment could be used to set 10 year monitoring targets. In summer 2012, the riparian trees and shrubs in the experiment will be 10 years old. We recommend that this experiment be resampled to provide data to improve success criteria and performance metrics presented in Chapter 5, especially for Success Criteria D (Survivorship, Health and Growth of Riparian Plantings).

HRNA Riparian Tree and Shrub Seedling Cohort Monitoring

- Measuring height and dbh of riparian tree and seedling cohorts over time (year 2 and 5.5) created a mean (and range) target for success criteria based on known ages of 5 common riparian trees/shrubs found along the Santa Clara River. The current CDFG success criteria (in the Stream Alteration Agreement that we reviewed) for minimum height of arroyo willow and red willow are both 15 ft. Mean height of arroyo willow on HRNA was 19.4 ft (± 5.9 SD) and red willow was 23 ft (± 5.2 SD). These data suggests that

minimum height requirement after 5 years growth for an area with similar soil moisture on a terrace landform could be 13.4 ft (mean – 1 standard deviation) for arroyo willow and 17.8 ft (mean – 1 standard deviation) for red willow.

- The CDFG success criteria for minimum height targets do not include shining willow which was found to have a mean height of 24.9 ft (± 4.8 SD) after growing 5.5 years on HRNA. 20.1 ft (mean - 1 standard deviation) could be used as a minimum height target for shining willow.
- We could not find a success criterion for dbh in the CDFG Stream Alteration Agreement we reviewed. We recommend using the average diameter of cutting (like the measurements we collected at the field experiment) for developing year 1 and 2 success criteria. For years 5 and 10 success criteria, we recommend using dbh of the tree or shrub.
- Areas E and F on HRNA should be used as a reference site to create a restoration trajectory for these height and dbh metrics and others (Success Criterion D: Survivorship, Health and Growth of Riparian Plantings). Height and dbh should be measured at 10 years to inform these metrics. Caution must be taken when using these data to develop targets for success criteria and performance metrics – these measurements can only be compared to plants grown from seed (container plants).

HRNA Lessons Learned

The following recommendations or lessons learned were compiled from our restoration work on HRNA since 1997 and interviews with FSCR and HRNA restoration staff (Sanger Hedrick, Dave Hubbard, and Jackie Worden, pers. comm.).

- **Non-native plant removal and riparian revegetation lessons learned:**
    - Clear goals and objectives must be established at the beginning of the restoration project.
    - Restoration approaches must be adapted if site conditions change.
    - Experiment with methods.
    - Methods and techniques can be optimized by learning about what works on your site and altering the approach accordingly.
    - Invasive plants and non-native weeds should be controlled if possible before planting for optimal revegetation success.

- Long project timelines (5-10 years) allows for greater efficiency and effectiveness of implementing restoration actions.
- Irrigation is not needed for establishment of riparian and wetland species in native soils with good relatively high moisture.
- Plants should be installed only in the winter after rains have thoroughly soaked the soil if irrigation is not used.
- Fertilizer is not needed to establish native plants. In fact, fertilizing encourages invasive plant and non-native weed growth.
- Battery operated drills with 1 inch auger heads can be very effective at creating holes for cutting placement in clay soils.

➢ **Photo monitoring lessons learned:**

- Photo monitoring points should be taken before and after both passive/active revegetation (see Appendix B for photo monitoring example at HRNA).
- Photo monitoring station descriptions must be very detailed and clear for relocation of these stations. Including landmarks in photos is helpful for relocation of stations.
- GPS locations and compass direction of photo must be recorded for each photo monitoring station.
- The biggest challenge in photo monitoring at HRNA was that the background views became blocked by vegetation in the foreground. Siting photo monitoring station at vantage points above the site or across water/sand/road is helpful in positioning stations.

➢ **Vegetation monitoring protocol lessons learned:**

- Randomly placed line intercept transects can be sampled throughout systematic zones of a restoration area to get a broad understanding of success of restoration actions over an entire site (i.e., percent cover of native vs. non-native plants).
- More specific vegetation monitoring protocol must be developed to evaluate the success of each project objective (see Chapter 5).

- Permanent plots must be established to track individual plant survivorship. It was estimated from anywhere between 50-95% (90% on average) for HRNA. But without sampling permanent plots, we cannot evaluate survivorship of plants installed during active revegetation relative to this success criterion.
- Opportunistically measuring riparian tree and shrub seedling cohorts after a flood event can provide valuable data for improving success criteria and establishing reference sites for the Santa Clara River.

CHAPTER 4
SITING AND TIMING OF INVASIVE PLANT REMOVAL, REVEGETATION, MONITORING, AND MAINTENANCE

Both locating priority sites for *Arundo* removal and riparian revegetation after removal as well as implementation timing of both these restoration actions are crucial to their success. Results of competition between *Arundo* and three native riparian plants measured in the UCLA Riparian Field Experiment, fire studies, and observation while working on the Santa Clara River from 1997-present have been used to formulate five conceptual siting and timing strategies for *Arundo* removal (Coffman 2007, Coffman et al. 2010). In addition, preferred methods for removal of *Arundo* and other CalIPC high ranking species removal are summarized. Timing of *Arundo* removal, revegetation, monitoring and maintenance is presented on Table 6.

Prioritization of *Arundo donax* Removal and Riparian Revegetation after Removal

Millions of dollars have been spent to remove *Arundo* infestations of riparian ecosystems throughout California (Katagi et al. 2002). Due to the lack of understanding of *Arundo* ecology, however, decisions regarding prioritization of removal areas and removal techniques often have to be made in the absence of sufficient scientific information. After analyzing research results (Coffman 2007) and the current body of literature available on *Arundo*, we propose the following management strategies, which incorporate the most current understanding of the *Arundo* invasion process, to most effectively and efficiently address this problem. We recommend that *Arundo* control efforts should be placed where ecological benefits are the greatest and associated removal effort the lowest (see priorities for the Santa Clara River below).

Currently, the preferred methods of *Arundo* removal in Southern California are called the bend-and-spray or hook methods, both which imitate nature. Alternatively, the cut-stump method can be used in areas where *Arundo* stems cannot be bent. Where *Arundo* is removed near the edge of streams, caution must be used so as not to allow any pieces of *Arundo* to fall in or near intermittent or perennial streams. Timing of *Arundo* stem spraying and removal is extremely important. Late summer through early fall (August to October) is the most effective time of year to treat *Arundo*. However, follow up spraying of resprouts must be done on an annual basis once resprouts are approximately three feet tall.

Due to the height of *Arundo* (up to 20 feet tall) and typical interspersion with surrounding native vegetation, sensitive species, and/or water, the bend-and-spray or hook methods have proven effective for remotely located small to moderately sized

infestations (Newhouser 2008). The bend-and-spray or hook method maximizes coverage of herbicide on *Arundo* stems, allows for sufficient translocation of the herbicide to the rhizomes by bending and spraying the *Arundo* stems, and minimizes residual spraying of non-target native species. Using the bend-and-spray method, a worker bends the *Arundo* stems away from the native vegetation and the applicator sprays the culm (or stems) with an approved herbicide. The person preparing the *Arundo* for herbicide spraying grasps the stems between stem nodes with two hands and bends or snaps the stem so that it splits longitudinally without breaking off. If done properly, over 90% of the bent stems will remain intact. *Arundo donax* stems must be living to translocate herbicide to their rhizomes and kill the plant. Thus, the nodes should not be bent as they tend to break off completely. Next, a fan shape should be created with the bent canes on the ground. With a crew of two or three workers to bend the *Arundo* stems and one applicator, the removal team can rotate between three or four clumps of *Arundo* at a time. This should kill most of the biomass within approximately 2 months. Then all dead *Arundo* biomass must be mulched on-site and/or carried off site to ensure that it does not spread during flood events or create a fire hazard.

The hook method allows the applicator to work solo, working the hook with left hand (between pumping) and spraying with the right hand. Using a hook, the worker gathers up to 10 *Arundo* stems to concentrate them for quicker application. This method uses the least amount of herbicide and has the least potential to overspray and risk of non-target plant species damage. The hook resembles a swimming pool rescue hook (8 foot wooden pole with an 18 inch PVC hook with and an additional side hook on top). It was designed to reach up and pull *Arundo* stems down away from desirable vegetation to spray them. The hook is very useful in reaching the center of small patches of *Arundo*. When employing the hook technique, the worker inserts the hook vertically into the upright canes and then turns the hook horizontally to grab approximately 10 canes. The next step is to pull the stems towards you while stepping back and sliding the hook up the canes. As you slide the hook up the stems, the *Arundo* stems will bend toward you and you will be able to spray the full length of the cluster of stems in the hook.

Planning a bending route is recommended so that it is easier to work your way methodically through the clump. Neither the ben-and-spray nor the cut-stump methods are recommended for large infestations of *Arundo*.

Alternatively, the cut-stump method may be used in remote areas where *Arundo* stems cannot be bent or in situations where a foliar spray application poses a significant risk to aquatic species, desirable vegetation, and other non-target species. In addition, use of this method may be desirable where standing dead *Arundo* poses a

significant fire hazard or when conducting a follow-up treatment on a small amount of regrowth. Using cut-stump method, *Arundo* stems are cut approximately one foot from the ground with a chainsaw, lopper, or machete. The stem stump is then immediately painted with herbicide (must be painted with herbicide within 1 minute of cutting to be effective). Dye should be added to the herbicide to mark treated stumps and ensure full coverage. All cut *Arundo* biomass must be mulched on-site and/or carried off site to ensure that it does not spread in a flood.

The following five priorities were developed upon analysis of *Arundo* studies that looked at contribution of wildfire, soil moisture, nutrients and light as well as other literature on *Arundo* ecology (Coffman 2007). We recommend that *Arundo* control efforts be placed where ecological benefits are the greatest and associated removal effort the lowest as follows.

Priority 1. Remove Arundo under mature riparian forests, especially adjacent to fire-prone shrublands

The highest priority location for *Arundo* removal is within mature riparian forests adjacent to coastal Southern California shrublands (chaparral and coastal sage scrub) and grassland. Recent research conducted throughout the Santa Clara River (Coffman 2007) suggests that *Arundo* removal in mature riparian forests would create the greatest environmental benefit, because these areas have the highest risk of further damage if removal is not conducted (i.e., increased fire hazard) and threat of reinfestation is lowest (i.e., where removal effort is long-lasting). *Arundo donax* may reinfest areas that are flooded occasionally but not completely scoured (e.g., higher terraces), especially where water and nutrient levels are high. In these locations, mature riparian forests may facilitate invasion by physically trapping propagules stranded by flooding (Dudley pers. comm.). Coffman (2007) showed that *Arundo* grows more rapidly under high light conditions than under low light conditions when high water and nutrient levels are present. Also, field observations reveal that the understory of mature riparian forests can be invaded by *Arundo* after large floods, however the invasion trajectory may be protracted due to the effect of canopy shading. When these mature riparian forests become heavily invaded, areas near fire-prone shrublands are highly susceptible to fire. The large, dry biomass produced by *Arundo* in these areas carries fires (i.e., ladder effect) through canopies of these once-natural firebreaks, burning across and along river systems. *Arundo* in mature riparian forests should be targeted for high priority removal due to the threat of an invasive plant-fire cycle and the lasting damage caused – risk of the complete loss of mature riparian forests on the Santa Clara River.

Priority 2. Remove the largest Arundo propagule source

Another high priority for *Arundo* removal high we recommend is to target areas containing the largest source of propagules. Removing these should help to curtail the distribution of *Arundo*, thereby working to control it in the initial phase of the invasion process. Due to its clonal growth form, dominant asexual reproduction, and flood-driven dispersal mechanisms, the largest *Arundo* infestations will produce the highest quantity of vegetative propagules (all pieces of stalk or rhizome regardless of size). Coffman (2007) suggested that the largest infestations are most prevalent in riparian ecosystems found within highly urbanized watersheds, located adjacent to agricultural and residential land uses, and in areas that have burned in southern California, the Western Cape region of South Africa, and other Mediterranean climate regions. Furthermore, large infestations in areas most frequently scoured by winter flooding contain the largest potential source of propagules.

Prioritization of removal in riparian ecosystems with the lowest likelihood of reinfestation has been suggested (i.e., areas outside the flood zone) (Coffman et al. 2004). In general, their findings suggest that *Arundo* is least likely to invade open substrates or recently scoured areas in which resources levels are low (i.e., low soil moisture and nutrient availability) and where native plants have established at the same time. Further investigation of the relationship between frequency of rhizome establishment and *Arundo* abundance in various locations, after flood events, is necessary to validate this recommendation. Riparian ecosystems downstream of large propagule sources along active floodplains are most likely to be reinfested and removal in these areas should be given lowest priority. Results of Coffman's studies (2007) suggest that *Arundo* is most likely to invade open (i.e., very low native vegetation cover) or recently scoured areas in which resources levels are high (i.e., high soil moisture and nutrient availability). These areas often are found next to agricultural land uses and areas exposed to wastewater treatment discharge from residential land use (Neely and Baker 1989).

Many *Arundo* removal projects to date have focused on large infestations. However, removing large propagule sources with active floodplains with high resource levels should not be prioritized because ecological benefits are low and associated removal efforts are high. Natural biological and physical processes in riparian ecosystems that are heavily invaded by *Arundo* are usually already degraded. Although removal efforts may slightly reduce propagule abundance, net ecological benefits from removing *Arundo* from heavily invaded riparian areas may be much lower than from areas less invaded. Coffman (2007) suggests that removal of *Arundo* in locations within riparian forests adjacent to fire-prone shrublands, watersheds with low nutrient inputs, and watersheds with little *Arundo* abundance will result in the greatest ecological

benefit. Furthermore, a considerable amount of money and effort is involved in removal of large infestations.

Priority 3. Control Arundo on a watershed scale

We suggest several watershed scale *Arundo* control strategies, given the natural dynamic flood regime in streams of Mediterranean-type climate regions and the widespread anthropogenic resource inputs that are not easily corrected. *Arundo donax* should be removed from low nutrient input watersheds where infestations are small or area of infestation is localized; the highest probability of eradication success at the lowest cost is possible in these locations. However, watershed-scale long-term control of *Arundo* in natural riparian ecosystems may require management of resource levels that promote invasion to reduce growth and competition. Manipulation of resource availability in favor of a given native (desired) species has been proposed to create a competitive advantage and a barrier to reinvasion (Blumenthal et al. 2003, Corbin and D'Antonio 2004, Suding et al. 2004, Prober et al. 2005, Perry and Galatowitsch 2006). Results of Coffman's studies (2007) suggest that reduction of nutrient inputs in urbanized watersheds may slow invasion of *Arundo* but likely will not, alone, prevent its eventual spread. Several researchers suggest that *Arundo* should be removed from the most frequently inundated floodplains only using a top-down directional approach, beginning in the upper reaches of the watershed and moving downstream (Bell 1997, Coffman et al. 2004). Removal of *Arundo* on higher terraces may not necessarily need to proceed in this downstream manner because reinfestation is much less likely. However, one study suggests that layering (i.e., rooting from nodes) is an important *Arundo* invasion mechanism in streams of southern California and, thus, an inside-out approach is required (Boland 2006). An inside-out approach means removing *Arundo* from the low flow channel to the banks of rivers and streams.

Both approaches are necessary depending on the flood dynamics of the reach of the river reach or stream, infestation size and distribution, and fluvial geomorphic location of the infestation. In the flood reset zone (or floodplain) of the main stem of the Santa Clara River where resource levels and flood frequencies are high, *Arundo* should be removed in a top-down manner.

Priority 4. Removal of Arundo immediately after fires or floods

Because removal of large areas of *Arundo* is very costly, the ideal time to remove it from a heavily infested watershed is immediately after a very large flood (i.e., 100-year flood) or wildfire event that removes most of the vegetation, resulting in much easier access to much reduced quantities of *Arundo* biomass. During this time, the impacts to special status species (i.e., Least Bell's Vireo, Southwestern Willow

Flycatcher) are low or absent. Removal of the rhizome is necessary to completely kill *Arundo* after floods, but is relatively easy to dig out in the first few weeks after flooding when biomass is low (Sanger Hedrick, pers. comm.). We found that after wildfires burned through large *Arundo* infestations (i.e., on the Santa Clara River), one herbicide treatments increased *Arundo* density less than one year after treatment (Coffman unpublished data). Therefore, we recommend that either multiple herbicide treatments (during the first 3 or until completely killed) be applied *Arundo* resprouts after burned or that the rhizomes are removed completely if feasible.

In order to prepare adequately for *Arundo* removal opportunities immediately after floods or fires, a contingency fund should be set up for this work. The timing of these events are unpredictable and do not easily fit into typical funding schedules. In lieu fee programs in California in which mitigation funds are accumulated have been set up in other watersheds and may be an effective strategy.

Priority 5. Revegetation after removal may not help resist or suppress Arundo

The management literature recommends revegetation of riparian systems with native species after removal of invasive species, including *Arundo*, to resist further invasion (Sonoma Ecology Center 1999, Ventura County Planning Division 2006a). Resistance to invasion may be achieved if natives obtain a much higher biomass than *Arundo* and suppress it when competing for resources. However, results of our two-year competition field experiment suggest that this is rarely the case; *Arundo* had a significantly higher biomass than almost all native plant species under all resource levels (Coffman 2007). Only minimal suppression by native plants was documented under a few conditions tested. Results of this competition field experiment indicate that *B. salicifolia* may increase in biomass when grown with *Arundo*, although it never obtained a significantly higher biomass than Arundo under any conditions. Longer studies are needed to validate these findings, although it appears that revegetation will not resist reinvasion without implementation of appropriate *Arundo* removal and maintenance. However, active revegetation after *Arundo* removal should help initiate restoration of riparian ecosystem functioning if *Arundo* removal is conducted in the appropriate location (see Priorities 1-4) and diligent maintenance is implemented for the first 3 years or until the *Arundo* is completely removed from the site.

Selection of active versus passive revegetation treatments for invasive plant removal sites depends on several factors: invasive plant species life history/invasion process; location relative to floodplain and terrace landforms; location in landscape/watershed; quantity of soil moisture, nutrients, shade; and wildfire potential. In the initial planning stages, the life history of each non-native, invasive

species located on the removal site and each native riparian species used in revegetation must be understood thoroughly to insure success and sustainability of removal and revegetation.

Removal Strategies for other CalIPC High Ranking Species

Four non-native invasive species with CalIPC high ratings were found in more limited distribution than *Arundo* within the Santa Clara River 500-year floodplain, including: perennial pepperweed (*Lepidium latifolium*), creeping water- primrose (*Ludwigia peploides* ssp. *montevidensis*), smallflower tamarisk (*Tamarix parviflora*), and salt cedar (*Tamarix ramosissima*). The locations, approximate distribution and extent, life history, invasion process and removal strategies are summarized for each below (see http://www.calflora.org/ and http://calphotos.berkeley.edu/for photos of these plants).

Perennial pepperweed (Lepidium latifolium)

During the 2005 vegetation mapping surveys, only one population of perennial pepperweed (*Lepidium latifolium*) was found within the 500-year floodplain (Stillwater Sciences and URS Corporation 2007). This population occurs on an upper floodplain terrace of the Hedrick Ranch Nature Area (HRNA) at approximately 34.362163, -118.999187 (Stillwater Sciences and URS Corporation 2007). The Friends of the Santa Clara River have been actively controlling this *L. latifolium* population since its identification during vegetation surveys conducted in 2002 on the property (URS Corporation 2003). The population remains small (approximately < 0.05 acres) but has not yet been completely eradicated. Other small populations such as this may exist along the Santa Clara River.

Perennial pepperweed is an herbaceous member of the Mustard Family (Brassicaceae) that reproduces by many small seeds it produces and vegetatively via a rhizome (http://www.cal-ipc.org/ip/management/ipcw/pages/detailreport.cfm@usernumber=58&surveynumber=182.php). It reaches heights of 4-8 feet at maturity. Leathery, ovate to oblong leaves are both basal and cauline. Many small, white flowers (and seeds 0.8-1.2mm) are produced on a panicle inflorescence in late May through early July. Seedlings have small, bright green cotyledons typical of annual mustards and are difficult to differentiate from other invasive members of the mustard family.

Native to southeastern Europe and western Asia, it invades many disturbed areas near water courses throughout California below 2,500m including: wet pastures, fields, grassland, saline meadows, canals, agricultural ditches, streambanks, and the edge of marshes. The mechanisms of its successful invasion include reproduction via seed

and root propagules and its ability to withstand flooding for long periods and saline conditions once established. The plants form large spreading clones under most moist conditions. Perennial pepperweed appears to successfully compete with other plant species for moisture, nutrients, and light.

Mechanical control and mowing of this species has been unsuccessful, since it can resprout from very small fragments (smaller than 3cm). Perennial pepperweed does not appear to survive lengthy periods of flooding during the growing season or high salinity levels (Young et al. 1997). Control of perennial pepperweed by grazing is not recommended since herbivores will only feed on the young leaves and, furthermore it is poisonous to many herbivores (Young et al. 1997). Biological Control methods are not an option due to safety considerations for host-specificity; there are too many valuable crop species in this family. Many herbicide treatments have been document to effectively kill the aerial portions of perennial pepperweed plants. The most effective herbicide control found is called chlorsulfuron, which works both in soil and on foliage. Hutchinson and Viers (2011) found that tarping *L. latifolium* infestations applied in combination with a mow and till treatment before tarping (Mow–Till–Tarp) had similar effects on control as herbicide treatments with Mow–glyphosate and with Mow–chlorsulfuron. However, they found the Mow–Till–Tarp treatment used extremely time consuming and may have the potential to limit native plant community recovery unless the area is actively revegetated.

Creeping water-primrose (Ludwigia peploides ssp. montevidensis)

During the 2005 vegetation mapping surveys, *Ludwigia peploides* (Kunth) Raven ssp. *montevidensis* (Spreng.) Raven (floating primrose-willow) was documented to occur within the 500-year floodplain (Stillwater Sciences and URS 2007). However, there are currently five species of water-primrose (*Ludwigia*) and two subspecies of *Ludwigia peploides* found in California, only two of which are native (Jepson Interchange - http://ucjeps.berkeley.edu/interchange.html) (Burkhart and Kelly 2005). These species are very difficult to differentiate based on plant morphology. Due to difficulties in distinguishing between species and subspecies of *Ludwigia*, researchers from UC Davis are conducting genetic testing of members of this genus and are creating a morphological key based on their findings (Brenda Grewell, pers. comm.). They have collected specimen from the Santa Clara River to positively identify and help in development of the key.

The non-native, invasive creeping water-primrose, *Ludwigia peploides* ssp. *montevidensis*, is a perennial aquatic plant member of the evening primrose family (Onagraceae) native to South America. *L. peploides* ssp. *montevidensis* can be found throughout California in rice fields, ditches, ponds, slow moving streams,

and along edges of lakes and reservoirs. At maturity it grows to 60-140cm in height. Stems are floating or creeping. Leaves are plants spreading-hairy and have glandular leaf tips. Fruit range from 25–40 mm in length. *L. peploides* ssp. *montevidensis* flowers in May through October with 5 bright yellow petals. This subspecies outcompetes native aquatic plants by forming dense, nearly impenetrable floating mats, rooting at the nodes, displacing native vegetation and open water habitat, and restricting fishing and boat access. Recent hydrologic changes in invaded wetlands may be the cause of its invasive spread throughout California.

Many control methods have been used with various levels of success to control *Ludwigia* species throughout California, including application of aquatic herbicide treatments (using air boats and track rigs), harvesting of dead biomass, and removal of dead biomass. Although these treatments appear to be successful initially, they have not proven to control *Ludwigia* species over time. Continual application of these control techniques and maintenance is required. Information regarding *L. peploides* ssp. *montevidensis* tolerance and response to a range of environmental conditions was researched by Grewell et al. (2006) to help inform water managers of most effective control. They found that as water depth increased shoot length, number of rooting nodes and branches, leaf area, relative growth rate and total plant biomass decreased. Plants growing at one meter in depth had the highest leaf mass ratio. At one meter depth, plants were not able to develop significant aerenchyma tissue as an adaptation to anoxia. Results of their study indicate that restoration of deep water habitat may help to suppress the spread of invasive *L. peploides* ssp. *montevidensis* in California.

Smallflower tamarisk (Tamarix parviflora)/salt cedar (Tamarix ramosissima)

Both *Tamarix parviflora* and *Tamarix ramosissima* were found growing along the Santa Clara River in small populations. Both species are members of the Tamaricaceae family and are known to invade river systems in throughout the arid southwest, inhabiting moist, saline soils. *Tamarix* species were introduced to the southwestern US in mid 1800s and have become naturalized as they spread westward due to their use as windbreaks, shade cover, erosion control, and as ornamental plants (Shafroth et al. 2005). Native to southeastern Europe, *Tamarix parviflora* is tree or shrub reaching between 1.5-5 meters tall. The branching twigs are covered in tiny linear leaves only 2 or 3 mm in length. The inflorescence consists of a dense spike flowers approximately 1-4 cm long that flower from March through April. Each small flower has four pink petals. Plants generally have four sepals, petals, and stamens.

Tamarix ramosissima is native to eastern Asia and may grow in the form of a tree or shrub up to 8 m tall. Leaves are small and linear (1.5-3.5mm long) with an acute to acuminate tip. Its inflorescence grows in a spike from 1.5-7cm in length. Petals are 1–2 mm and elliptic to oblanceolate. *Tamarix ramosissima* flowers from April through August. Plants generally have five sepals, petals, and stamens.

Both *Tamarix* species spread rapidly throughout streams and rivers via wind-dispersed seeds (Graf 1978). Their seeds are short-lived (only a few months in summer), have no dormancy requirements, and germinate in less than 24 hr. *Tamarix* species seeds require a moist, fine-grained (silt or smaller particle size) substrate to germinate, readily found in arid southwestern riparian habitats after flood waters subside. *Tamarix* species appear to be more tolerant of harsh environmental extremes (especially high salinity levels) than are native species. Graf (1978)describes *Tamarix* as an effective geomorphic agent due to its rapid colonization of moist sand surfaces, high growth rate, and ability to stabilize sediment. Like *Arundo, Tamarix* species form dense stands, often excluding other native species.

Tamarix spp. can be removed by hand, using herbicide application, cut-stump, or basal bark methods. When plants are small, hand pulling or using a weed wrench to uproot and remove individuals is most effective, insuring that plants do not resprout. If these removal methods are used, all biomass must be removed from the site. On smaller sites the cut-stump method (similar to that described for *Arundo*) has been found successful when triclopyr herbicides are used. Aerial application of imazapyr herbicide, alone or in combination with glyphosate, has been found effective at controlling *T. ramosissima* in dense stands where little or no native vegetation is present. On plants with a basal diameter of less than 4 inches, basal bark applications of Garlon4 have proven effective. Other herbicides and combinations of herbicides have been found effective on small infestations. A tamarisk biocontrol program was initiated in the 1960's, due to the difficulties and limitations found with mechanical and chemical control methods. After many years of testing, the leaf beetle *Diorhabda elongata* was released in the wild in 2001. By 2004, the beetles successfully defoliated vast stands (i.e., over 10,000 ha damaged at one site) at sites in northern Nevada (http://rivrlab.msi.ucsb.edu/tamarisk.php).

CHAPTER 5
EVALUATING SUCCESS OF INVASIVE PLANT REMOVAL AND REVEGETATION

Introduction

Evaluation of the success of restoration actions is an essential component of river ecosystem restoration (Jordan et al. 1987, Kondolf 1995a, Kondolf and Micheli 1995, The Federal Interagency Stream Restoration Working Group 1998, Downs and Kondolf 2002, Downs et al. 2002, Newhouser et al. 2005, Lennox et al. 2007, Stillwater Sciences 2008, Lewis et al. 2009). However, most invasive plant removal projects focus on monitoring the removal of the weed population from a site for only a short period based on funding availability or the minimum timeframe associated with mitigation requirements (1-5 years). Ecosystem recovery is the primary goal of invasive plant removal in river systems, not simply removal of the weed populations over the short term (Zavaleta et al. 2001). Riparian revegetation of invasive plant removal areas is an important component of recovery under many conditions (Coffman et al. 2004, Coffman 2007, Stillwater Sciences 2008). Therefore, evaluating success of invasive plant removal not only includes monitoring of removal of invasive plants, but riparian vegetation and riparian ecosystem recovery metrics as well. Also, many of these metrics should be measured over a much longer timeframe to insure that long-term sustainability of the riparian ecosystems is attained.

Millions of dollars are spent on *Arundo* removal throughout streams and rivers in California each year, utilizing limited funding and expending immense effort. To protect these investments and assure the most successful riparian ecosystem recovery, removal efforts must be located thoughtfully (see Chapter 4) and monitored carefully over the long-term both at the site-specific and watershed scale. Chapter 5 of the handbook focuses on monitoring strategies and conceptual techniques of both invasive weed removal as well as riparian vegetation recovery after invasive weed removal on the Santa Clara River.

Invasive weed removal and revegetation of riparian ecosystems on the Santa Clara River may be implemented for a variety of goals, including: habitat for migratory bird species, shade and passage for native fish, improved habitat for other riparian dependent wildlife species, recovery of a diversity of native plant communities after invasive plant removal, erosion control, fuel reduction for fire hazard, and/or wetland/riparian mitigation. Regardless of the restoration project goals, carefully planned monitoring is essential to evaluating performance or success of each project action relative to target trajectories and attainment of project goals and objectives. Success criteria or standards must be developed for each parameter of interest

monitored to evaluate the success of weed removal, planting, and long-term sustainability of the riparian ecosystem relative to restoration trajectories. A restoration action is deemed successful if parameters monitored fall along this trajectory. Kondolf (1995) stresses that all stream restoration projects constitute potential experiments, so we must adequately measure the relevant variables related to our restoration actions both before and for ten years after implementation.

Collection of baseline vegetation data for both current pre-restoration and historical conditions is essential for a meaningful comparison to post-project monitoring of riparian habitat revegetation success (Kondolf 1995b). We must carefully select monitoring variables related to riparian restoration project objectives, and adequately measure these relevant variables for a sufficient length of time (at least ten years) to understand riparian ecosystem recovery. Monitoring regrowth of invasive plants after removal is needed to properly retreat areas and insure long-term invasive weed eradication at each removal site. Revegetation monitoring will help to assure that riparian habitat is being restored to or maintained in areas in which invasive plants are removed. Also, monitoring assesses the need to implement contingency measures in the event that success or performance criteria are inadequately met.

Three types of monitoring are important to a complete restoration project assessment: implementation, effectiveness and validation monitoring (Kersher 1997). Detailed monitoring plans should include success criteria and metrics that evaluate each restoration action relative to all three types of monitoring. Implementation monitoring helps evaluate if the project implemented as planned. Effectiveness monitoring assesses if the restoration actions were effective at meeting the project goals and objectives. Finally, validation monitoring help answer the question: Are the basic assumptions behind the conceptual model developed for the project valid? We have integrated all three types of monitoring in our proposed set of success criteria and metrics for monitoring invasive plant removal and revegetation on the Santa Clara River.

Adaptive Management Framework

An adaptive management framework should be developed for the overall ecosystem restoration of the Santa Clara River to more effectively coordinate and implement restoration actions at the watershed scale. Adaptive management is a systematic process for continually improving environmental management (i.e., restoration recovery of various metrics) by learning from the outcomes of previously employed practices. In other words, if restoration actions are treated as experiments, monitoring will provide a scientific basis for changing management or restoration

actions to reset performance trajectories (Holling 1978). Monitoring strategies presented in this Chapter should be integrated into a larger adaptive management framework developed for the entire river system. An excellent example of a monitoring program for riparian restoration within an adaptive management framework is presented in the Lower Redwood Creek Restoration at Muir Beach: Geomorphic and Habitat Assessment Framework (Stillwater Sciences 2009).

We recommend forming a Santa Clara River technical advisory committee (TAC) to develop and help implement the river wide adaptive management framework. This framework should include TAC peer-review all restoration monitoring reports to continuously inform management decisions. Review of monitoring reports by TAC will help identify metrics that are not on an anticipated trajectory and identify appropriate change in management actions. In this way, analysis of the monitoring data will help to inform and assist in the efficacy of long-term management and recovery of each restoration area and the entire Santa Clara River. TAC should produce brief recommendation reports at the end of their evaluation period. The TAC should consist of a combination of botanists, plant ecologists, wildlife ecologists, and ecological managers working on the Santa Clara River and in similar coastal systems in California.

Monitoring Strategy for the Santa Clara River

The two main restoration actions discussed in this report are removal of target invasive plant species and revegetation of riparian habitat after removal. Monitoring must be conducted before and after both of these restoration actions in order to evaluate their success relative to targets established in the form of success criteria. California statewide monitoring frameworks for both of these restoration actions have been developed in the past few years. In this handbook, we propose various monitoring parameters for each of these actions and performance standards for each based on these statewide monitoring standards and results discussed in chapters 2 and 3 of this handbook.

The California Invasive Plant Council (CalIPC) developed the California Weed Mapping Handbook as a training resource for groups (i.e., Weed Management Areas) involved in wildland weed mapping (http://cain.ice.ucdavis.edu/weedhandbook). The primary goal of this handbook is to guide organizations working on weed issues to develop mapping systems that will support project goals on both a local and state level. The handbook provides two types of information, including: shared data mapping standards for State-wide comparison of data, and instructional information on mapping techniques.

The Southern California Coastal Water Research Project (SCCWRP) is developing the *Integrated Wetlands Regional Assessment Program (IWRAP)* that uses a three-level (tiered) approach to wetland assessment based on U.S. Environmental Protection Agency's (USEPA) Level 1-2-3 framework (USEPA 2006). This framework enables the USEPA and the State governments to determine whether their programs meet the prerequisites of Section 305b of the Clean Water Act (CWA). We recommend using a combination of these 3 levels of monitoring to evaluate success of removal of target invasive plant species and revegetation of riparian habitat after removal.

- Level 1 Assessment – Riverine wetlands inventory
- Level 2 Assessment - California Rapid Assessment Method (CRAM)
- Level 3 Assessment - Intensive site assessment/monitoring

Mapping the extent of riverine wetlands and riparian habitat on a revegetation area in GIS is an example of a Level 1 Assessment. We recommend using a combination of the US Army Corps of Engineers (USACE) wetland delineation protocol, California Department of Fish and Game riparian habitat delineation protocol, and US Fish and Wildlife Service protocol to map wetland types within the revegetation area (Environmental Laboratory 1987).

The California Rapid Assessment Method (CRAM) for evaluating the conditions of wetland ecosystems is an example of a Level 2 Assessment (Collins 2008). The primary goal of CRAM is to provide rapid, scientifically defensible, standardized, cost-effective assessments of the status and trends in the condition of wetlands and related policies, programs and projects throughout California (http://www.cramwetlands.org)(Collins 2008, 2009). It has been tested on various wetland types throughout California by the Southern California Coastal Water Research Project, San Francisco Estuary Institute, Moss Landing Marine Lab and Humboldt State University (Stein et al. 2009). Rapid assessments are used to evaluate the general condition of wetlands using field indicators. These methods provide standardized, cost-effective tools for land use planning and project evaluation. A rapid assessment method is especially helpful when full funding is not available for intensive monitoring or more frequent monitoring of a site.

CRAM was developed specifically for the wetland types of California, including riverine wetlands (and associated riparian habitats) associated with rivers like the Santa Clara River, as a tool to assess the status of and trends in the condition of wetlands throughout the state. It is designed to enable standardized ambient assessments at multiple scales: projects, watersheds, regions, and statewide. In addition, the Los

Angeles District of the USACE is in the process of adopting this rapid assessment method as part of their regulatory requirements for assessments of wetland impacts and for mitigation.

The goal of Level 3 monitoring is to generate more detailed information about the *condition* of *specific riverine wetland sites and their adjacent riparian habitat.* Level-3 monitoring facilitates an assessment of trends in the condition of sites over time, providing information about the success of specific restoration efforts or the success of wetland regulatory efforts. It can also yield insight into the spatial heterogeneity of certain indicators (such as faunal populations and plant community composition) within a given riverine wetland site, as well as facilitate studies on the relationships between specific stressors and the condition of wetland ecosystems. The minimum core indicators or variables for use in Level 3 monitoring that are recommended by the IWRAP are: CRAM, benthic macroinvertebrates, benthic algae, plant community composition, and amphibian species richness. Monitoring associated with restoration actions described in this handbook will focus on evaluation of extent and distribution of target invasive species; survivorship and growth of native riparian plantings; and plant community composition along transects perpendicular to the stream or river.

The Science Advisory Panel of IWRAP suggests that some of the same indicators recommended for Level 2 monitoring (CRAM) should be incorporated in Level 3, *but the primary indicators chosen should be those that answer project-specific questions.* Such questions may address causative factors for wetland/riparian habitat condition, or examine stressor response relationships (*e.g.*, as they relate to performance standards), in contrast to the kinds of indicators that are of interest for ambient monitoring.

Site-specific assessment of wetland/riparian habitat condition (Level 3 monitoring) is currently the most commonly practiced form of assessment in Southern California. These assessments are used in restoration and mitigation monitoring and for site-condition assessments conducted as part of the environmental review process when impacts to wetlands could occur. However, the State has not yet adopted standardized, detailed monitoring protocols developed for use in evaluating success of invasive plant removal or revegetation of riverine wetlands or riparian habitat. Site specific monitoring protocols for these restoration activities have typically been developed on a project by project basis. The California Department of Fish and Game (CDFG) have developed standardized conditions per their streambed alteration agreement that include performance standards. However, monitoring protocol and report format have not been standardized.

It is the intent of this Chapter of the Handbook to present monitoring strategies and an array of protocols for invasive species removal and revegetation of riverine wetlands and riparian habitat on the Santa Clara River (Level 3) that integrate into the IWRAP framework. A conceptual monitoring program for evaluation of invasive plant removal and riparian restoration success along the Santa Clara River was developed. This chapter includes proposed success criteria, metrics and monitoring protocols to meet the restoration goals and objectives of the Trustee Council, its parent agencies, and others (see Chapter 1). A more detailed and comprehensive monitoring program must be developed by a team of interdisciplinary scientists and managers familiar with the Santa Clara River, such as the proposed TAC. Success criteria targets should be continuously improved with results of reference sites studies and restoration project data analyses. Proposed monitoring designs should be refined by the TAC as well after further testing of various designs proposed under differing conditions is completed.

Monitoring Parameters

IWRAP recommends monitoring efforts should be focused on evaluating indicators of riverine wetland extent (area of riverine wetland/riparian habitat within a watershed or site), distribution, habitat condition (value to wildlife and riparian species), physical structure, and biotic structure (i.e. community abundance and composition).

The following is an array of recommended parameters that can help measure success of invasive plant species removal and riparian revegetation:

- Extent and location of invasive plant species
- Extent and location of riverine wetlands and riparian habitat (areal coverage)
- Riverine wetlands and riparian habitat quality
- Survivorship and growth of riparian plants installed
- Plant community composition (native and non-native)
- Plant species diversity
- Biomass of invasive species
- Wildlife species surveys

Setting Success Criteria

Success criteria describe measurable attributes that can be used to evaluate success in meeting the goals and objectives of a restoration project or activity. Success criteria (also called performance criteria or standards) and associated metrics describe a desired state, threshold value, amount of change, or trend to be achieved for a particular

population or habitat characteristic over time after a restoration action is implemented. Performance metrics are used to guide site management activities (adaptive management) during the post project monitoring period and may be used as benchmarks measured during the final monitoring to evaluate success of habitat, population, and/or ecosystem recovery.

Proposed success criteria were developed to measure success of riverine wetland and riparian habitat restoration associated with removal of invasive plant species and native plant revegetation. The eight success criteria developed were based on the parameters recommended by the Science Advisory Panel of IWRAP for Level 3 monitoring of invasive plant species removal and riparian revegetation. Success criteria and associated metrics were developed for this handbook to evaluate the success of the following restoration objectives: invasive plant species eradication (see Success Criteria A and C); riparian plant establishment, health, and growth (see Success Criteria D, E and F); extent of riverine wetlands and riparian habitat restored (see Success Criteria B and C); and wildlife use of restored habitat (see Success Criterion G). Also, long-term sustainability of riverine wetlands and riparian habitat restored should be monitored and evaluated relative to established success criteria over a 30 year period (see Success Criteria C and H).

The California Department of Fish and Game's standard Stream Alteration Agreement (SAA) conditions for riparian restoration actions in Southern California and several project specific SAA conditions were reviewed in the process of writing this handbook. We made recommendations for updating survivorship and growth (mean height) metrics of three riparian tree species and one shrub species after 1 and 2 years under various soil moisture and light conditions based on our research (see Chapter 3). However, all other metrics were developed based on professional restoration experience and other ecological studies in which we have been involved throughout Southern California. Success criteria and metric targets should be updated as new ecological data become available related to invasive plant removal and revegetation with native riparian plant species. These success criteria targets were developed primarily for reaches of the Santa Clara River with high soil moisture and groundwater tables similar to HRNA. In drier reaches of the Santa Clara River, success criteria should be evaluated and modified by TAC on a case by case basis until data is available from reference sites to understand plant performance and natural vegetation in these areas (such as the alluvial scrub vegetation type).

We recommend including as many of the eight success criteria and associated 24 metrics as possible when developing a Monitoring Plan for an invasive species removal

and riparian revegetation project on the Santa Clara River. We recognize that time and budget constraints might prevent use of all of these. The Santa Clara River TAC should be involved in guiding organizations proposing restoration activities as to the most important success criteria and metrics for their project. Measures D4 and G3 should only be used if site conditions meet the descriptions below. Details of each of these success criteria are as follows:

NOTE: If any of these performance metrics are not met after the stated monitoring timeframes, a contingency plan must be implemented and replacement plantings installed between years 1-10 of monitoring. If you must replant some of the riparian cuttings or take some other remedial action to reset the restoration trajectory, the monitoring period for those replacement plants or invasive plant removal must be reset to time 0. Year 1 monitoring will start at the end of the growing season of the following year and continue for the next 10 years.

Success Criterion A: Extent of Invasive Plant Species

Metric A1 (Monitor in Years 1-10)
The following target invasive plant species shall be completely removed from the weed removal/riparian planting areas: *Arundo donax*, *Lepidium latifolium*, *Ludwigia peploides* ssp. *montevidensis*, *Tamarix parviflora*, or *Tamarix ramosissima*) by the end of the 10 year monitoring period. During the first 3 years, less than 5% of the originally mapped acreage of each of these species is acceptable while control and maintenance measures are ongoing. From year 4 – 9, extent of these 5 invasive plant species should be < 1% cover or better of the entire site.

Success Criterion B: Extent of Riverine Wetlands and Riparian Habitat

Metric B1 (Monitor in Years 1, 2, 5 and 10)
The extent of riverine wetlands and riparian habitat as defined by the USACE/USEPA, USFWS, and CDFG must meet minimum mitigation goals (target ratio or acreage cited in the permit) 1 year after planting riparian and/or wetland plants. For non-mitigation restoration projects, the extent of riverine wetlands and riparian habitats should measure within 10% of the target extent (below or above) 1 year after riparian planting and remain within 10% for the 10 year monitoring period.

Success Criterion C: Quality of Riverine Wetland and Riparian Habitat

Metric C1 (Monitor in Years 1-10, 15, 20, 25, and 30)
Using the California Rapid Assessment Method (CRAM), the revegetation area must attain a score within 10% of the CRAM score for Riverine Non-confined reference sites along the Santa Clara River by the next growing season after both invasive species have been removed and native riparian and wetland plants installed (or by year 5 at the latest).

Success Criterion D: Survivorship, Health and Growth of Riparian Plantings

Metric D1 (Monitor in Years 1, 2, and 5)
Riparian tree and shrub species planted in the revegetation area must achieve at least 80% survivorship one year after the site is revegetated. Note each species must attain 80% survivorship (not a combined 80%). Of the year 1 survivors, 95% must survive after 2 and 5 years.

Metric D2 (Monitor in Years 1, 2 and 5)
80% of all planted riparian species (individual species analyzed separately) that survive in riparian area must achieve a health (vigor) rating of 3 or higher one year after the site is planted. 95% of the planted riparian species (individual species analyzed separately) must have a health rating of 3 or 4 during monitoring in Years 2 and 5.

Metric D3 (Monitor in Years 1 and 2)
Native riparian trees and shrub species planted should have a mean cutting diameter 10% larger than the year before or found within the range of each species of similar age at the reference site(s) chosen.

Metric D4 (Monitor in Years 1 and 2)
If the following 3 native tree species and 1 shrub species are used in revegetation actions, their mean heights must be within 10% of the mean heights of each species shown in Table 4 per the revegetation area's soil moisture and light availability.

Metric D5 (Monitor in Year 5)
Native riparian species must achieve at least a combined aerial cover of 50% in the planting area 5 years after planting.

Metric D6 (Monitor in Years 5 and 10)
All riparian species must achieve a health rating of 3 or higher 5 years and 10 years after planting.

Metric D7 (Monitor in Years 5 and 10)
Native riparian trees and shrub species planted should have a diameter breast height (dbh) within the range of each species of similar age at the reference site(s) chosen.

Metric D8 (Monitor in Year 10)
Native riparian species must achieve at least 70% aerial cover in the planting area.

Metric D9 (Monitor in Year 1, 2, 5 and 10)
Biomass of each native tree and shrub species (estimated based on a volume calculation) must be within 10% of the same species found in the reference site.

Success Criterion E: Plant Species Diversity

MetricE1 (Monitor in Years 1-10)
The Shannon-Weiner Diversity Index for all native trees, saplings and shrubs (both planted and naturally recruited) in the revegetation site must measure within 10% of the reference site(s) chosen.

Metric E2 (Monitor in Years 1-10)
Species richness for all native plants (both planted and naturally recruited) in the revegetation site must measure within 10% of the reference site(s) chosen.

Success Criterion F: Plant Community Structure and Composition

Metric F1 (Monitor in Years 1, 2, 5 and 10)
The restored native riparian plant community must be composed of a diversity of life forms (also called growth forms). The riparian restoration area must have at least the following number of species and absolute % aerial cover in each of 5 strata as defined in the monitoring protocol section of this chapter (see Table 7).

Metric F2 (Monitor in Years 1-10)
Non-native plant species (other than the 5 target invasive species) should consist of less than 10% total absolute cover in years 1 – 3, less than 5% in years 4-10.

Metric F3 (Monitor in Years 5 and 10)
The restored native riparian plant community must be composed of a diversity of life forms, with varied heights occupying at all strata. The restored riparian habitat must have at least 10% of each life form in one or more of the height classes. (More study of reference sites is needed to better define the targets for this metric.)

Success Criterion G: Wildlife Activity in and near Restored Riverine Wetlands and/or Riparian Habitat

Metric G1 (Monitor in Years 1-10)
Used as an indicator of revegetation success, bird species diversity and abundance relative to reference site(s) with the same soil moisture and light levels chosen will measure the following: Year 1 (50%), Year 2 (40%), Year 3 (30%), Year 4 (20%), and Years 5-10 within 10% or greater than.

Metric G2 (Monitor in Years 1-10)
A diversity of common and rare native wildlife species use of the revegetation areas shall be recorded (tracks, faeces, visual observation, or sound) in and around the riparian revegetation area while annual bird surveys are being conducted. Diversity and abundance of common wildlife species relative to reference site(s) chosen will measure the following: Year 1 (50%), Year 2 (40%), Year 3 (30%), Year 4 (20%), and Years 5-10 within 10% or greater than.

Metric G3 (Monitor in Years 1-10)
If a portion of the Santa Clara River or its tributary runs within the revegetation area, native fish use adjacent to the revegetation area shall have a species diversity and abundance measuring the following relative to that of the reference site(s) chosen: Year 1 (70%), Year 2 (60%), Year 3 (50%), Year 4 (40%), and Years 5-10 within 30% or greater than.

Success Criterion H: Long-term Sustainability of Ecosystem

Metric H1 (Monitor in Years 15, 20, 25, and 30)
Non-native plant species (other than the 5 target invasive species) should consist of less than 5% absolute cover.

Metric H2 (Monitor in Years 15, 20, 25, and 30)
The 5 target invasive species should not be present on the revegetation site.

Metric H3 (Monitor in Years 15, 20, 25, and 30)
The riverine wetland and/or riparian habitat revegetated must have 60% total absolute aerial cover or greater of native riparian plant species (in the absence of flooding or wildfire).

Metric H4 (Monitor in Years 15, 20, 25, and 30)
The riverine wetland and/or riparian habitat revegetated must measure within 5% of the area attained in Year 10 of monitoring or greater (if Performance Measure B1 is met in Year 10) (in the absence of flooding or wildfire).

Developing the Monitoring Approach and Sampling Design

The approach chosen for monitoring a restoration area depends on the success criteria and metrics selected. The size (area), configuration, and fluvial geomorphic location of the restoration area relative to the active floodplain and low flow channel of the Santa Clara River will determine the sampling design. We recommend the following approaches and sampling design strategies for revegetation areas along the Santa Clara River.

Monitoring Approach

Table 8 lists recommended approaches for monitoring of each metric associated with the specific success criteria.

Sampling Design

Permanent long-term monitoring plots, transects (permanent or randomly selected), or the combination of the two may be used to monitor success criteria, depending on the size (area), configuration, and fluvial geomorphic location of the restoration site relative to the active floodplain and low flow channel of the Santa Clara River. Sampling designs for each restoration area should be consistent among sites with similar conditions. Since many physical conditions (i.e., depth to groundwater, soil moisture availability, geomorphic location etc…) exist along the Santa Clara River, the TAC should be involved in sampling design for all revegetation efforts.

Plot-based Sampling

Permanent, long-term monitoring plots may be established in revegetation sites that are both small (generally less than 1 acre or less than 100 riparian plantings) and situated entirely in one geomorphic location (i.e., the active floodplain or floodplain terrace); and those sites located far from the influence of the Santa Clara river hydrology (floodplain terrace). Also, riparian plant survivorship, health and growth metrics are best measured in permanent long-term monitoring plots (but may be located along transects for efficiency of access).

We recommend using the following plot sizes (Coffman 2000):

- Herbaceous plant stratum ($1m^2$; 3.28ft x 3.28ft square quadrat)
- Shrub and vine strata ($25m^2$; 16.4ft x 16.4ft square)
- Trees stratum ($100m^2$; 32.8ft x 32.8ft square)

All plots of the same vegetation type to be analyzed in a study must be the same size (area not necessarily exact configuration). Plot shapes are dependent on the vegetation type. If the riparian revegetation area or plant strata are linear, the plot should be configured to this area. Plot dimensions should not go beyond the community's natural ecological boundaries.

At least 5 permanent, long-term monitoring plots should be randomly located within the revegetation area using a grid overlaid on the sampling area. For each long-term monitoring plot, the center of the tree, shrub and herbaceous strata sampling area should be nested according to Figure 13 (Ponce-Hernandez 2004). The center of each permanent plot should be GPSed and permanently marked with rebar.

Transect-based Sampling

The transect-based monitoring design presented was based on a protocol developed for the USEPA in Calleguas Creek watershed for sampling riparian vegetation in southern California (Coffman 2000). We amended this riparian vegetation sampling protocol for use in monitoring performance of riparian revegetation projects (Lennox et al. 2007). Success of invasive plant removal and riparian revegetation may be monitored quantitatively and efficiently along transects placed perpendicular to the river across various restoration treatments or geomorphic landforms along the Santa Clara River.

Transect-based sampling is recommended for planting areas that extend across the river or cover multiple landforms – both active floodplain and floodplain terrace or those located along smaller tributaries to the Santa Clara River. Vegetation transects are typically placed along permanent cross-sections surveyed in fluvial geomorphology studies to understand vegetation dynamics over time or distribution of plant assemblages relative to physical gradients in a river system. Sampling vegetation along transects located at cross-sections helps ecologists to understand the relationship between physical factors of fluvial geomorphology (location relative to disturbance), distance to standing water/water table, and vegetation composition. Sampling along transects in revegetation areas can help with direct comparisons to reference and control sites at similar landform positions, and to evaluate reasons for success of plant species relative to varying physical conditions in each landform or treatment.

Vegetation transects should be positioned along an established cross-section if possible or perpendicular to stream or river flow if permanent cross-sections are not present in the revegetation area. At each revegetation area along a river or stream reach, at least three transects should be randomly chosen, perpendicular to the flow of water and at least 50 meters from one another. Landforms and/or restoration

treatment areas (i.e., each revegetation area with a differing plant planting palette or plant composition) should be visually delineated along the length of each transect and 20 meters perpendicular to each transect. The linear distance of each restoration treatment or landform along the transect should be measured and recorded..

Geomorphological landforms on the Santa Clara River were defined using a combination of sources. The main landforms consist of: low flow channel(s) (wetted width during the summer months), channel bed (from wetted width of low-flow channel to terrace bank), and/or floodplain/terrace (from terrace bank to the valley floor) (Figure 13). We define the combination of the channel bed and the low-flow channel as the flood reset zone. The floodplain/terrace boundaries are difficult to delineate on the Santa Clara River due to channel incision. Giessow et al. (2011) further defined landforms for mapping *Arundo* in rivers of southern California based on amount of vegetation present (level of flood disturbance):

- ***Low-flow Channel*** – The part of the main channel where water is flowing at the time of aerial photos. In those cases where the riverbed is dry, the area appearing to have the most recent flows was delineated as low flow.
- ***Bar/Channel/Floodplain - unvegetated*** – Main channel or floodplain areas with less than 50% vegetation cover, usually consisting of bar surfaces, dry channel beds, or recent deposition or scour.
- ***Floodplain - vegetated*** – Areas on the river floodplain with more than 50% vegetation cover.
- ***Floodplain/Low Terrace – vegetated*** – Areas on either the river floodplain or an adjacent low terrace with more than 50% vegetation cover.
- ***Upper Terrace - vegetated –*** Areas on higher ground adjacent to the low terraces with more than 50% vegetation cover. The mapping did not go beyond levees or roads in most cases.

According to the belt grid transect method, vegetation will be sampled in five plots located randomly within each landform or restoration treatment according to a grid system (x coordinate along the survey tape and y coordinate 20m perpendicular to the transect) (Figure 13). A survey tape should be laid out along the transect length. Starting at one end of the transect, five random locations should be chosen (using a random number generator) along the survey tape within the length of the highest landform. These locations may be marked with pinflags (or write on your data form) for ease of location – this will mark the x coordinates of each sampling location in this landform/treatment. Find five random numbers for your y coordinates (within the 20m width of the belt transect). The sampling locations are found by starting at each pinflag and using the 1 m^2 quadrat as a measuring device to find the y coordinate. This

procedure should be used to locate plots and sample plant metrics in five quadrats in each of the remainder of the landforms/treatmenst along all transects.

Selecting Reference Sites

Carefully selected reference and control sites can provide a useful context for evaluating the trajectory of each ecosystem attribute using a suite of success criteria and eventually interpreting overall project success (Lewis et al. 2009). At least one reference site (preferably multiple sites if possible) and one control site exhibiting similar physical characteristics to the revegetation site should be identified, sampled, and used for comparison to the revegetation area. A reference site is a natural area that represents the ideal restored conditions or the least anthropogenically altered conditions found in the same watershed and subject the same physical conditions. For the purposes of this handbook, a suitable reference site consists of healthy riparian habitat or riverine wetlands – a site completely free of *Arundo* and other invasive weeds exhibiting high plant species diversity, vegetation structure, and wildlife use. The suitable reference site must have similar physical conditions to the proposed revegetation site, including: depth to groundwater, soil moisture content, soil texture, and geomorphic landform position. Whereas a control site consists of a river reach or smaller area within one morphological landform in the vicinity of the proposed restoration site that is similar in terms of human and natural disturbance, but has not received any restoration treatments. Ideally, the TAC would select these reference sites and the UC Research Station and Conservation Center scientists would monitor these over time to determine the most appropriate success criteria targets for each physical condition along the Santa Clara River.

Physical characteristics such as soil texture, soil moisture and light availability conditions, depth to groundwater, stream order, and stream gradient should be assessed throughout the restoration site in order to identify an appropriate reference site. Currently, there are only a few areas in the low gradient reaches of the Santa Clara River that may be good candidates for use as reference sites (where *Arundo* and other invasive plants are absent). These potential reference sites occur primarily on the floodplain terrace landform. We have identified ten potential reference site locations along the Santa Clara River during vegetation mapping in 2005 and assessment of the current aerial photography (Figure 14) (Stillwater Sciences and URS Corporation 2007). However, this list is not meant to be exhaustive, just a starting point in the identification of reference sites.

Portions of HRNA contain the largest, most natural riverine wetland and riparian habitat conditions in the low gradient portions of the Santa Clara River. Active and passive restoration actions on HRNA have created a mosaic of natural riverine wetland and riparian vegetation types in which *Arundo* has been completely removed. HRNA is not a typical reference site since much of the riverine wetland and riparian habitat on the property was actively restored, however it still represents the most natural conditions along the River. The 2011 final monitoring report for restoration at HRNA will be useful for identifying reference sites (in preparation). The most natural riparian conditions in the watershed occur in much higher gradient tributaries to the Santa Clara River (i.e., Sespe Creek) and exhibit differing riparian habitat characteristics due to differing physical conditions.

Since reference sites and conditions on the Santa Clara River may be difficult to identify and access, historical vegetation conditions of the proposed restoration site may be investigated to better understand reference conditions relative to the site. Historical information, such as aerial photographs, maps, ground photography and land and biological survey records can be used to establish prior conditions (Palmer et al. 2005). The Ventura County Historical Ecology study documents historical landscape patterns and ecological and hydrologic dynamics and trends along the main stem of the Santa Clara River in Ventura County by synthesizing an array of historical records (Beller et al. 2011). Chapter 3 of this study presents historical maps and photos as well as a narrative describing the historical distribution, abundance, and functions of the pre-European riparian habitats and riverine wetlands of the lower Santa Clara River. The Ventura County Historical Study created a geo-database containing a comprehensive dataset of historical aerial photos of the reaches of the Santa Clara River located in Ventura County (contact Erin Beller at SFEI for review of the geo-database, erin@sfei.org). In addition, interviews with current or former land owners of the proposed restoration site and adjacent properties may be helpful in understanding historical vegetation conditions of this site.

Monitoring Protocol and Methods

Extent of Invasive Plant Species

As part of the baseline conditions assessment for a proposed restoration area, the extent and location of each of the following target invasive plant species must be mapped. These species should be mapped during the growing season before the plant populations will be removed and each year of the 10 year monitoring period: *Arundo*

donax, *Lepidium latifolium*, *Ludwigia peploides* ssp. *montevidensis*, *Tamarix parviflora*, and *Tamarix ramosissima*. Mapping should be done using a Trimble GPS XH or XT unit (and the GPS Pathfinder ProXH receiver) or similar GPS with sub-foot accuracy if at all possible to get an accurate estimate of extent of each weed. For each monoculture infestation, the extent of the population should be mapped with a GPS polygon feature. In areas where invasive weeds and native plants are mixed and cannot be easily separated to GPS individual populations, the associated percent cover of each weed species in the infested area should be estimated and its phenological stage noted (Newhouser et al. 2005). After collected, the GPS data should be uploaded to a GIS geo-database GIS data and be reported each year for the duration of the 10 year monitoring period to Calflora using the Cal Weed Mapper tool (http://www.calweedmapper.org/).

Extent of Riverine Wetlands and Riparian Habitat

The extent and location of riverine wetlands and riparian habitat as defined by the USACE/USEPA and CDFG must be determined one year before the proposed restoration actions are implemented and again in years 1, 2, 5 and 10 of monitoring. Potentially jurisdictional waters of the U.S., including wetlands (i.e. riverine wetlands), must be delineated on the proposed restoration site using the U.S. Army Corps of Engineers Wetlands Delineation Manual and the Arid West Supplement (Environmental Laboratory 1987, U.S. Army Engineer Research and Development Center 2008). In combination, these manuals provide technical guidance and procedures for identifying and delineating wetlands that may be subject to regulatory jurisdiction under Section 404 of the Clean Water Act or Section 10 of the Rivers and Harbors Act. Wakeman and Fong (1984) provide additional guidance for identifying and delineating USACE potentially jurisdictional wetlands in riparian areas. Also, the USACE Sacramento District web site contains more information related to delineations of wetlands as defined by the USACE and USEPA(http://www.spk.usace.army.mil/organizations/cespk-co/regulatory/delineations.html).

Riparian habitat must be delineated before the onset of invasive weed removal or revegetation and during the monitoring period (years 1, 2, 5 and 10). Riparian habitat should be identified and delineated according to the CDFG guidelines for stream delineation. CDFG Code 1600 regulates riparian vegetation associated with streams and lakes. These areas are often more expansive than extent of USACE jurisdictional wetlands, however much less guidance is available for delineating riparian habitats. The CDFG Environmental Services Division developed “A Field Guide to Lake and Streambed Alteration Agreements, Sections 1600-1607, California Fish and Game Code” that

provides some guidance for determination of the geographical extent of those areas under state jurisdiction (California Department of Fish and Game Environmental Services 1994). The outer edge of riparian vegetation is generally used as the line of demarcation between riparian (including wetland) and upland habitats and is therefore a reasonable and identifiable boundary for the lateral extent of a stream for protection. For streams that contain riparian vegetation along their edges, the outer drip line of the riparian vegetation shall be used to determine the extent of the stream. The outer drip line shall be estimated by walking under the tree canopy and then moving outward such that a vertical line from the ground to the sky is not covered by any tree canopy associated with riparian trees or shrubs.

Quality of Riverine Wetland and Riparian Habitat

CRAM should be used to assess the condition of riverine wetlands and riparian habitat on each proposed restoration area along the Santa Clara River before the restoration actions are implemented and during post-project monitoring years 1-10, 15, 20, 25 and 30 (Collins 2008, 2009). Using the CRAM Riverine Wetlands Field Book, four attributes (buffer and landscape context, hydrology, physical structure, biotic structure) are assessed to fully understand the pre- and post-project short-term efficacy of the restoration actions and the long-term sustainability of these actions. The CRAM scores for each revegetation area will then be compared to scores for reference riverine wetlands along the Santa Clara River to evaluate the effect of restoration actions on the area. CRAM assessments were completed before (in 2010) and one year after *Arundo* removal on a 250-acre site located along the floodplain of the Santa Ana River near Corona, CA. Overall scores have increased significantly (especially for biotic and physical structure attributes) only one year after removal when reassessed in July 2011 (Lindsay Teunis pers. comm.).

A full CRAM assessment takes an average of 4 hours to complete, but may vary between 2-6 hours depending on access, size, and density of vegetation in the assessment area. The first pre-project assessment may take up to 6 hours in order to identify the assessment area. CRAM assessments completed after project implementation should take less time on average. We highly recommend that CRAM assessments are carried out by a pair of certified CRAM practitioners to insure consistency among assessments.

Survivorship, Health and Growth of Riparian Plantings

Riparian plant survivorship, health and growth metrics (implementation metrics) are best monitored in permanent plots during the middle of the growing season. At least five replicate plots should be established in each revegetation treatment area. Survivorship should be measured at years 1, 2 and 5. In each replicate permanent plot, count and record the number of each species that is alive and dead.

Health rating should be evaluated during the middle of the growing season in years 1, 2, 5, and 10. Assess the health of each plant installed in the permanent plot and record its rating on your data form.

We recommend using the following health rating system:

4 = healthy, robust, vigorous; all leaves are green

3 = robust; a couple leaves are lighter in color or some insect damage

2 = many leaves light green in color; smaller in stature due to herbivory or other stressors

1 = most leaves very light green or white; very small in stature; heavy damage from herbivory

0 = plant dead; all above ground biomass dead

Growth metrics should be used to measure each native riparian plant within permanent plots or transects. Sampling should occur in the middle of the growing season within during the following years associated with each growth metric as described below:

- **Cutting diameter (monitor years 1 and 2)** – Each cutting diameter should be measured at three locations (10cm from the ground surface, in the middle of the cutting and 2.5cm from the top of the cutting) along each native riparian tree or shrub cuttings. The average cutting diameter should be calculated.
- **Height (monitor years 1 and 2)** – The height of each riparian plant installed should be measured. Without moving the plant to measure it, the height of the tallest branch or leaf should be measured perpendicular to the ground surface.
- **Absolute total percent cover (monitoring years 5 and 10)** – The absolute percent cover of all riparian plant species should be estimated within each replicate plot along each transect or each permanent plot.

- **Diameter breast height (dbh) (monitoring years 5 and 10)** – Diameter at breast height (dbh) of each riparian tree and shrub species planted should be measured in each replicate plot along each transect or permanent plot.
- **Volume (monitoring years 1, 5 and 10)** – Biomass should be estimated based on volume calculated for each riparian tree and shrub. The following tree measurements must be made for each tree sampled: height, dbh, length of crown (branches and leaves in the tree canopy), average width of the crown (2 perpendicular widths), and height of trunk from base of the crown to the ground. Tree volumes can be calculating trunk volume and crown volume and adding them together. Trunk volume can be estimated by imputing dbh and trunk height into the formula for a cylinder: $Trunk\ Volume = h \times \pi(dbh/2)^2$. Crown volume can be estimated by using the formula for the shape of the crown and plugging in the height of the crown and average width.
    - **Volume of a cone** – $Volume = \frac{1}{3}rh$, where h = total height of tree – trunk height.
    - **Volume of a hemisphere** –$Volume = \frac{2}{3}\pi r^3$

The volume of the crown estimated by these equations is the gross total volume. However, much of this volume is empty, interstitial space. The actual proportion of the volume occupied by branches and leaves should be estimated by standing beneath the canopy, beside the trunk, and carefully estimate the % canopy structure versus interstitial space. This proportion is then used to discount the air space in the crown volume: solid volume = V (m^3) × proportion of branches and foliage in crown volume. Shrubs volume can be simply estimated by these procedures, but by leaving out the trunk estimation step.

<u>Plant Species Diversity</u>

Both species diversity and richness should be sampled in either permanent plots or transects annually for 10 years. The Shannon-Weiner Diversity Index should be calculated for all native trees, saplings and shrubs (both planted and naturally recruited) in each the revegetation site. The index combines two quantifiable metrics: species richness (number of species within the planting area or plant community) and species equitability (how even are the total numbers of species). To calculate the Shannon-Weiner Diversity Index, the total number of species (per unit area) and the frequency

each species occurs in each plot (density/unit area) must be tallied. The formula for the Shannon-Weiner Diversity Index is:

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$

Where S is the total number of species and p_i is the frequency of the *i*th species.

Species richness should be calculated for all native plants (both planted and naturally recruited) in each revegetation site. Species richness is the number of native species per unit area.

Plant Community Structure and Composition

Plant community structure and composition metrics should be monitored in years 1, 2, 5, and 10 as follows. These metrics can be sampled either in permanent plots or in plots located along belt grid transects. We recommend the following protocols for each metric based on a combination of the California Native Plant Society (CNPS) guidelines and standard plant ecology sampling protocol. However, we recognize that many other protocols are available and the TAC should refine these methods in their detailed Monitoring Plan for the River.

- **Absolute percent cover** - Each plant found in permanent plots or plots along transects should be identified to species and recorded. Percent cover should be estimated to the nearest 1% within the first 10% and to the nearest 5% from 15%-100%. Percent cover is considered the proportion of the ground occupied by a perpendicular projection of the aerial parts of individuals of a species (Moore and Chapman 1986). When estimating percent cover, it is often helpful to think of coverage in terms of the following cover intervals at first:

  <1%, 1-5%, >5-15%, >15-25%, >25-50%, >50-75%, >75%.

  Keeping these classes in mind, then refine your estimate to a specific percentage***. Note: All field staff estimating percent cover must be trained by a member of the UC Reserve staff to insure consistency in estimation of percent aerial cover.***

- **Plant growth forms** - For each plant species that absolute percent cover is recorded, plant growth forms must be recorded. Growth forms indicate functional groups within a plant community, including: trees, saplings, seedlings, shrubs, vines, graminoids, and forbs. However, the CNPS Vegetation Program classifies plants into 6 strata: tree, seedling, sapling, herbaceous, vine and non-

vascular (will likely not be found on the Santa Clara River). We recommend using a combination of these two methods, by recording the following functional groups as defined by CNPS and Hickman (1993):

- **Tree** = A woody perennial plant that has a single trunk
- **Shrub** = A perennial, woody plant, that is multi-branched and doesn't die back to the ground every year
- **Seedling** = A tree species clearly of a very young age that is < 1" dbh.
- **Sapling** = 1" - <6" dbh and young in age, OR small trees that are < 1"diameter at breast height, are clearly of appreciable age, and kept short by repeated browsing, burning, or other disturbance.
- **Vine** = a trailing or climbing plant, sometimes attaching to its support by tendrils.
- **Graminoid** = grasses (family Poaceae) and grass-like plants such as sedges (family Cyperaceae) and rushes (family Juncaceae).
- **Forb** = a non-woody (herbaceous) flowering plant other than a grass, sedge, or rush.

- **Native vs. non-native status** – For each plant species identified in a permanent plot or along a belt grid transect, native or non-native status should be recorded for each.
- **Height class** - According to the California Native Plant Society (CNPS) and California Wildlife-Habitat Relationships (CWHR), the size/height class should be recorded for tree, shrub, and/or herbaceous categories (vines, graminoids and forbs combined) (http://www.cnps.org/cnps/vegetation/pdf/protocol-combined.pdf). These three categories are based on functional life forms. An estimate of height for each functional life form in a plot should be made using the height intervals listed below.
  - **Height Classes:** 01 =< 1/2m, 02=1/2-1m, 03 = 1-2 m, 04 = 2-5 m, 05 = 5-10 m, 06 = 10-15 m, 07 = 15-20 m, 08 = 20-35 m, 09 = 35-50 m, 10 => 50m.

Record an average height value per each category by estimating the mean height for each life form. An individual plant is recorded in only one layer, according to the height of the tallest point on that individual and its life-form.

- **Collection of voucher specimen** - One voucher specimen for each species should be collected, pressed and mounted to show positive identification of all species recorded for on a restoration area. We recommend that the UC Research Station and Conservation Center keep a herbarium of plants collected along the River.

Wildlife Activity in and near Restored Riverine Wetlands and/or Riparian Habitat

We recommend these metrics should be evaluated based on point counts (and replicates) located within each revegetation area (typically 3 during the breading season for birds) not on USFWS protocol surveys. More work is needed to better understand the most appropriate metrics and targets for the Wildlife Activity success criterion and associated metrics. These must be developed further by a team of wildlife biologists and plant ecologists familiar with the Santa Clara River birds, fish, and other wildlife and the Santa Clara River TAC. The Trustee Council supported restoration on a portion of HRNA as well as bird and other wildlife surveys associated with these activities. The final report will be completed in summer 2011 and should be used to develop this criterion and metrics. Other organizations and resources that we recommend using to develop these include: Western Foundation of Vertebrate Zoology (http://www.wfvz.org/), Riparian Habitat Joint Venture (http://www.rhjv.org/), and Point Reyes Bird Observatory (http://www.prbo.org/).

Long-term Sustainability of Ecosystem

Protocol for collecting metrics for long-term sustainability of riparian ecosystem restoration actions are as follows:

- **Percent cover of non-native plant species** – Percent aerial cover of non-native plant species (other than the 5 target invasive species) should be estimated. See plant community structure and composition for detailed methods.
- **Survey extent of 5 target invasive species** – Resurvey for 5 target invasive species and GPS the extent (area) of each as a polygon if present**.**
- **Percent cover of native riparian plants species** – Percent aerial cover of native riparian and wetland plant species should be estimated. See plant community structure and composition for detailed methods.
- **Survey extent of riverine wetland and/or riparian habitat** – Resurvey the extent of riverine wetlands and riparian habitat as discussed earlier.

Photo Monitoring

Photo monitoring is simple yet illustrative tool often used in long-term monitoring studies, including restoration project monitoring. The goal of long-term photo monitoring in restoration projects is to detect visual change due to the restoration action over time. Typically, photo monitoring helps in understanding of vegetation and channel form change and is used to evaluate the long-term success of restoration actions.

Location of each photo station should be strategically chosen, anticipating potential rapid growth of riparian plants over time (see photo monitoring examples from HRNA in Appendix B). We recommend placing at least one station in a location higher in elevation in order to get a landscape overview photo. At least 10 photo stations should be carefully established throughout each revegetation area (more stations if the site is larger or there are more invasive plant removal areas) to show a diversity of removal areas, planting locations, vegetation types, and invasive plant removal areas. If transects are used in the vegetation monitoring approach. One photo station should be placed at each transect. If long-term monitoring plots are the chosen approach, photo stations should be established at each of these.

When establishing each photo station, record a GPS location and compass reading for each photo point. A permanent marker such as a piece of rebar can be installed to ensure exact relocation. If possible, all photos should have a permanent landmark in the photo (i.e., mountain, large tree, transmission line etc…) so that they are easy to locate. A map of the photo monitoring plots should be created and included in the Monitoring Plan.

Photo stations must be established at least one growing season before the restoration project is implemented; immediately before and after removing invasive plants; and immediately before and after planting. Photos must be taken at each monitoring station twice a year during years 1-2 and once a year from years 4-10 and in year 15, 20, 25 and 30. In the first 3 years, photos should be taken immediately after planting in the winter (and at this same time for years 2 and 3). In all years, photos must be taken from photo stations consistently in the middle of the growing season (i.e., usually sometime in July). Ideal timing of photo monitoring is during the same timeframe as the vegetation monitoring.

Using Volunteer Labor

Adequate implementation of a restoration monitoring plan can consume more time and funding than is often available. Student interns, community volunteers, and members of non-profit environmental organizations were successfully used to help in data collection at the UCLA riparian field experiment over two year study. Trained volunteers are the backbone of several major water quality monitoring efforts along the Santa Clara River, Ventura River and Malibu Creek Watershed. Also, student and community volunteers have contributed significantly to habitat restoration efforts on HRNA since 1998. We recommend considering augmenting your revegetation monitoring team by incorporation student interns and volunteers using elements of the following as models as part of the UC Research Station and Conservation Center.

Heal the Bay's Stream Team is a citizen monitoring program developed to collect high quality useable data to help determine the environmental health of the Malibu Creek Watershed (http://sites.healthebay.org/streamteam/). The Stream Team partners citizens who want to volunteer to actively work for the environment with environmental organizations and government agencies who have environmental data needs. Data collected is intended to enhance the ecological function and improve water quality throughout the watershed while educating community members about their watershed. Since November of 1998, more than 5800 Stream Team volunteers have been trained by Heal the Bay to collect and analyze water quality in the watershed. Data collected is entered into GIS and distributed to government agencies. In addition, Stream Team data is used to track trends in water quality to assist local planning agencies in developing future water quality protection goals and land use management strategies.

In fall 2004, FSCR received funding from the State Water Resources Control Board (SWRCB) to develop a Santa Clara River Stream Team (http://www.fscr.org/html/2004-01-01.html). FSCR trained a group of citizen volunteers to regularly monitor water quality at selected sites along the Santa Clara River from Soledad Canyon to the estuary. This three-year program focused on nutrient loading, sampling at 6-10 sites along the river. Teams consisting of 3-4 volunteers were assigned to cover two or three sites per session on a one-weekend-per-month sampling schedule. All volunteers were required to complete a volunteer monitor training course. This monitoring effort was quite successful due in large part to support from University of Santa Barbara laboratory which analyzed all of the nutrient samples and trained volunteer labor.

The Ventura River Watershed Monitoring Program ("Stream Team") was established conceptually in the spring of 2000 as a joint project of Santa Barbara Channelkeeper and Surfrider, Ventura Chapter (http://www.stream-team.org/Ventura/main.html). The Stream Team is conducts volunteer-based water quality monitoring at 15 sites throughout the Ventura River Watershed, from just above the estuary at the Main Street Bridge to pristine sites above Matilija Dam. As of 2006, volunteers collected over 250 data points each month since January 2001, and logged over 850 hours in the field.

Since 1999, FSCR have developed a strong volunteer base that helped with removal of invasive and noon-native weeds and planting on HRNA. With Trustee Council funding, a Volunteer Coordinator was hired to recruit and organize volunteers and to develop a stewardship program for the HRNA. A total of 40 workdays were conducted from 2005-2010 (October – April consisting of a total of 1,739 labor hours (Friends of the Santa Clara River 2011). The Volunteer Coordinator encouraged volunteer participation in all phases of the restoration project, including weed removal, installation of native plants, and on-going monitoring. Volunteers included school groups, home school groups, scout troops, Roots & Shoots (Jane Goodall Institute's international environmental and humanitarian program for youth of all ages), and local citizens. A press release for the entire volunteer season was sent to local newspapers, radio stations, schools, service clubs and scout troops, and former volunteers.

Schedule and Timing of Monitoring Period

Most monitoring of revegetation areas will be conducted in the first 10 years, either annually, or during selected years. Performance metrics for long-term sustainability of the ecosystem restored should be implemented every 5 years from years 10-30 after implementation of the restoration action. Recommended timing of monitoring each performance measure varies and is described in the section above on Setting Success criteria.

Vegetation monitoring should be conducted once a year between the middle and end of the growing season. Depending on the weather each year and environmental site conditions, optimal monitoring should be conducted between June 1 and August 30. A combination of preliminary site inspections and professional ecological judgment must be used when determining the timing of monitoring each year.

Reporting

The Monitoring Plan for each restoration area should be finalized at least 1 year before the restoration actions are implemented so that pre-project baseline monitoring data can be collected. The plan should include at the minimum the following sections:

- Introduction and background
- Monitoring approach and design
- Schedule
- Monitoring methods and protocols
    - Invasive and non-native plants
    - Native riparian plants
    - Plant community structure
    - Bird and wildlife surveys
    - Mapping extent of invasive species and native riparian habitat
    - Riverine wetlands and riparian habitat conditions assessment (CRAM)
    - Long-term sustainability assessment
    - Other surveys based on project specific goals and objectives
- Reference and control sites
- Photo monitoring
- Literature cited

Monitoring reports should be prepared at the end of each monitoring year for the duration of the 10 year monitoring period. Reports should present results of each monitoring metric related to each success criteria target, reference sites, and control sites over time. Any changes in methods or protocols should be noted in the report and should include recommendations on any adaptive management that should be taken resulting from data analyzed during that monitoring period. A final comprehensive Monitoring Report should be conducted after the year 10 monitoring data for all performance metrics. Monitoring reports should be prepared for years 15, 20, 25 and 30 as well as 10 year monitoring reports for any supplemental plantings.

The following data should be submitted at the end of each monitoring year to each of the following organizations:

- Annual invasive and non-native species mapping and location data to Calflora using the Cal Weed Mapper tool (http://www.calweedmapper.org/).

- Annual CRAM scores online to the California Wetlands Portal located at: http://www.cramwetlands.org/cramdataentry.html
- Plant composition data to CNPS/CDFG Vegetation Program

Management and Implementation

Long-term Management and Restoration Plan

The following are recommendations for restoration management and implementation that we have compiled from experiences working on riparian restoration projects throughout California. We recommend developing a long-term management and conceptual restoration plan all properties in the Santa Clara River Parkway. The HRNA management and restoration plan may be used as a model for the larger Parkway (URS Corporation 2003).

The HRNA plan is based on the restoration element approach that prioritizes restoration activities and integrates these into long-term management programs. According to this approach, a series of 'restoration elements' and 'restoration actions,' is developed and then combined into several restoration scenarios. Restoration elements are broader categories, such as the riparian enhancement element, whereas restoration actions are various subsets of elements or tasks related to an element (i.e., restoration of a large riparian forest or riparian habitat enhancement through invasive plant removal). Selected elements and actions are combined into feasible, logical scenarios, by cost and type of funding/action. Scenarios are then evaluated to determine the preferred scenario as each funding opportunity becomes available and then incorporated into a preferred long-term ecosystem management and restoration program. Alternatively, if none of the restoration scenarios developed in this plan adequately addresses the funding opportunity sought, elements may be used individually or with other elements in various combinations.

The HRNA plan presented the range of possible management and restoration elements and actions that could be implemented on HRNA. Five restoration scenarios were developed according to funding type and three were grouped according to implementation cost (high, medium and low cost). Cost estimates associated with each restoration element action were presented in this plan. Using this plan, Friends of the Santa Clara River (FSCR) HRNA Steering Committee were able to successfully make decisions as to which restoration elements to implement both in the short and long term based on the particular funding opportunities that were available. All restoration elements/actions were not necessarily implemented due to passive revegetation that

occurred after the January and February 2005 floods. Restoration of natural riverine wetlands and riparian habitats were successfully restored by the FSCR from 2003 until 2011.

UC Research Station and Conservation Center and Manager

The Trustee Council, State Coastal Conservancy and TNC support the development of a UC Research Station and Conservation Center on the Santa Clara River. The vision for the Santa Clara River field station is to support and conduct environmental research, biodiversity conservation, and ecosystem restoration in the Santa Clara River watershed. The Center will serve as a base for academic research studies, teaching and outreach programs that include an interpretive center and volunteer program, and a natural resource information center to support regional floodplain management and restoration. The UC Research Station and Conservation Center staff will serve in an advisory role and assist with planning, implementation, and coordination of ecological-based monitoring and restoration projects in the watershed. The UC Research Station and Conservation Center Manager will be in charge of managing ecological monitoring and ecological restoration research projects on the Santa Clara River, and will serve as the head of the TAC that reviews all restoration monitoring reports. In partnership with TNC, the station is proposed to be based in Santa Paula, CA on a 1,000 acre property with a diversity of riparian and upland habitats.

Build a Native Plant Nursery on the UC Research Station and Conservation Center Site

A native plant nursery is planned to be constructed as part of the proposed UC Research Station and Conservation Center site. This nursery must be large enough to support multiple revegetation areas on the Santa Clara River concurrently. Currently, there are two proposed locations: (1) expansion of the native plant nursery established on HRNA for on-site restoration, or (2) development of a native plant nursery adjacent to the proposed UC Research Station and Conservation Center.

Data Management and Dissemination

We have tried to incorporate as many existing state and federal monitoring protocols into our recommended monitoring framework presented in this handbook in an attempt to share monitoring data with these agencies and organizations. Our intent is to provide consistently collected, high quality data that can be compared both throughout the Santa Clara River watershed and the State of California. These monitoring datasets may be used to for multiple purposes including: (1) insure that

invasive weed removal and revegetation is implemented per project plans, (2) improve our understanding of the effectiveness of invasive weed removal and revegetation techniques of riverine wetlands and riparian habitat after removal; and (3) provide high-resolution spacial data on five invasive, non-native target species and extent of riverine wetlands, as well as CRAM scores at each restoration area for statewide use.

The UC Research Station and Conservation Center Manager will manage all monitoring data on a GIS geo-database established for the river. After collected, spatial GPS data and other monitoring data should be entered into the established Santa Clara River monitoring database by the UC Research Station and Conservation Center staff or submitted by the organization collecting the data in the proper database format. GIS data collected for the five invasive, non-native target species should be reported each year for the duration of the 10 year monitoring period to Calflora using the Cal Weed Mapper tool (http://www.calweedmapper.org/). GIS data on extent of riverine wetlands should be submitted to CDFG's Biogeographical Information and Observation System (BIOS) (http://bios.dfg.ca.gov/). CRAM data collected should be submitted to the California Wetlands Portal (http://www.cramwetlands.org/cramdataentry.html). Also, plant composition data should be sent to CNPS/CDFG Vegetation Program.

The Santa Clara River Parkway website (http://www.santaclarariver parkway.org/) was developed by the State Coastal Conservancy to facilitate the sharing of information among stakeholders and the public. Monitoring reports and GIS shapefile data should be made available on this web site for use by various stakeholders.

Bi-annual Science Symposium

The State Coastal Conservancy sponsored the first Santa Clara River science symposium on February 16, 2007 to facilitate sharing of scientific and management related study results among stakeholders involved in conservation and restoration on the Santa Clara River. This one-day workshop was held at Faulkner Farm and University of California, Hansen Agricultural Center in Santa Paula, California. Due to the success of this first science workshop and continued interest in conservation and restoration in the watershed, the State Coastal Conservancy and other organizations involved would like to continue holding a bi-annual science symposium on the State of the Santa Clara River. Results of invasive, weed removal and revegetation monitoring and lessons learned should be presented at this symposium by the UC Research Station and Conservation Center staff and restoration ecologists working on these projects.

CHAPTER 6
RECOMMENDED NEXT STEPS

Develop Detailed Strategic Plan for Invasive Species Removal and Revegetation of Priority Sites

Based on updated mapping for each target invasive plant species, a detailed plan for prioritization of removal and revegetation sites should be completed. The goal of this task is to develop a comprehensive set of watershed maps illustrating prioritization of sites for target plant removal/revegetation based on our UCLA research results and results of other removal and revegetation projects in southern California. GIS spatial analyses will be performed as part of this task.

Currently, Stillwater Sciences and the UC Research Station and Conservation Center staff are working on a Strategic Plan for *Arundo* removal for the State Coastal Conservancy. The plan summarizes: 1) cost/acre estimates for different treatment methods, 2) potential permit requirements, and 3) *Arundo* treatment priorities for parcels in the Santa Clara River Parkway. In identifying treatment priorities, they are using the historical flood mapping for the Santa Clara River (Stillwater Sciences 2007) to define a "flood reset zone". They recommend herbicide treatment is contingent upon *Arundo* being naturally scoured away by high flow events. Above this zone, we recommend different treatment types based on the level of interspersed native vegetation, ranging from mowing before herbicide application to hand removal before herbicide application. Treatment priorities for Santa Clara River Parkway parcels (i.e., what *Arundo* patches should be treated first and why) are further based on criteria such as: onsite habitat quality, adjacent habitat quality, risk of reinfestation, fire risk, special features such as nodes of unusual vegetation, and the amount of surrounding *Arundo*.

Update Current Extent of Each Invasive Plant Species along the River

Vegetation mapping was conducted on the 500-year floodplain of the Upper Santa Clara River from November 2004-March 2005 by the VCRCD (Ventura County Resource Conservation District 2006) and on the Lower Santa Clara River from July to November 2005 with Trustee Council funding (Stillwater Sciences and URS Corporation 2007). A data gaps analysis was completed as part of the Santa Clara River Watershed Invasive Plant Removal (SCIPR) Program to review both vegetation mapping efforts and prepare a single database and a complete set of maps with a consistent resolution of data for the entire watershed. Recommended actions to improve the data set and to fill in these data gaps include:

1. Utilize a single mapping protocol to consolidate the current data and additional areas for mapping.
2. Conduct surveys in areas not previously surveyed, especially along tributaries.
3. Verify vegetation classification in areas impacted by flooding and/or wildfires.
4. Review atypical vegetation classification from previous surveys

Thorough and updated mapping of *Arundo* and Tamarisk populations along the River is essential for prioritizing and planning of removal of these infestations (Stillwater Sciences 2008, Wildscape Restoration 2009). These mapping efforts only represent a "snapshot" in time. The Santa Clara River is dynamic in nature - Large flood events, periods of drought or high rainfall, and wildfires change the vegetation and invasive plant species distribution along the River. For example, flood events in January and February, 2005 on the Santa Clara River resulted in extensive vegetation scouring and essentially resetting of portions of the floodplain. Thus, mapping in 2004 before the flooding in the upper Santa Clara River is inaccurate.

Arundo and Tamarisk population distributions were mapped over 6 years ago. Since there has not been a significant flood event since winter 2005, extent and biomass of *Arundo* and Tamarisk infestations have increased significantly in the floodplain areas reset these floods (Orr et al. 2011). Thus, we recommend updating of current extent of all five priority invasive species to inform prioritization removal strategies. Priority invasive species mapping should be updated regularly (every 5 years) using the following strategies or combination of these strategies:

- Remote sensing techniques can creates cost effective mapping solutions that allow more time, money and effort to be spent on removal of invasive plant infestations with greater distribution, such as *Arundo donax* and associated revegetation. Griswold et. al. (2009) demonstrated the ability to use readily available low cost natural color band aerial imagery to accurately, efficiently, and quantitatively map select invasive species like giant reed (*Arundo donax*) over time. This mapping approach utilizes supervised segmentation software in an automated process whereby the software extracts individual vegetation groups or features and creates digital polygons to represent them. The user then assigns the features according to land use or vegetation type. They utilized ground-truth data collected by plant ecologists to "train" the image analysis software to recognize the presence or absence of *Arundo* at the site. After the editing process, the features were exported into a GIS for mapping and analysis. Using 2005 NAIP

imagery (1m spatial resolution), *Arundo* was correctly classified nearly 80% of the time when compared to known *Arundo* stands. *Arundo* mapping was found to be less accurate using the 2008 QuickBird imagery with near-infrared (NIR) band but lower spatial resolution (2.4m multispectral and 0.6m panchromatic).

- If remote sensing is used, accuracy assessment must be included.
- Vegetation types should be classified to Alliance level using A Manual of California Vegetation (Sawyer et al. 2009).
- Field verification must be conducted for any remote sensed mapping effort.
- If funding for remapping all five invasive species is limited, priority should be given to *Arundo* and Tamarisk located in priority removal areas identified by the Detailed Strategic Plan for Invasive Species Removal and Revegetation of Priority Sites (Stillwater Science and UCSB in preparation).
- Timing of mapping should be carefully assessed after flood events and/or wildfire. If mapping is done immediately after a flood event or wildfire in the areas most affected, mapping can be used for removal projects. Otherwise, waiting 1-2 years may be advantageous for mapping the extent of invasive plants post-flood more accurately.
- Mapping of invasive plants should be conducted as specified in Chapter 5 for as part of monitoring and evaluation of success criteria.

Survey Invasive Plant Species on Watch List

Surveys should be conducted along the 500-year floodplain of the Santa Clara River to assess the presence and distribution of the other 40 target invasive species on the watch list (Table 1). This task could be undertaken in a number of ways including:

- Conduct thorough invasive plant surveys when vegetation mapping is updated next. This will only work for species that are widely distributed, such as *Arundo*, if vegetation mapping is conducted using remote sensing technology. If vegetation is mapped primarily by field verification as in 2004-5, this would be the most efficient time to search and document these target invasive species.
- If planned and implemented carefully, a community-based volunteer monitoring program could be the most cost-effective way to carry out on-going invasive plant species mapping. Based on a successful model program

implemented at Hedrick Ranch Nature Area and the Upper San Joaquin River, a volunteer coordination team would be developed to oversee and work closely with local college student interns and community volunteers (i.e., California Native Plant Society) to identify and map invasive species on the Watch List. The UC Research Station and Conservation Center staff would train interns and volunteers in invasive plant identification and mapping protocols. To gain community support for this approach, several public outreach training workshops should be conducted for local land owners to find out more about target invasive species on their property. An initial pilot mapping effort along the river is recommended to demonstrate viability. The extent of target riparian invasive species would be mapped during field surveys with handheld GPS as polygons and waypoints depending on extent of each. This mapping method would require development of a Watershed mapping tool on the Santa Clara River Watershed Portal similar to the one developed by David Siedband for Putah Creek (http://www.watershedportals.org/lpccc/maps).

- Mapping of each plant species either by individual waypoints when their distribution is limited or by GPSing polygons when the species population is greater than the minimum mapping unit (approximately 100ft^2). When invasive plants are mixed with native vegetation, percent cover of each invasive species found within each vegetation type mapped may be estimated in the field (Stillwater Sciences and URS Corporation 2007).

Finalize the Santa Clara River Invasive Plant Removal Plan (SCIPR), Environmental Impact Report (EIR), and Programmatic Permits for the Lower Santa Clara River

The permitting requirements to conduct non-native plant control programs are onerous and expensive, often discouraging capable applicants and increasing proposed costs. Developing programmatic permits will facilitate implementation of on the ground habitat restoration work by reducing costs and time necessary to begin work. The following activities have been initiated to streamline this process, but a comprehensive permitting and environmental compliance program needs to be finalized for the Santa Clara River. Currently, programmatic permitting, environmental documentation, and implementation efforts described below are on hold. We believe finalizing a comprehensive permitting, environmental compliance program, and implementation

plan is important for implementation of cost-effective and streamlined invasive plant removal and revegetation efforts.

The planning for the upper watershed contained several major tasks: 1) development of the Upper Santa Clara River *Arundo*/Tamarisk Removal Plan (SCARP); 2) surveying and mapping 16,400 acres within the upper watershed; 3) development of the programmatic California Environmental Quality Act (CEQA) Environmental Impact Report (EIR); 4) development of a water quality monitoring plan and quality assurance project plan; and 5) initiating baseline water quality monitoring at five sites.

The Ventura County Resource Conservation District (VCRCD, Somis, CA) completed the Upper Santa Clara River Watershed *Arundo*/Tamarisk Removal Plan (SCARP), Environmental Impact Report (EIR), and Programmatic Permits for the portion of the Santa Clara River watershed that is upstream of the Ventura/Los Angeles County line (funded by Proposition 13 and the Trustee Council). A long-term *Arundo*/Tamarisk removal implementation plan was developed for the 500-year floodplain of the upper Santa Clara River watershed (approximately 16,300 acres). In addition, this project included vegetation mapping, using a modified Sawyer Keeler-Wolf classification system. The EIR for the implementation work was prepared for the long-term plan and approved in February 2006. Wildscape Restoration, Inc. obtained the associated programmatic permits for the VCRCD for SCARP.

Wildscape Restoration, Inc. began preparing the Santa Clara River Invasive Plant Removal Plan (SCIPR), Environmental Impact Report (EIR), and Programmatic Permits for the VCRCD on the lower Santa Clara River. The original plan was for SCIPR to be integrated with SCARP to facilitate the removal of species such as *Arundo* (*Arundo donax*) and tamarisk (*Tamarix* spp.) through the inception of a programmatic review and permitting process on a watershed-wide basis (both Los Angeles and Ventura Counties).

Develop a Detailed Monitoring Plan for Santa Clara River

One a Strategic Plan for *Arundo* removal is completed, the UC Research Station and Conservation Center and TAC should be developed based on recommendations in this handbook and site specific surveys.

Establish and Monitor Reference Sites along the Santa Clara River

A series of reference sites should be identified and monitored along the Santa Clara River that represents the suite of physical conditions found along the river. Data collected from these reference sites will help to further develop success criteria based on

ecological data. Three types of reference sites should be established: reference reaches sampled using transects and cross sections, from field experiments like our UCLA riparian field experiment next to HRNA, and establishing permanent monitoring plots in areas reset by the next flood or fire (sampling native plant species cohorts over time). Summer 2012 will be a unique opportunity to measure native plants at the UCLA Riparian Field Experiment - 10 years after establishment – to help in development of the 10 year targets for various performance metrics for 3 dominant native riparian species found on the river.

Remove Target Invasive Species throughout Watershed and Riparian Revegetation

Using the strategies presented in this handbook and other CalIPC resources (http://www.cal-ipc.org/ip/management/index.php), site-specific removal and revegetation implementation plans should be developed for target invasive plant species including: *Arundo* (*Arundo donax*), perennial pepperweed (*Lepidium latifolium*), creeping water- primrose (*Ludwigia peploides* ssp. *montevidensis*), smallflower tamarisk (*Tamarix parviflora*), and salt cedar (*Tamarix ramosissima*) and other new arrivals with high CalIPC ratings. Also, techniques for *Arundo* and Tamarisk removal and revegetation are summarized in the Calleguas Creek Watershed *Arundo*/Tamarisk Removal Program: Arroyo Simi Pilot Project Implementation Plan prepared for Ventura County Resource Conservation District (Wildscape Restoration 2008). The Trustee Council, State Coastal Conservancy and The Nature Conservancy should work together to plan and facilitate removal at priority sites as funding is available.

We recommend implementing removal and revegetation of large infestations using local contractors. Smaller invasive species infestations could be removed and revegetated continuously and most efficiently throughout the watershed through a Community Involvement Program. On terraces and floodplain areas not prone to frequent flooding, active riparian revegetation techniques should be employed, whereas allowing flood prone areas to passively revegetate is the most cost-effective strategy. See discussion in Chapter 2 for more detailed strategies.

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TABLES

Table 1. Preliminary list of invasive non-native riparian and aquatic plant species found or that have the potential to be found on the 500-year floodplain of the Santa Clara River. This list is not comprehensive, but reflects the most notable problem species.

Plant Species		CalIPC Rating		Removal Priority		Rationale for Removal Priority
Scientific name	Common name	High	Moderate	High Priority[1]	Watch List[2]	
Ailanthus altissima	tree-of-heaven		X		X	Moderate rating. Unknown distribution in watershed.
*Arundo donax**	giant reed	X		X		High rating. Wide distribution.
*Bromus diandrus**	ripgut brome		X		X	Moderate rating. Wide distribution.
Bromus madritensis ssp. *rubens*	red brome	X			X	High rating. Unknown distribution in watershed.
*Carduus pycnocephalus**	Italian thistle		X		X	Moderate rating. Wide distribution.
*Carpobrotus chilensis**	iceplant		X		X	Moderate rating. Limited distribution.
*Carpobrotus edulis**	Hottentot-fig	X			X	High rating. Invading in limited areas.
*Centaurea melitensis**	tocalote	X			X	High rating. Unknown distribution.
*Centaurea solstitialis**	yellow starthistle	X			X	High rating. Unknown distribution.
*Cirsium vulgare**	bull thistle		X		X	Moderate rating. Wide distribution.
*Conium maculates**	poison-hemlock		X		X	Moderate rating. Wide distribution.
*Cortaderia jubata**	jubatagrass	X		X	X	High rating. Limited distribution.
Cortaderia selloana	pampasgrass	X			X	High rating. Unknown distribution.
*Delaria odorata**	cape ivy	X			X	High rating. Limited distribution.
Egeria densa	Brazilian egeria	X			X	High rating. Not recorded in watershed.
Eichhornia crassipes	water hyacinth	X			X	High rating. Not recorded in watershed.
*Eucalyptus globulus**	Tasmanian blue gum		X		X	Moderate rating. Limited distribution.
*Festuca arundinacea**	tall fescue		X		X	Moderate rating. Limited distribution.
Ficus carica	edible fig		X		X	Moderate rating. Unknown distribution.
*Foeniculum vulgare**	Fennel	X			X	High rating. Limited distribution along

[1] Removal and revegetation discussed in this handbook.
[2] The watch list includes some species not yet observed on the Santa Clara River, but have been included on this list due to their known occurrence in other semi-arid systems of California (Vaghti and Greco 2007).
* = Plants found along the Santa Clara River.

Table 1. Preliminary list of invasive non-native riparian and aquatic plant species found or that have the potential to be found on the 500-year floodplain of the Santa Clara River. This list is not comprehensive, but reflects the most notable problem species.

Plant Species		CalIPC Rating		Removal Priority		Rationale for Removal Priority
Scientific name	Common name	High	Moderate	High Priority[1]	Watch List[2]	
						riparian/ upland ecotone.
Hedera helix, H. canariensis	English and Algerian ivy	X			X	High rating. Unknown distribution.
*Hirschfeldia incana**	shortpod mustard		X		X	Moderate rating. Wide distribution.
Hydrilla verticillata	hydrilla	X			X	High rating. Not recorded in watershed.
*Lepidium latifolium**	perennial pepperweed	X		X		High rating. Distribution known to fluctuate. Know populations in estuary and on HRNA.
Ludwigia peploides ssp. *montevidensis**	creeping water-primrose	X		X		High rating. Subspecies not confirmed but presumed non-native.
Mentha pulegium	pennyroyal		X		X	Moderate rating. Unknown distribution.
Lythrum salicaria	purple loosestrife	X			X	High rating. Not recorded in watershed.
*Mesembryantemum crystallinum**	crystalline iceplant		X		X	Moderate rating. Limited distribution.
*Myoporum laetum**	myoporum		X		X	Moderate rating. Limited distribution.
Myriophyllum aquaticum	parrotfeather	X			X	High rating. Not recorded in watershed.
*Nicotiana glauca**	tree tobacco		X		X	Moderate rating. Wide distribution.
*Phalaris aquatica**	hardinggrass		X		X	Moderate rating. Not recorded in watershed.
*Ricinus communis**	castorbean		limited		X	Limited rating. Wide distribution.
Rubus armeniacus	Himalaya blackberry	X			X	High rating. Unknown distribution.
*Schinus molle**	Peruvian peppertree		limited		X	Limited rating. Limited distribution.
Sesbania punicea	scarlet wisteria	X			X	High rating. Not recorded in watershed.
*Spartium junceum**	Spanish broom	X				High rating. Limited distribution.
*Tamarix parviflora**	smallflower tamarisk	X		X		High rating. Limited distribution.
*Tamarix ramosissima**	salt cedar	X		X		High rating. Wide distribution.
Vinca major	big periwinkle		X		X	Moderate rating. Unknown distribution.

Table 2. Plant distribution in competition plant groupings (four plants per grouping) used in the field experiment. (Source: modified from Coffman 2007)

Competition grouping treatment	Plant species (number of species per grouping)			
	Arundo donax	***Baccharis salicifolia***	***Salix laevigata***	***Populus balsamifera* ssp. *trichocarpa***
1-species grouping (monoculture)	4			
		4		
			4	
				4
2-species grouping	2	2		
	2		2	
	2			2
4-species grouping	1	1	1	1

Table 3. Four-way ANOVA significance table for percent plant survivorship during establishment by factors of species from one-species and two-species groupings combined (*Arundo donax* and three native riparian species, *Salix laevigata*, *Populus balsamifera* ssp. *trichocarpa*, and *Baccharis salicifolia*), soil moisture (high and low), nutrient additions (high and none), and light (high and low). Results are for three time periods: 1) cutting survivorship (March 2003), 2) plant survivorship at end of 2003, and 3) plant survivorship at end of 2004. Significant results are in bold. (Source: Coffman 2007)

Factors and interactions	Cuttings	2003	2004
Species	$F_{(3,48)} = 1.821$, $P = 0.156$	$F_{(3,48)} = 2.352$, $P = 0.084$	$F_{(3,48)} = 2.523$, $P = 0.069$
Soil moisture	$F_{(1,48)} = 1.346$, $P = 0.252$	$F_{(1,48)} = 4.029$, $P = 0.050$	$F_{(1,48)} = 1.858$, $P = 0.179$
Nutrients	$F_{(1,48)} = 0.050$, $P = 0.824$	$F_{(1,48)} = 0.042$, $P = 0.839$	$F_{(1,48)} = 0.046$, $P = 0.831$
Light	$F_{(1,48)} = 1.625$, $P = 0.208$	$F_{(1,48)} = 0.855$, $P = 0.360$	$F_{(1,48)} = 0.170$, $P = 0.682$
Species x soil moisture	$F_{(3,48)} = 1.456$, $P = 0.238$	**$F_{(3,48)} = 3.628$, $P = 0.019$***	$F_{(3,48)} = 2.100$, $P = 0.113$
Species x nutrients	$F_{(3,48)} = 0.398$, $P = 0.755$	$F_{(3,48)} = 0.513$, $P = 0.675$	$F_{(3,48)} = 0.723$, $P = 0.543$
Species x light	$F_{(3,48)} = 0.400$, $P = 0.754$	$F_{(3,48)} = 1.197$, $P = 0.321$	$F_{(3,48)} = 0.412$, $P = 0.745$
Soil moisture x nutrients	$F_{(1,48)} = 0.361$, $P = 0.551$	$F_{(1,48)} = 0.490$, $P = 0.487$	$F_{(1,48)} = 1.018$, $P = 0.318$
Soil moisture x light	$F_{(1,48)} = 0.022$, $P = 0.884$	$F_{(1,48)} = 0.000$, $P = 0.984$	$F_{(1,48)} = 1.455$, $P = 0.234$
Nutrients x light	$F_{(1,48)} = 0.624$, $P = 0.434$	$F_{(1,48)} = 0.001$, $P = 0.980$	$F_{(1,48)} = 0.138$, $P = 0.712$
Species x soil moisture x nutrients	$F_{(3,48)} = 0.124$, $P = 0.946$	$F_{(3,48)} = 0.265$, $P = 0.850$	$F_{(3,48)} = 1.266$, $P = 0.296$
Species x soil moisture x light	$F_{(3,48)} = 2.431$, $P = 0.077$	$F_{(3,48)} = 1.253$, $P = 0.301$	$F_{(3,48)} = 1.543$, $P = 0.215$
Species x nutrients x light	$F_{(3,48)} = 1.193$, $P = 0.322$	$F_{(3,48)} = 2.046$, $P = 0.120$	$F_{(3,48)} = 0.921$, $P = 0.438$
Soil moisture x nutrients x light	$F_{(1,48)} = 0.111$, $P = 0.740$	$F_{(1,48)} = 0.772$, $P = 0.384$	$F_{(1,48)} = 1.359$, $P = 0.249$
Species x soil moisture x nutrients x light	$F_{(3,48)} = 2.212$, $P = 0.099$	$F_{(3,48)} = 2.104$, $P = 0.112$	$F_{(3,48)} = 2.431$, $P = 0.077$
r^2	0.428	0.490	0.457

* = $0.05 \geq P > 0.01$ = significant; ** = $0.01 \geq P > 0.001$ = highly significant; *** = $P \leq 0.001$ = very highly significant.

Table 4. Minimum height of riparian plant species 3 and 5 years after planting. (Source: CDFG Stream Alteration Agreement reviewed).

TABLE OF MINIMUM HEIGHT AFTER 3 AND 5 YEARS				
SPECIES	SIZE AT PLANTING (GALLONS)	PLANTING CENTERS	HEIGHT	
			3 years	5 years
arroyo willow	1 gallon	8 ft	10 ft	15 ft
black willow	1 gallon	8 ft	12 ft	18 ft
sandbar willow	1 gallon	5 ft	4 ft	6 ft
red willow	1 gallon	8 ft	9 ft	15 ft
California sycamore	1 gallon	20 ft	5 ft	9 ft
California bay laurel	1 gallon	20 ft	5 ft	7 ft
Black walnut	1 gallon	20 ft	7 ft	12 ft
black and Freemont cottonwood	1 gallon	20 ft	7 ft	12 ft
white alder	1 gallon	15 ft*	6 ft	11 ft
OAKS				
coast live oak	1 gallon	20 ft	3 ft	6 ft
canyon live oak	1 gallon	20 ft	3 ft	6 ft
scrub oaks	1 gallon	20 ft	2 ft	4 ft
all shrub species	1 gallon	8 ft	2 ft	4 ft

*** 40 ft on center if used as a supplementary species.**

Table 5. Mean height [in feet (cm)] of three native riparian trees, one native shrub, and invasive, non-native *Arundo donax* at the end of the first and second growing seasons with no artificial irrigation added (± 0.1 refers to the standard error of the mean).

Plant Species	Year 1				Year 2			
	High Soil Moisture		Low Soil Moisture		High Soil Moisture		Low Soil Moisture	
	High Light	Low Light	High Light	Low Light	High Light	Low Light	High Light	Low Light
Black Cottonwood (*Populus balsamifera* ssp. *trichocarpa*)	8.4 ± 0.3 (257 ± 8)	8.2 ± 0.2 (251 ± 7)	6.5 ± 0.2 (198 ± 5)	6.0 ± 0.2 (184 ± 5)	13.7 ± 0.5 (418 ±15)	11.4 ± 0.3 (347 ± 9)	8.2 ± 0.2 (251 ± 7)	9.1 ± 0.3 (276 ± 8)
Mule Fat (*Baccharis salicifolia*)	8.7 ± 0.1 (265 ± 4)	8.8 ± 0.2 (269 ± 6)	7.4 ± 0.1 (225 ± 4)	8.4 ± 0.1 (256 ± 4)	11.6 ± 0.2 (354 ± 5)	10.8 ± 0.2 (329 ± 6)	10.3 ± 0.1 (314 ± 4)	11.1 ± 0.2 (339 ± 5)
Red Willow (*Salix laevigata*)	8.3 ± 0.3 (254 ± 11)	7.4 ± 0.3 (226 ± 8)	6.1 ± 0.2 (185 ± 6)	7.6 ± 0.2 (231 ± 5)	13.4 ± 0.6 (408 ± 19)	11.1 ± 0.4 (339 ± 12)	7.2 ± 0.3 (221 ± 8)	11.2 ± 0.2 (341 ± 7)
Arroyo Willow[3] (*Salix lasiolepis*)		8.4 ± 0.2 (255 ± 7)				11.5 ± 0.1 (349 ± 2)		
Arundo (*Arundo donax*)	11.2 ± 0.2 (343 ± 6)	11.6 ± 0.2 (354 ± 7)	8.5 ± 0.2 (260 ± 5)	12.0 ± 0.2 (365 ± 7)	17.9 ± 0.4 (546 ± 11)	16.7 ± 0.3 (510 ± 9)	11.4 ± 0.2 (346 ± 5)	16.3 ± 0.2 (497 ± 5)

[3] These averages are only based on sample size of 3 individuals from the high soil moisture shaded treatment.

Table 6. Conceptual timing of *Arundo* removal, revegetation, monitoring, and maintenance on the Santa Clara River (timing may vary slightly for some activities based on weather and site conditions).

Restoration Activity (associated tasks)	Timing											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
***Arundo* Removal**[4]												
• bend-and-spray method								X	X	X	X	
• hook method								X	X	X	X	
• cut-stump method								X	X	X	X	
Riparian Revegetation												
• cut 1m poles (cuttings) after riparian plants senesce	X										X	X
• soak in water for 1 day – 1 week immediately after cutting	X										X	X
• install riparian pole cuttings	X	X									X	X
• collect seed from native riparian plants (depends on plant species phenology and weather)						X	X	X	X	X		
• grow plants from seeds (depends on propagation method, seed treatment requirements, and irrigation type)	X	X								X	X	X
• install container plants	X	X									X	X

[4] Follow up spraying of resprouts must be done on an annual basis once resprouts are approximately three feet tall.

Table 6. Conceptual timing of *Arundo* removal, revegetation, monitoring, and maintenance on the Santa Clara River (timing may vary slightly for some activities based on weather and site conditions).

Restoration Activity (associated tasks)	Timing											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monitoring (Success Criteria)												
• Extent of Invasive Plant Species						X	X					
• Extent of Riverine Wetlands and Riparian Habitat			X	X								
• Quality of Riverine Wetland and Riparian Habitat							X					
• Survivorship, Health and Growth of Riparian Plantings							X					
• Plant Species Diversity							X					
• Plant Community Structure and Composition							X					
• Wildlife Activity in and near Restored Riverine Wetlands and/or Riparian Habitat	• Surveys should be conducted during breading season for each bird species											
• Long-term Sustainability of Ecosystem			H4	H4			H1-3					
Maintenance												
• plant replacement cuttings and container plants	X										X	X
• respray *Arundo* (or as soon as plants reach 3 feet tall)								X	X	X		

Table 7. Minimum number of species and % cover for each riparian growth form at 1-2, 5 and 10 year monitoring periods.

Riparian Plant Growth Form	Years 1-2		Year 5		Year 10	
	No. species	% cover	No. species	% cover	No. species	% cover
trees	4	5%	4	20%	3	40%
shrubs	2	5%	2	10%	2	20%
graminoids	3	5%	2	10%	2	10%
forbs	7	5%	6	10%	5	10%
vines	2	5%	2	10%	1	10%

Note: These success criterion targets are based on understanding of the general community structure of riparian plant communities along the Santa Clara River is gaining reaches. Data on these targets should be measured at reference sites and modified based on data collected on this metric over a 10 year period.

Table 8. Recommended monitoring approaches for measuring eight success criteria and associated metrics.

Success Criteria		GPS extent (area)	CRAM conditions assessment	Permanent Plot	Transect	Measure all Plantings
A	**Extent of Invasive Plant Species**	X				
B	**Extent of Riverine Wetlands and Riparian Habitat**	X				
C	**Quality of Riverine Wetland and Riparian Habitat**		X			
D	**Survivorship, Health and Growth of Riparian Plantings**			D5-D8	D5-D8	D1-D4
E	**Plant Species Diversity**			Years 3-10	Years 3-10	Years 1-2
F	**Plant Community Structure and Composition**			F2 & F1 (Years 3-10)	F2 & F1 (Years 3-10)	F1 (Years 1-2)
G	**Wildlife Activity in and near Restored Riverine Wetlands and/or Riparian Habitat**			G1-G2	G1-G2	G3 (entire river reach next to plantings)
H	**Long-term Sustainability of Ecosystem**	H2, H4		H1, H3	H1, H3	

FIGURES

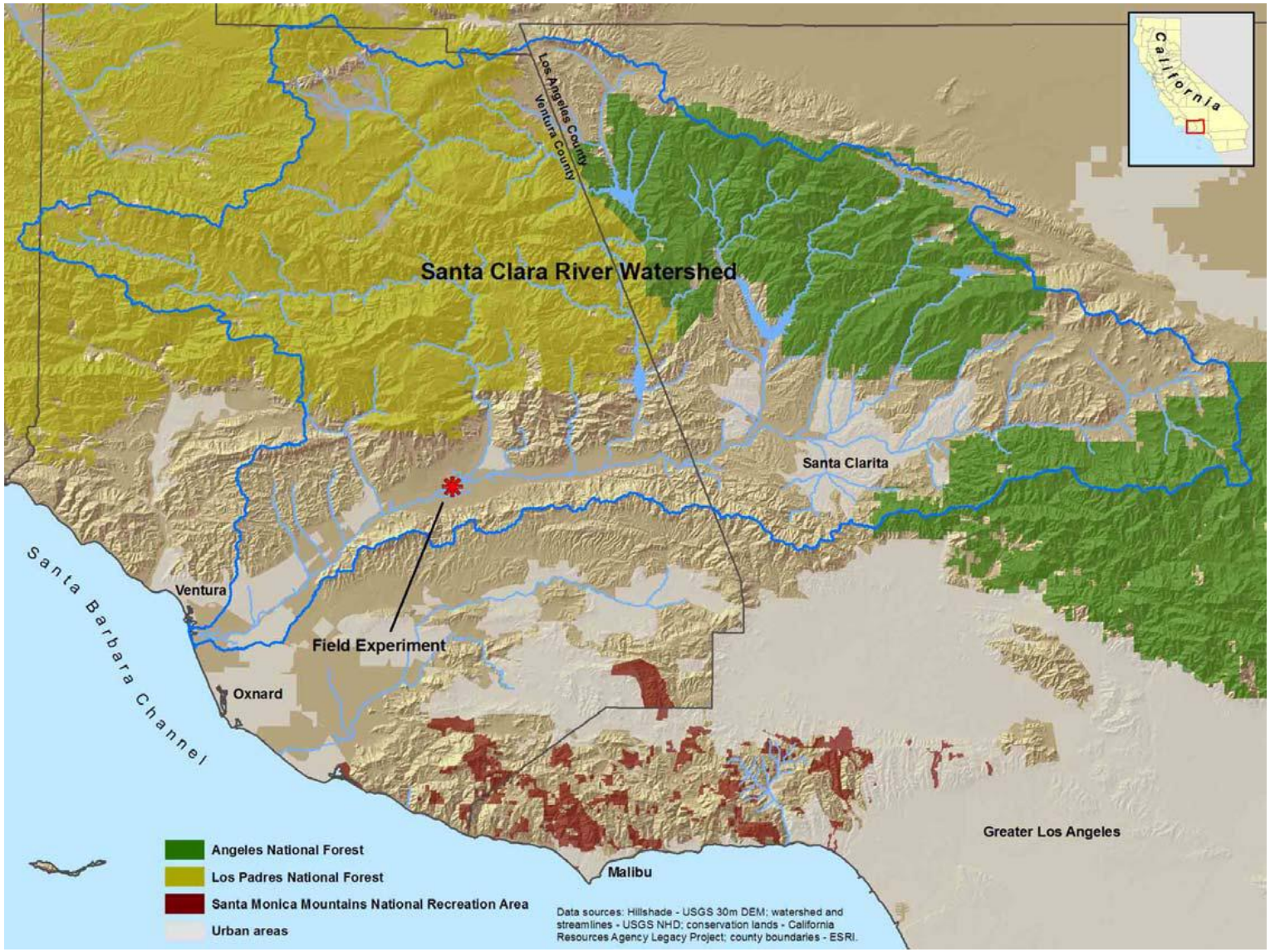


Figure 1. Location of UCLA riparian field experiment study site, Santa Clara River Watershed, Ventura County, California.

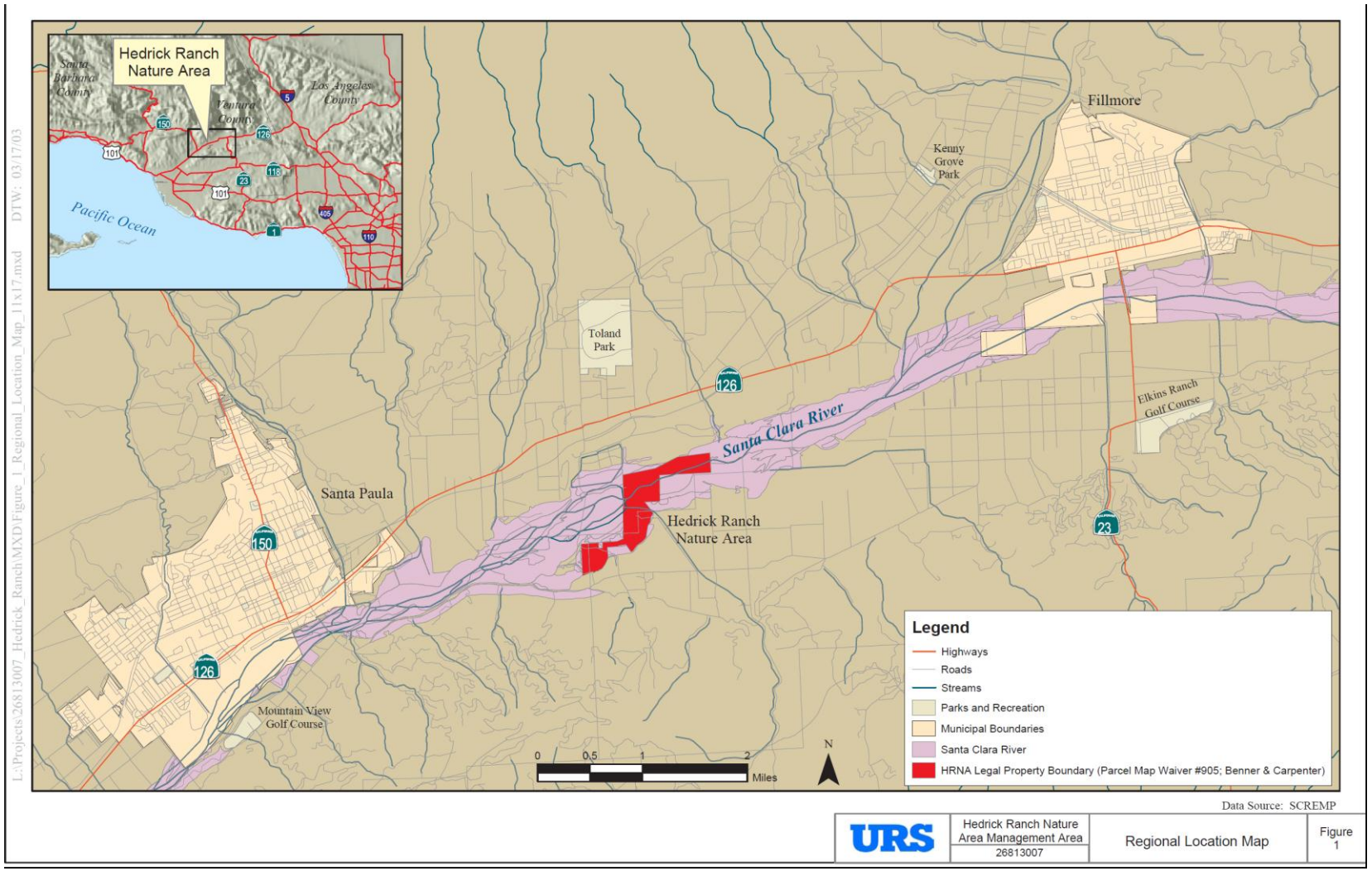


Figure 2. Location of Hedrick Ranch Nature Area, Santa Clara River Parkway property, Ventura County, California. (Source: Coffman 2007)

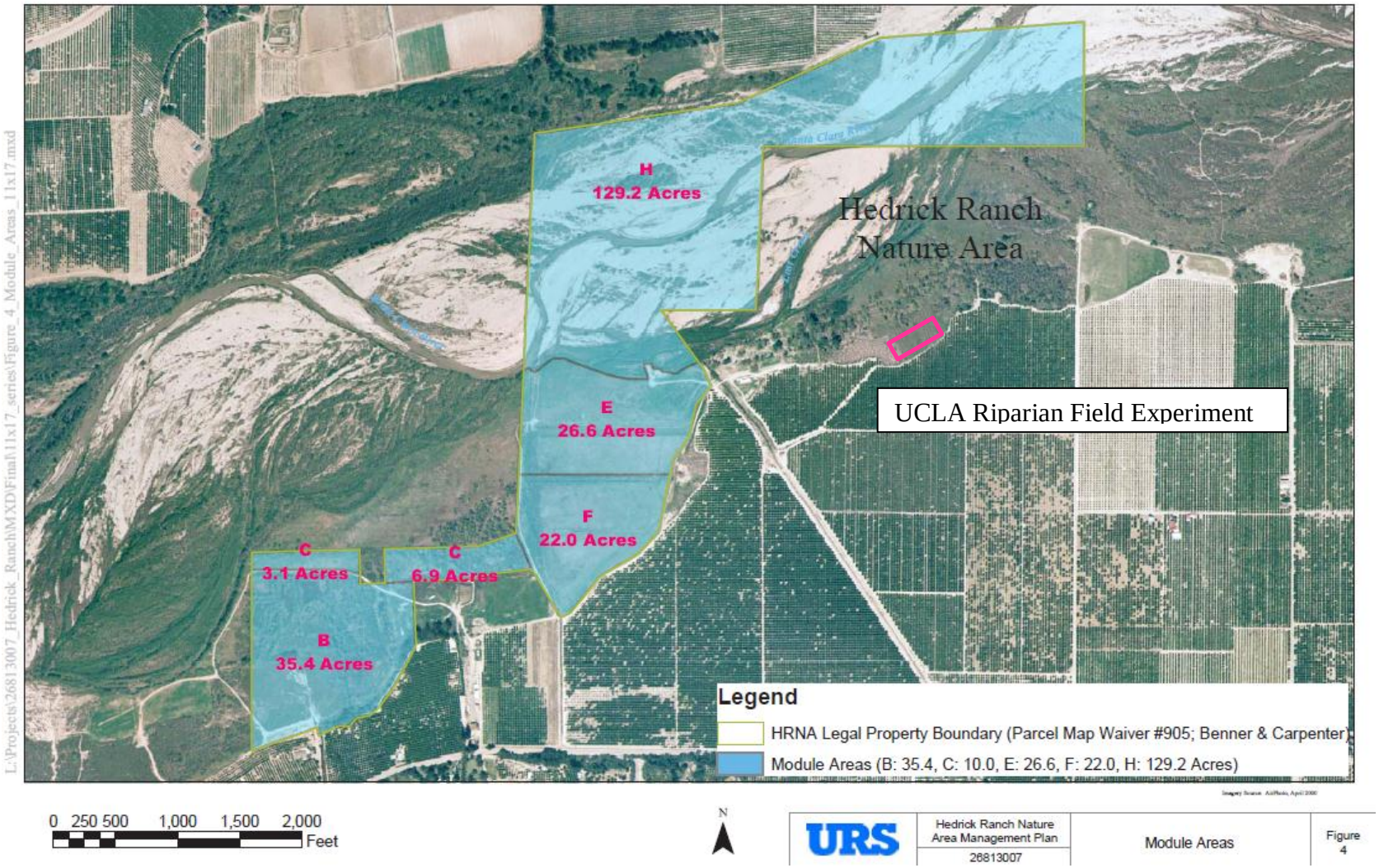


Figure 3. HRNA and UCLA Riparian Field Experiment boundaries and restoration areas. (Source: URS 2003)

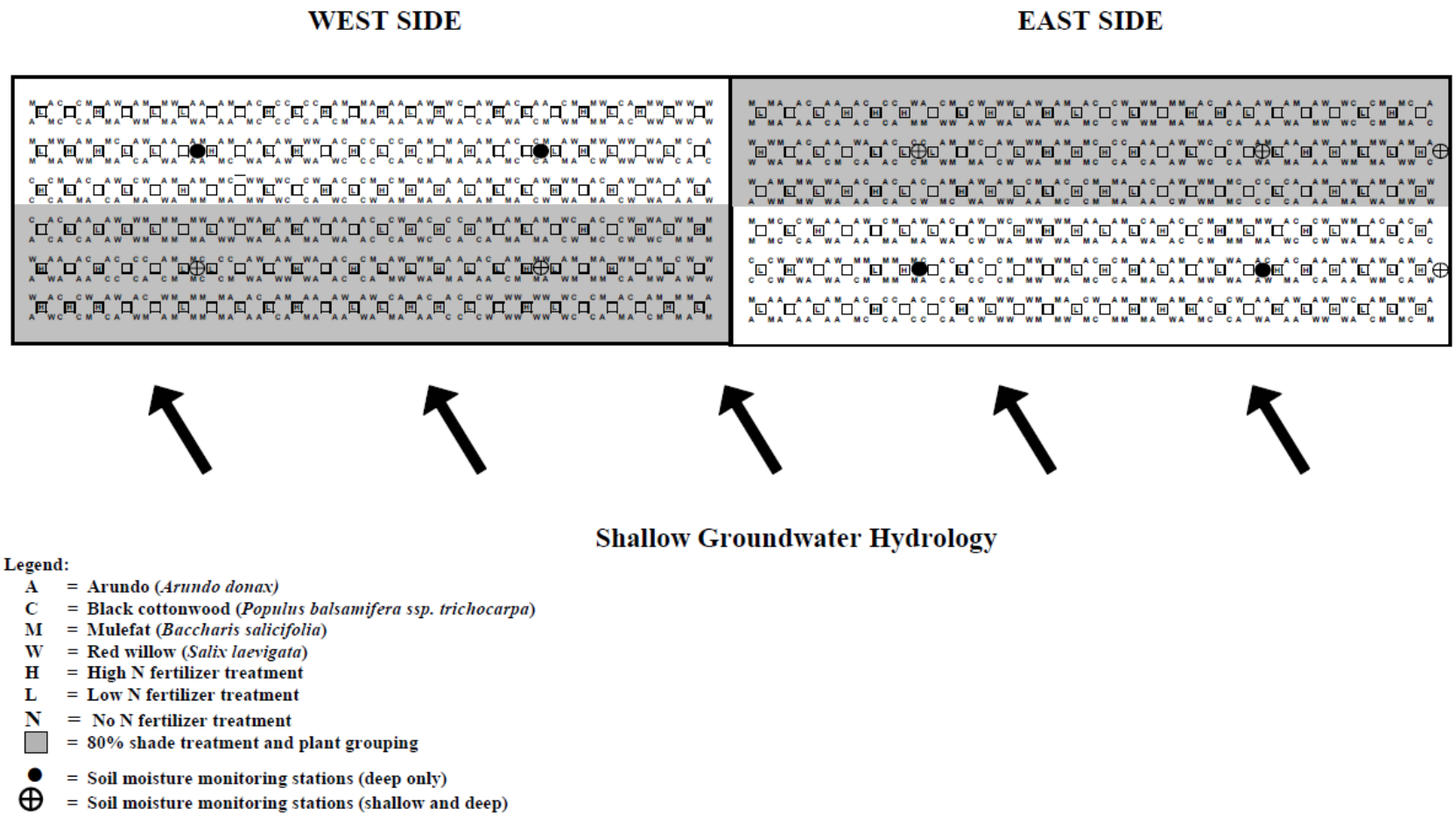


Figure 4. UCLA riparian field experiment planting and sampling layout. (Source: Coffman 2007)

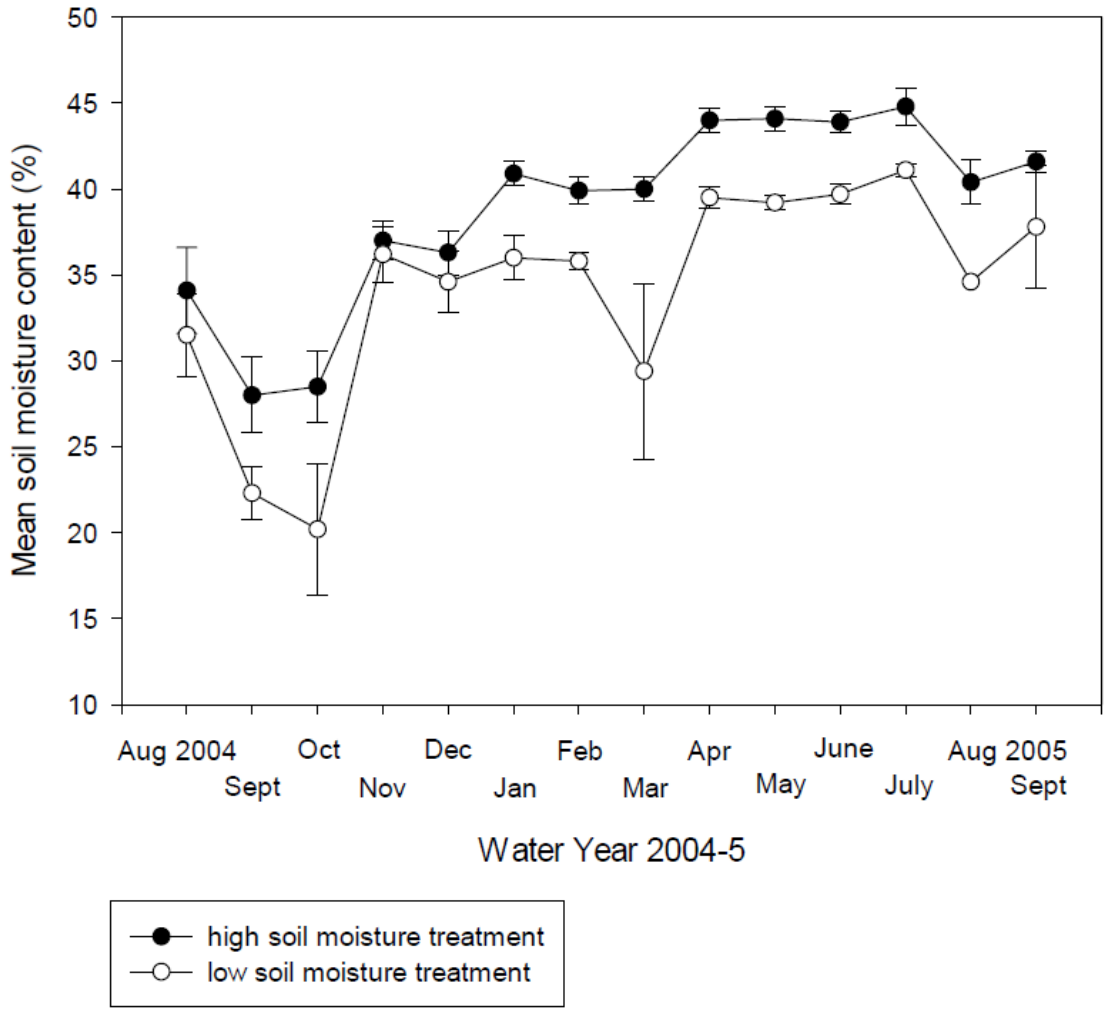


Figure 5. Mean monthly soil moisture content (percent) at 60–80 cm depth in the east compared to the west side of the experiment (high and low soil moisture treatments). (Source: Coffman 2007)

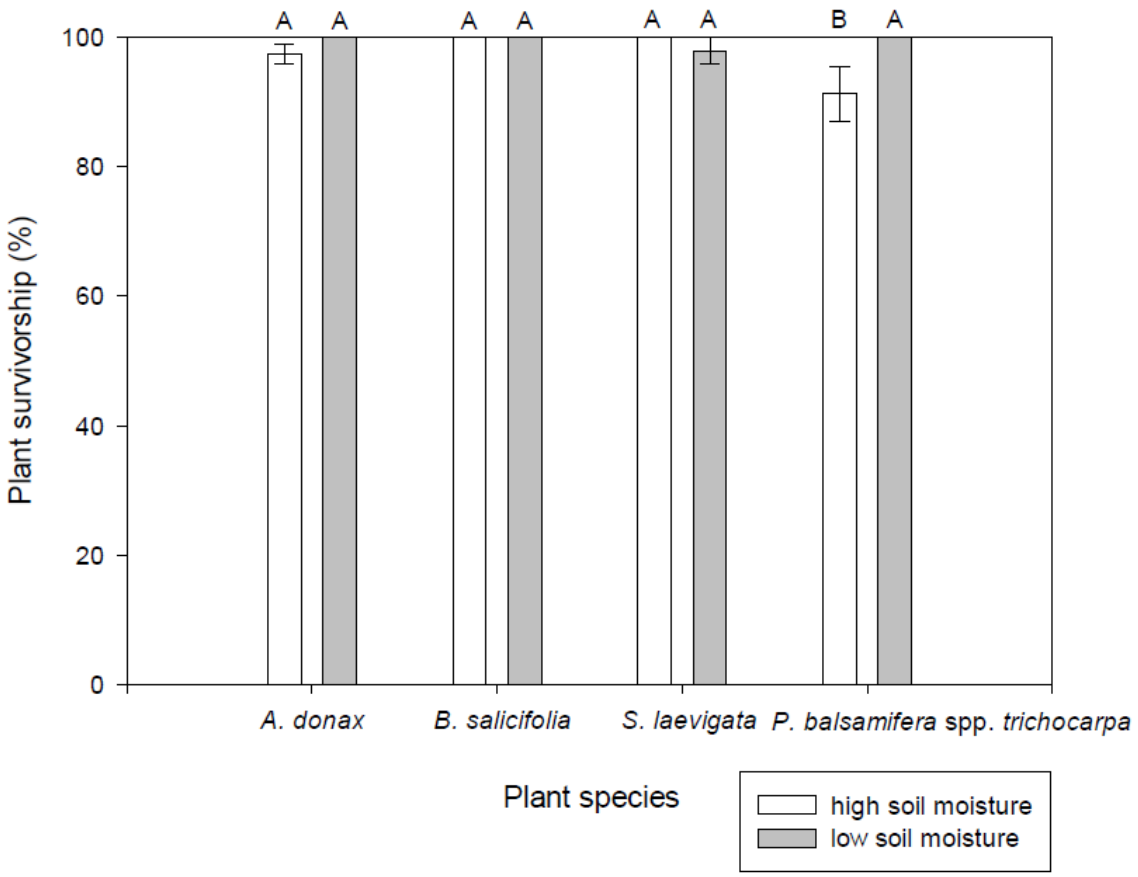


Figure 6. Effects of soil moisture availability treatments on percent plant survivorship of *A. donax* compared to three native riparian plant species at the end of the first growing season (fall 2003) based on the four-way ANOVA (competition x soil moisture x nutrients x light). Letters (A and Bs) denote results of post-hoc hypothesis tests (comparison of means) between individual treatments, with significance recognized at α <0.05. (Source: Coffman 2007)

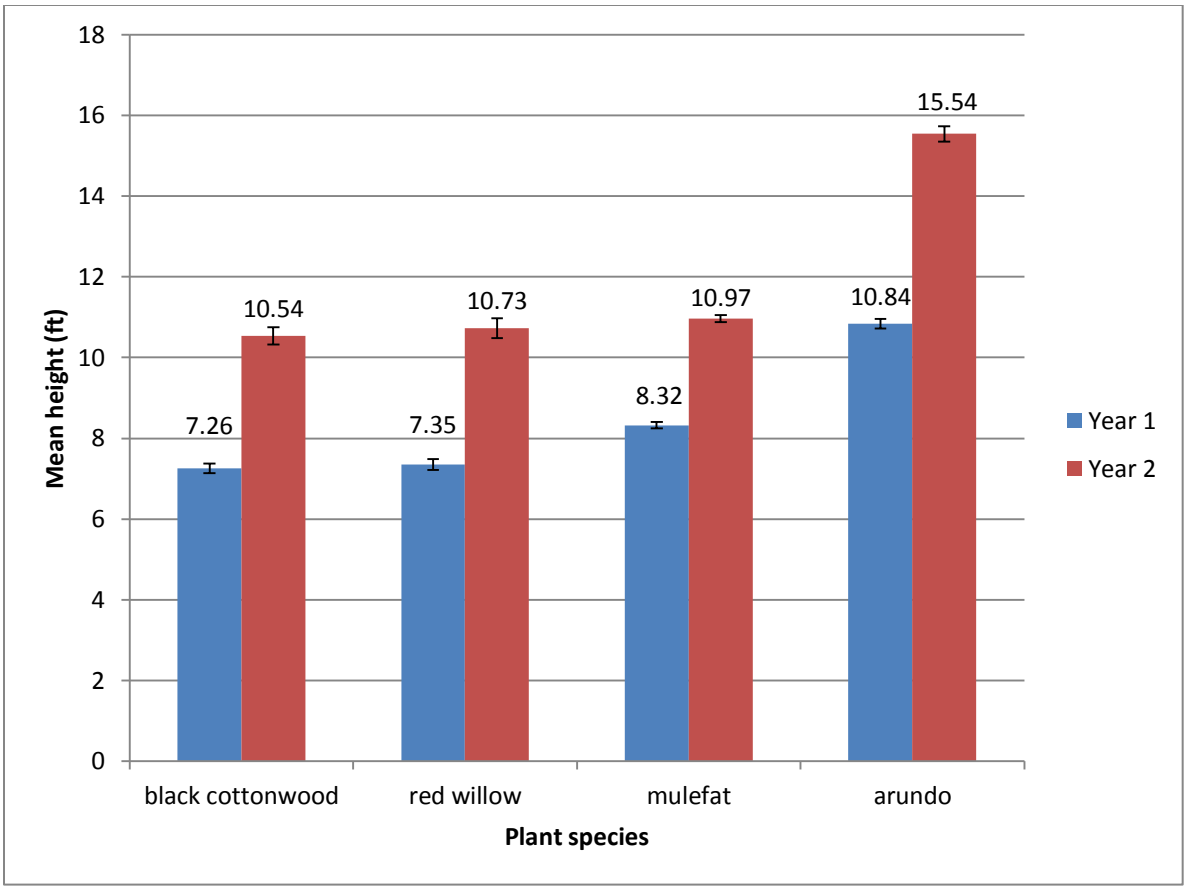


Figure 7. Comparison of mean heights (in feet) of native black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), red willow (*Salix laevigata*), mulefat (*Baccharis salicifolia*) cuttings and non-native *Arundo* (*Arundo donax*) at the end of the first (year 1 = 2003) and second (year 2 = 2004) growing seasons. Mean heights include each of three native riparian cuttings and *Arundo* planted within all treatments combined (soil moisture, nutrients, light, and competition).

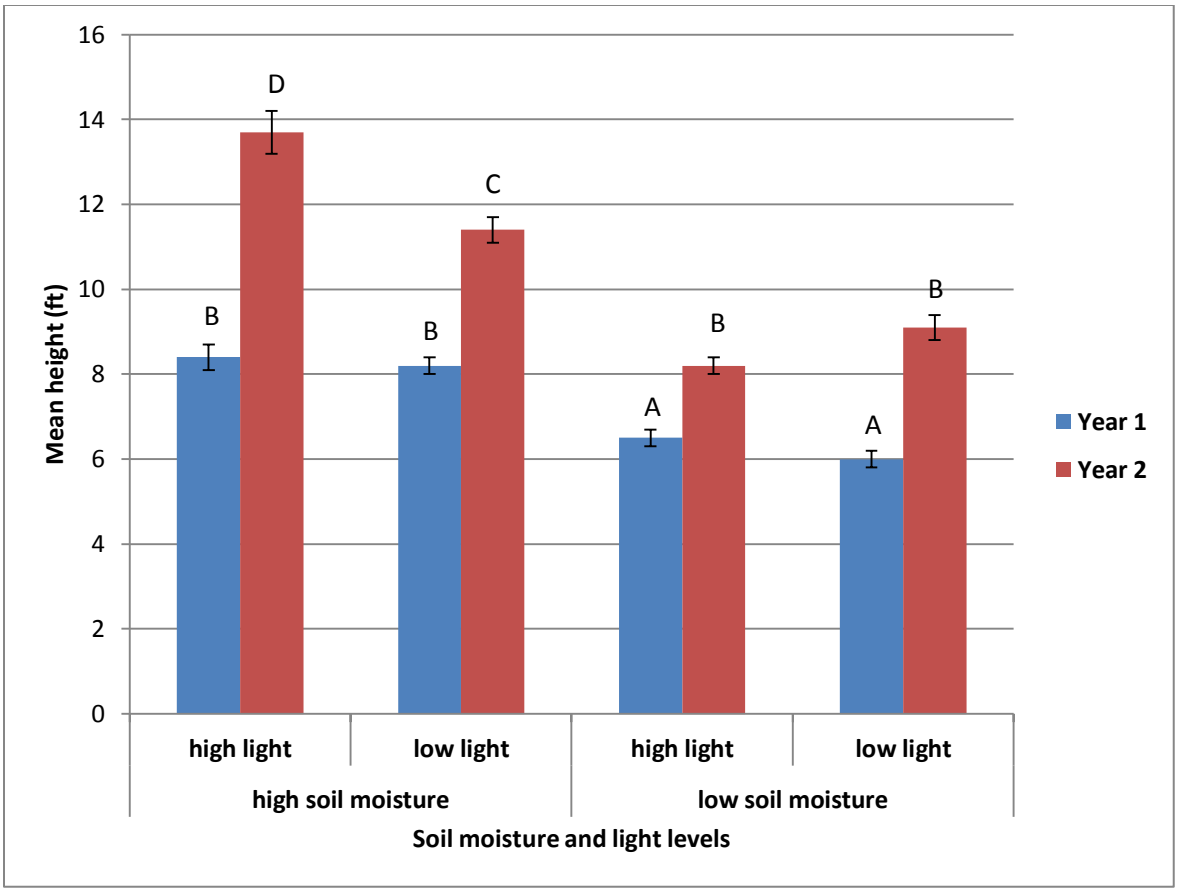


Figure 8. Comparison of mean heights in feet (± SE) of black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) cuttings at the end of the first (year 1 = 2003) and second (year 2 = 2004) growing seasons grown under varying soil moisture and light treatment levels. Letters denote results of post-hoc hypothesis tests (comparison of means) between individual treatments, with significance recognized at α <0.05.

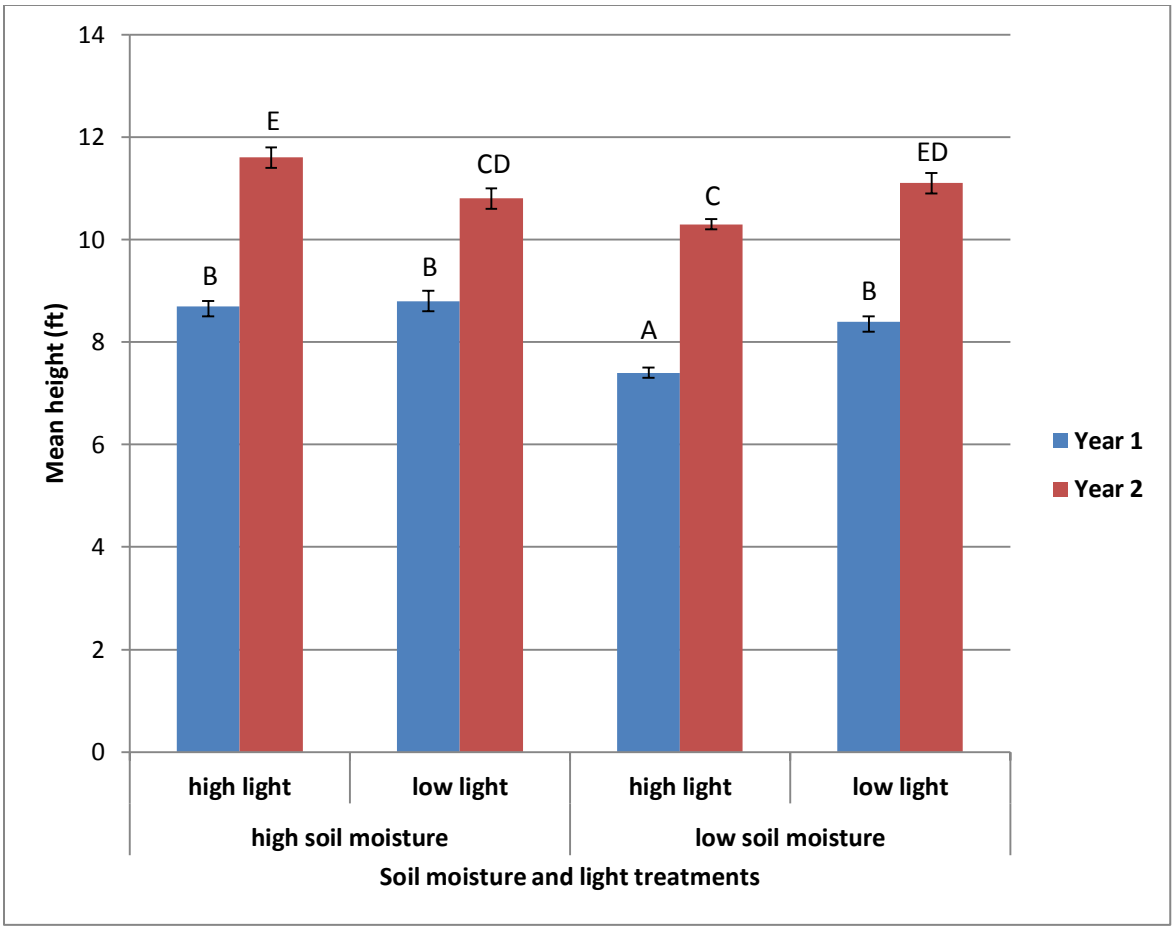


Figure 9. Comparison of mean heights in feet (± SE) of mulefat (*Baccharis salicifolia*) cuttings at the end of the first (year 1 = 2003) and second (year 2 = 2004) growing seasons grown under varying soil moisture and light treatment levels. Letters denote results of post-hoc hypothesis tests (comparison of means) between individual treatments, with significance recognized at α <0.05.

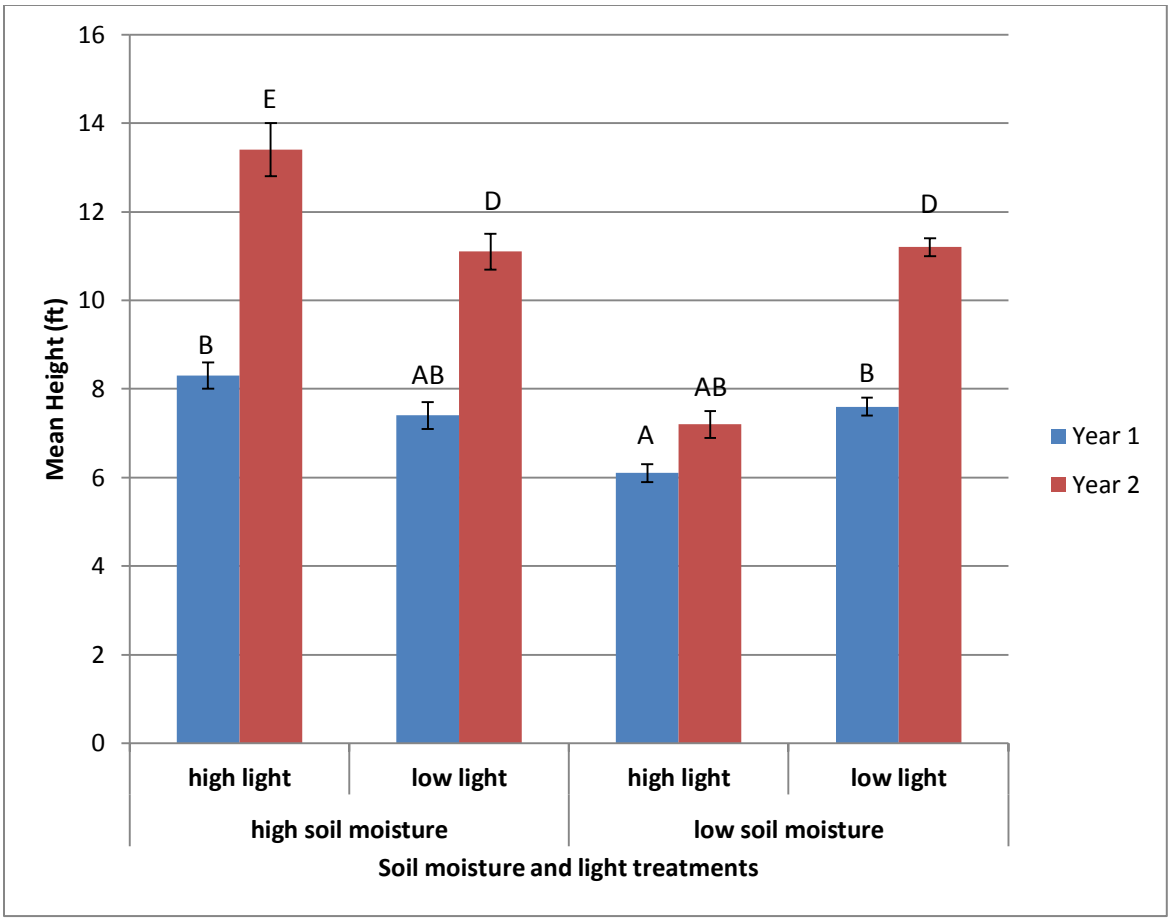


Figure 10. Comparison of mean heights in feet (± SE) of red willow (*Salix laevigata*) cuttings at the end of the first (year 1 = 2003) and second (year 2 = 2004) growing seasons grown under varying soil moisture and light treatment levels. Letters denote results of post-hoc hypothesis tests (comparison of means) between individual treatments, with significance recognized at α <0.05.

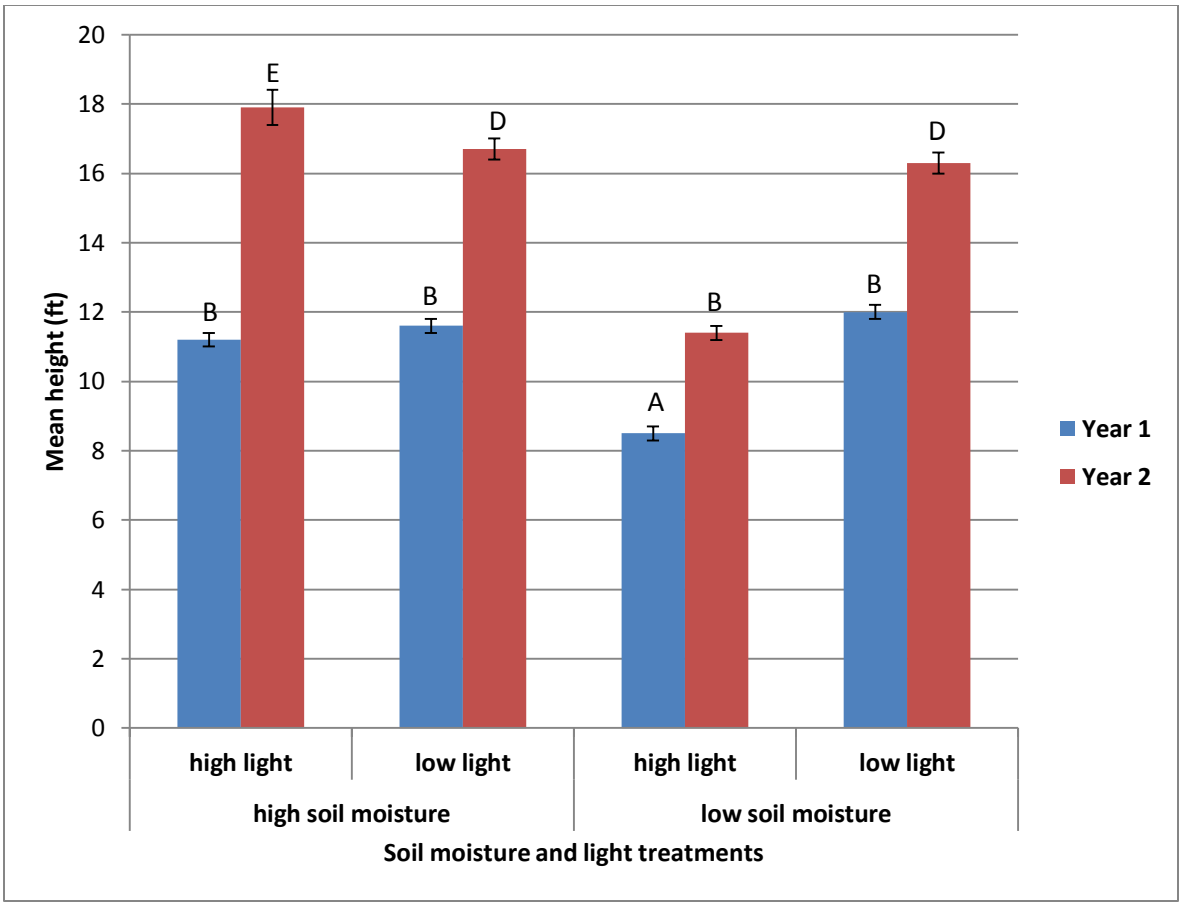
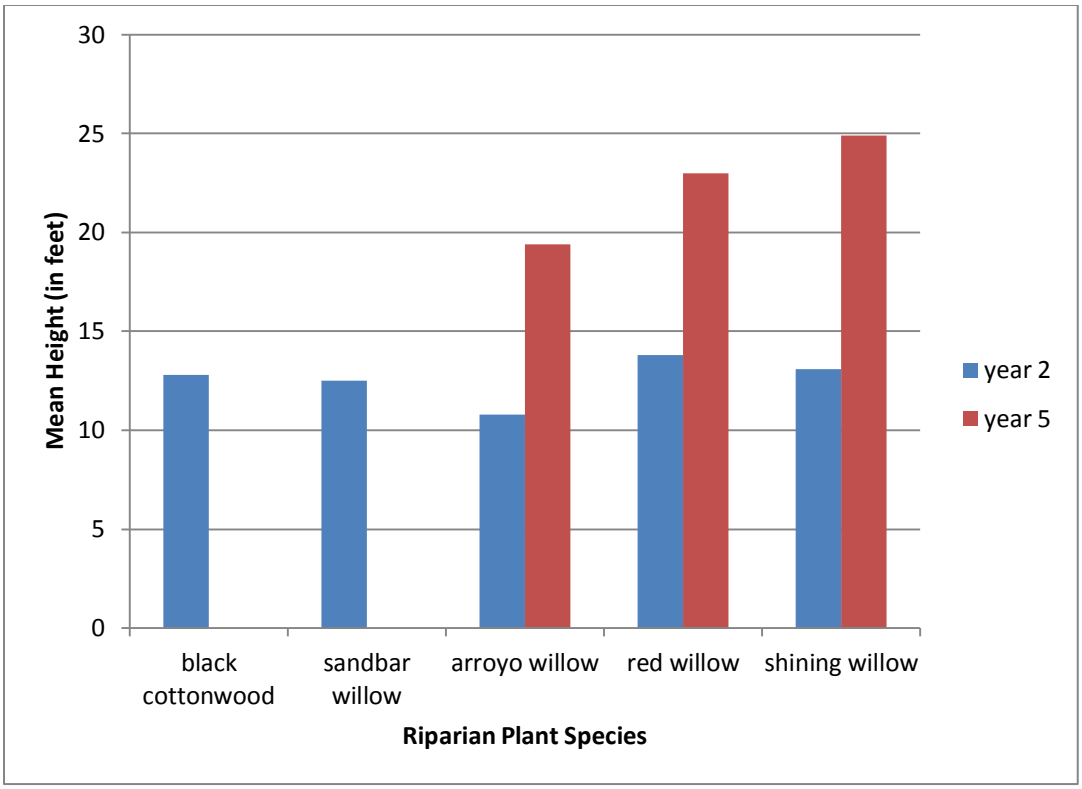
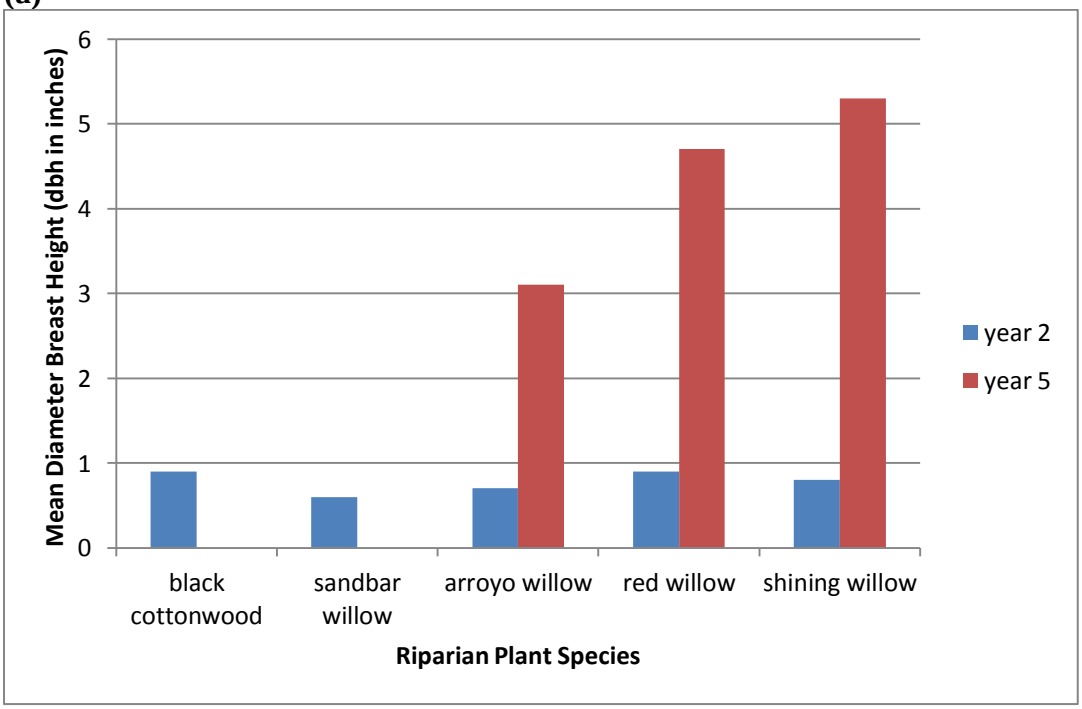


Figure 11. Comparison of mean heights in feet (± SE) of *Arundo* (*Arundo donax*) culms at the end of the first (year 1 = 2003) and second (year 2 = 2004) growing seasons grown under varying soil moisture and light treatment levels. Letters denote results of post-hoc hypothesis tests (comparison of means) between individual treatments, with significance recognized at α <0.05

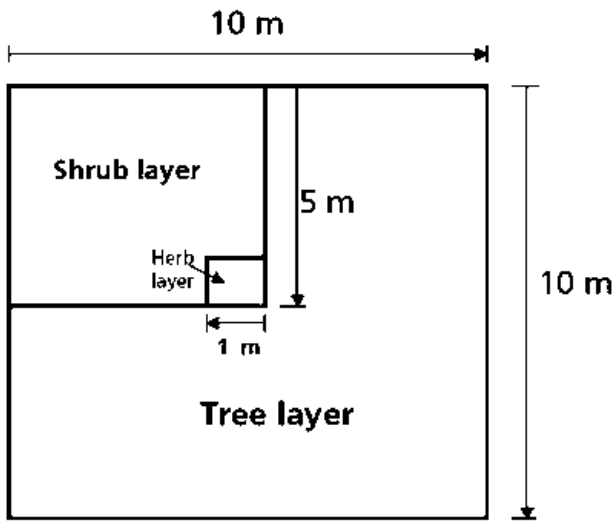


(a)

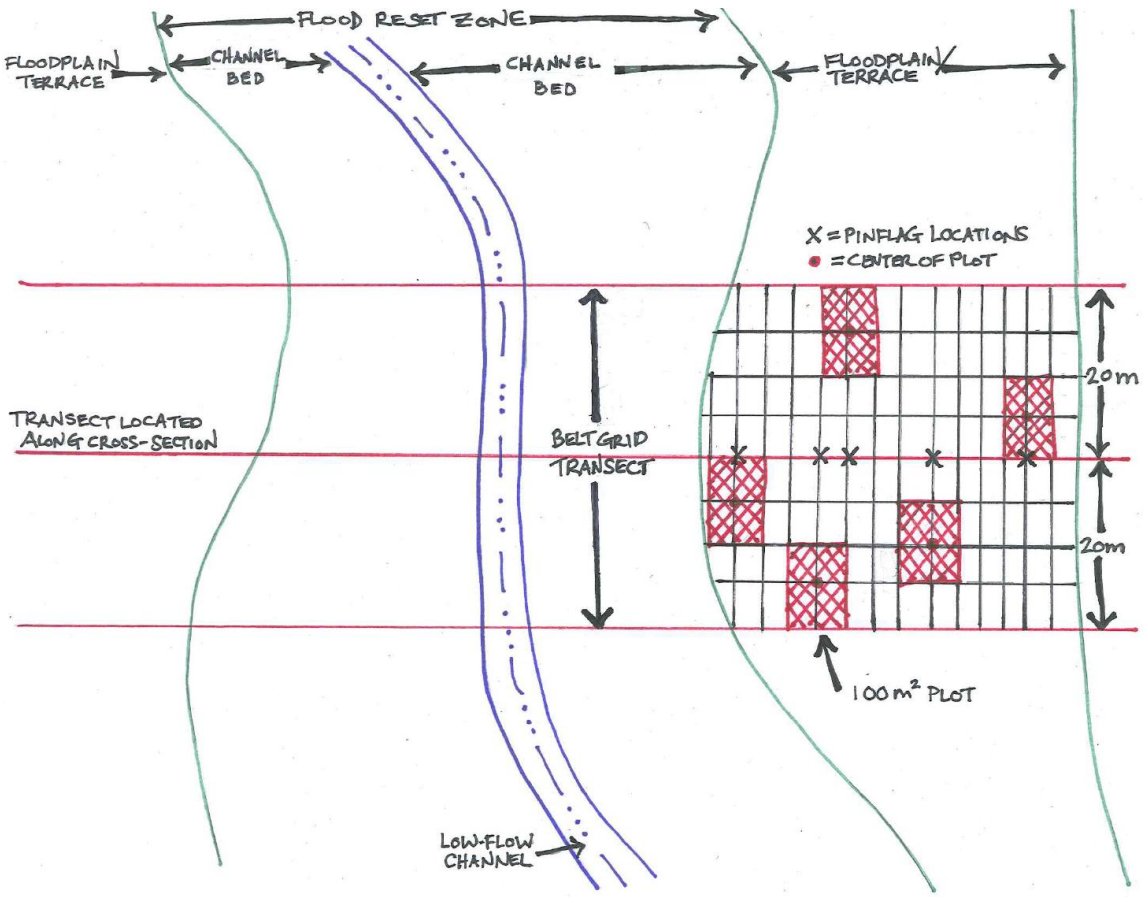


(b)

Figure 12. Comparison of (a) mean heights and (b) dbh in feet (± SE) of riparian tree and shrub species seedling cohorts at the end of the second (year 2 = 2007) and fifth (year 5 = 2010) growing seasons after 2005 floods.



(a) ***Source: Ponce-Hernandez 2004***



(b) ***Coffman 2011***

Figure 13. Conceptual diagrams of plot-based sampling design (a) and transect based sampling design (b) for riparian revegetation monitoring.

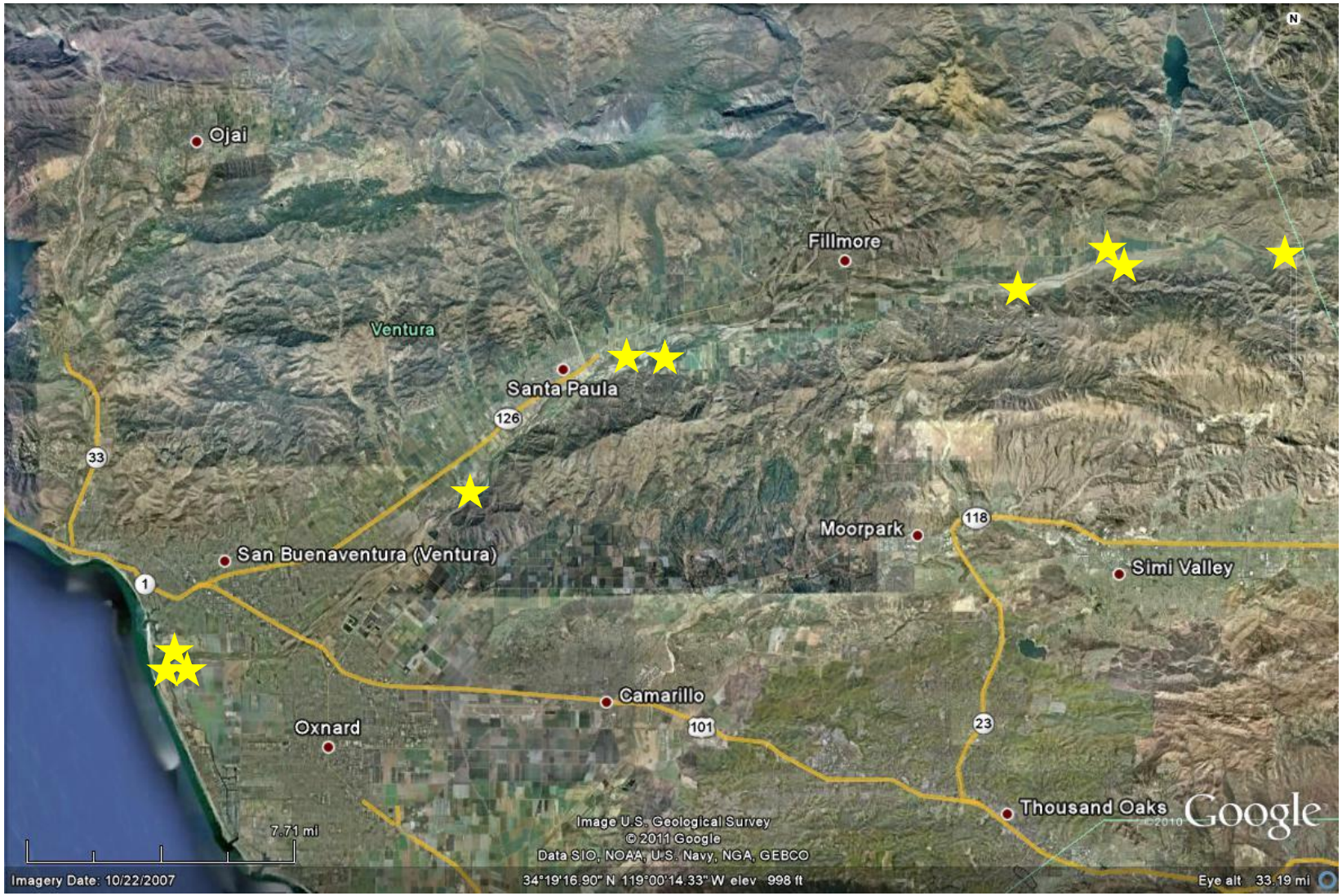


Figure 14. Location of potential reference site locations, including a variety of the largest most natural riverine wetland and riparian habitat conditions in the low gradient portions of the Santa Clara River.

ARUNDO AND SALTCEDAR: THE DEADLY DUO

A Workshop on Combating the Threat from Arundo & Saltcedar

PROCEEDINGS OF THE ARUNDO AND SALTCEDAR WORKSHOP

June 17, 1998
Ontario Hilton Hotel
Ontario, CA

Presented by:

California Exotic Pest Plant Council
Monsanto Company
Riverside County Regional Park & Open Space District
Team Arundo
The Nature Conservancy
University of California Cooperative Extension, Imperial County

PROCEEDINGS

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Introduction

Arundo and saltcedar are two of the most serious invasive exotic pest plants in California. This workshop was held to present new information regarding the impact and management of these plants as a follow-up to two very successful workshops, one on Arundo in 1993 and one on Saltcedar in 1996. The workshop attracted 136 people and would not have happened without the dedicated effort of the organizing committee and the contributions of the invited speakers and poster contributors. This Proceedings presents written versions of these oral presentations and posters. Addresses and contact information for the authors is available from the list of participants at the back of this document.

The Organizing Committee for the workshop were Nelroy Jackson, Monsanto Company; Paul Frandsen, Riverside County Regional Parks and Open Space District; Valerie Vartanian, The Nature Conservancy; and Carl E. Bell, University of California Cooperative Extension, Imperial County. The Editor for the Proceedings is Carl E. Bell. Additional copies of the Proceedings are available; to order, send a check payable to the Ag Extension Trust Fund for $10.00 per copy to Arundo/Saltcedar Proceedings, Cooperative Extension, 1050 E. Holton Rd., Holtville, CA. 92250-9615. Copies of the Proceedings of the 1996 Saltcedar Management Workshop are also available for the same cost from the same source.

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BIOLOGY AND ECOLOGY OF GIANT REED[1]

Joseph M. DiTomaso
University of California, Davis

Giant Reed (*Arundo donax*)

Native Distribution

Arundo has three species native to warmer tropical and temperate regions of the Old World (Hoshovsky 1989). *Arundo donax* is the largest and most widespread member of the genus and is commonly referred to as giant reed, wild cane, or Spanish cane. It is native to several countries from the Mediterranean Sea to the Lower Himalayas (Rieger and Kreager 1989).

Introduction and Spread

In Europe, *Arundo donax* was probably cultivated as far back as the 1600s. It is not certain, however, when *Arundo* was introduced into the US. It has been suggested that it was first introduced in the 1700s. Others indicated that it was brought into the US for use as a windbreak by French immigrants in the 1800s. It appears that the first introduction of *Arundo donax* into California probably occurred from the Mediterranean in the 1820s by the early Spanish settlers in the Los Angeles areas (Bell 1993, Iverson 1993). Its primary use for erosion control in drainage canals. It was similarly introduced for this purpose in other southwestern states. It has also been widely planted as an ornamental in other warmer areas of the US.

It soon spread throughout, mostly through intentional human introductions, and is now distributed from Arkansas and Texas to California, where it is found throughout the state, and in the east, from Virginia to Kentucky and Missouri and generally southward.

Taxonomy

Arundo donax and *Phragmites communis* (common reed) are difficult to distinguish vegetatively (Ollendorf et al. 1988). The leaves of *Arundo* may be slightly larger and more scabrous along the margin than *Phragmites*. Culms also tend to be somewhat larger in *Arundo*. Both species have rhizomes, although *Phragmites* can also have stolons. *Arundo* can form clumps, whereas *Phragmites* occurs in extensive colonies. These

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[1] Dr. DiTomaso also presented similar information on the biology and ecology of saltcedar (*Tamarix spp.*). Published reviews of saltcedar by Dr. DiTomaso are available: 1) Proceedings of the Saltcedar Management Workshop an 1996 UC Cooperative Extension, Rancho Mirage, CA pp ; and 2) highlighted above.

characteristics are not often of diagnostic value. It is important to note, however, that *Phragmites communis* is a native California grass. Thus, it is essential to be certain of the proper identification of *Arundo donax* prior to implementing control strategies.

Ethnobotany

Arundo has historically and currently used in many ways. Egyptians used giant reed as early as 5000 BC to line underground grain storage. Mummies of the fourth century AD were wrapped in *Arundo* leaves (Hoshovsky 1989).

Arundo donax was commonly grown in Europe, China, Japan and India, because of its usefulness. Industries bases on fishing-poles, paper-making, rayon-making, and musical-reeds are the most important uses of the stem of this grass. Stems serve as support for vines and similar climbing plants, and for making trellises for climbing cultivated plants. Stems are also used for garden fences, measuring rods, walking sticks, baskets, chicken pens, arrows, livestock fodder, crude shelters, thatching for mats and roofs of sheds, barns, and other buildings (Bell 1993). It makes a good quality paper, and in Italy the plant is used in the manufacture of rayon. Variegated and glaucous-leaved varieties are still used as ornamentals.

Arundo donax also had medicinal applications (Hoshovsky 1989). The rhizome or rootstock was used as a cure for dropsy. Boiled in wine with honey, the root or rhizome were used for cancer. An infusion of the roots was also considered to be an effective depurative, diaphoretic (increase perspiration), and diuretic (increase urine production).

Giant reed has played an important role in the culture of the western world through its influence on the development of music, which can be traced back 5000 years (Hoshovsky 1989). The basis for the origin of the most primitive pipe organ, the Pan pipe or syrinx, was made from *Arundo donax*. Even today, all of the musical instruments which have a vibrating reed use *Arundo donax*, including oboes, bassoons, clarinets, and saxophones (Perdue 1958). The cultivation of *Arundo donax* for this purpose is primarily in the south of France.

Impact

Arundo readily invades riparian channels, especially in disturbed areas, and reduces ground-water recharge, compromised water quality, chokes riversides and stream channels and interrupts surface water flow and flood control, contributes to mosquito habitat, displaces native plants, provides habitat for exotic and feral wildlife, and increases fire potential (Jackson 1993). Stands of *Arundo* form an explosive fuel and pose a serious threat to life and property along the urban/forest interface.

The long, fibrous, interconnecting root mats of giant reed form a framework for debris dams behind bridges, culverts, and other structures that lead to damage. When *Arundo* debris is dislodged, it will eventually float downstream and, when combined with

sand and trash, form into huge debris piles for removal by work crews (Douce 1993). Thus, the plant can be just as much a problem when dead as when alive.

All evidence indicates that giant reed does not provide either food or habitat for native species of wildlife (Bell 1993). Dense, homogenous stands of *Arundo donax* create zones essentially devoid of wildlife and its presence is viewed as being potentially disastrous for the overall habitat quality of the riparian system (Rieger and Kreager 1989). Infestations have threatened the nesting ground of the Least Bell's vireo, a small songbird that is listed as endangered by both federal and state agencies (Frandsen and Jackson 1993). In Simi Valley, giant reed has choked the habitat of the 3-spine stickleback, an endangered fish species.

Biology and Ecology

Giant reed is a hydrophyte, growing along lakes, streams, drains and other wet sites (Bell 1993). It grows best in well drained soils along river banks and in other areas where abundant moisture is available, particularly where water tables are close to, or at, the soil surface (Hoshovsky 1989). *Arundo* is best developed in poor sandy soil and in sunny situations, but tolerates all types of soils, from heavy clays to loose sands and gravelly soils. It also tolerates a wide range of environmental or human related stresses, including extreme temperatures, drought, floods, damage, diseases, fire, and bulldozers (Bautista 1994). *Arundo* survives in areas with average annual precipitation of 3 to 40 dm, pH values between 5 to 8.7, and high salinity. It can spread from the water's edge up the banks and far beyond the zone previously occupied by riparian woody vegetation.

Establishment

Giant reed can be seriously retarded by lack of moisture during its first year, but drought causes no great damage to patches two to three years old. Once established this species tends to form large, continuous clonal root masses, sometimes covering several acres, usually at the expense of native riparian vegetation which cannot compete with *Arundo*.

Growth

Culms of *Arundo* can reach a height of 20 ft tall and grow 2.5 to 3 inches per day under optimal conditions (Rieger and Kreager 1989). Weedy stands in the US have been reported to yield 8.3 tons of oven-dry cane per acre. Its extensive rhizomes allow it to resprout very quickly after disturbances and out-compete the slower responding native riparian vegetation (Rieger and Kreager 1989). Because it propagates vegetatively, it can form rather pure stands, often at the expense of other plants (Hoshovsky 1989). When established, it has a strong ability to out-compete and completely suppress native vegetation. *Arundo* can survive very low temperatures when dormant but is subject to serious damage by frosts after the start of spring growth. Individuals will survive extended periods of severe drought accompanied by low-pressure humidity or periods of excessive moisture. The ability of *Arundo* to tolerate or even grow well under conditions

of extreme drought is due to the development of coarse, drought resistant rhizomes and deeply penetrating roots that can reach deep soil moisture.

Reproduction

Giant reed flowers between March and September with large (12 to 24 in long) plume-like terminal panicles (Hoshovsky 1989). The seeds produced in this country, however, are seldom, if ever, fertile (Bell 1993). Even in areas were it is well adapted, *Arundo donax* does not usually produced viable seeds (Perdue 1958). Some plants have been grown in scattered locations from seed collected in Asia. Reproduction of giant reed is primarily vegetative, through rhizomes (Bell 1993). These fragments can float miles downstream where they can root and initiate new infestations. Due to its rapid growth rate and vegetative reproduction, new infestations can quickly form pure stands at the expense of other species (Bell 1993). Because the spread of *Arundo* is primarily through vegetative fragments, it is essentially an intra-basin and downstream phenomenon, often caused by flooding events.

Effect on Fire Frequency

Giant reed is highly flammable throughout most of the year, and the plant appears highly adapted to extreme fire events (Scott 1993). While fire is a natural and beneficial process in many natural communities, it is a largely unnatural and pervasive threat to riparian areas. Because it is extremely flammable, the establishment of giant reed within a riparian area redirects the history of a site by increasing the probability of wildfires and increasing fire intensity once it does occur (Bell 1993). Consequently, giant reed effectively alters riparian forests from a flood-defined to a fire-defined natural community. Burning *Arundo* only encourages further growth. Rhizomes respond quickly after fire, sending up new sprouts and rapidly outgrowing native species in a burned-over site (Bell 1993, Rieger and Kreager 1989). Thus, fire events select for pure stands of *Arundo donax*.

Water Usage

Arundo uses prodigious amounts of water to supply its incredible rate of growth. Although there are no specific studies on the evapotranspiration rates of *Arundo*, it has been estimate that it evaporates water at approximately the same rate as rice. This means that every acre of *Arundo* uses about 5.6 acre-feet of water per year. Native species use only about a third this amount, 1.9 acre-feet per year. The water lost to evapotranspiration would otherwise be available for groundwater recharge and ultimately drinking water supplies (Iverson 1993).

Water Quality

Studies indicate that giant reed lacks the structure necessary to provide significant shading of bank-edge river habitats, resulting in warmer water than would be found with native trees and shrubs (Iverson 1993). Consequently, the water is exposed to more

sunlight, and subsequently higher photosynthesis activity. Warmer water in conjunction with more sunlight promotes algae growth, which tends to raise the pH of the water. High pH facilitates the conversion of total ammonia to toxic un-ionized ammonia, which further degrades water quality for aquatic species and downstream users (Bell 1993). Un-ionized ammonia is more toxic to fish and other aquatic life. As a result, aquatic areas dominated by giant reed usually have lower diversity of aquatic animals, including fishes. In the Santa Ana River system, where *Arundo* dominates, the lack of streambank structure and shading has been implicated in the reduction of rare native stream fished including the arroyo chub, three-spined stickleback, speckled dace, and Santa Ana sucker. *Arundo* therefore degrades the quality of water resources as well as the quantity (Bell 1993, Iverson 1993).

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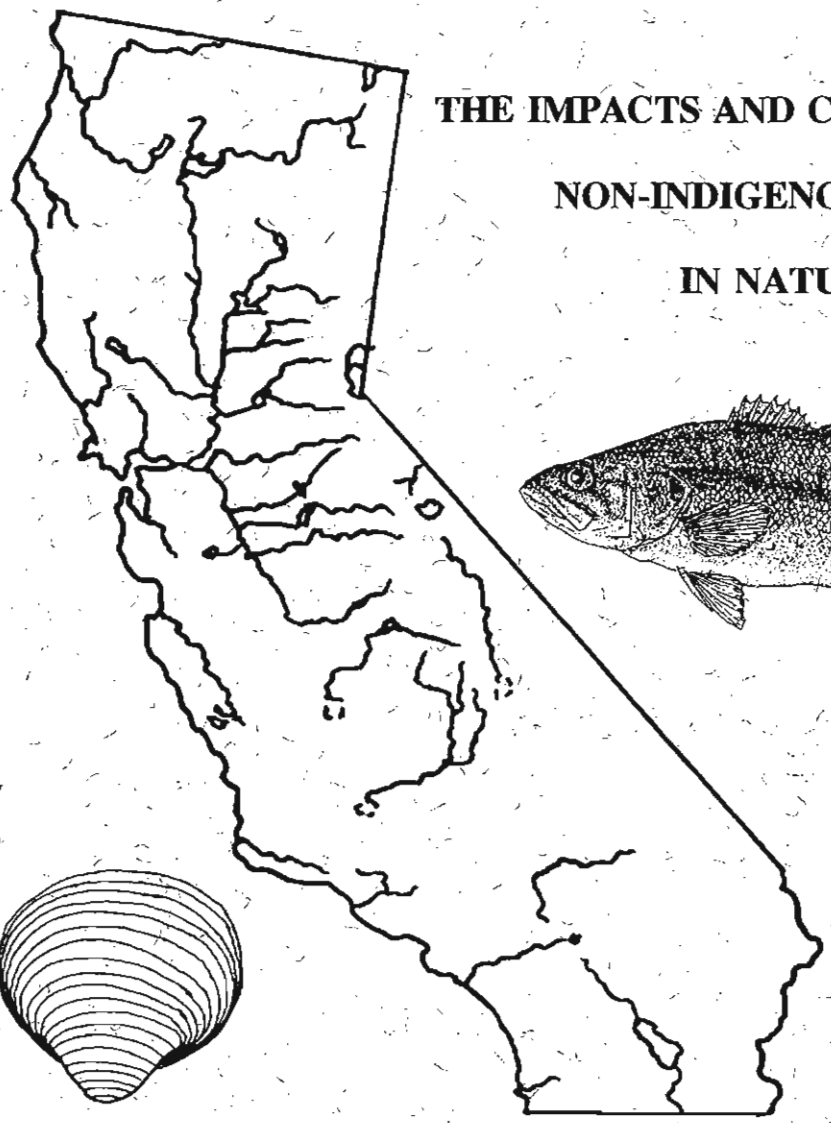
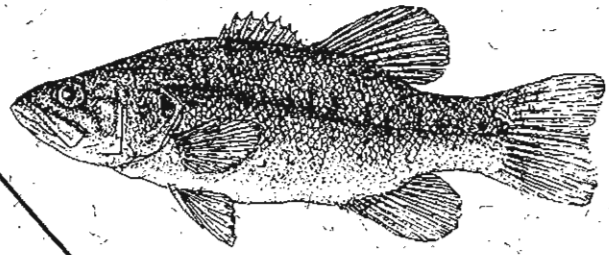
BIOLOGICAL INVASIONS IN CALIFORNIA WETLANDS

THE IMPACTS AND CONTROL OF NON-INDIGENOUS SPECIES IN NATURAL AREAS





Tom Dudley
Beth Collins

Pacific Institute for Studies in Development, Environment, and Security

February 1995

BIOLOGICAL INVASIONS IN CALIFORNIA WETLANDS:

THE IMPACTS AND CONTROL OF NON-INDIGENOUS SPECIES (NIS) IN NATURAL AREAS

Tom Dudley & Beth Collins

With assistance from Judi Tamasi & Jennifer O'Neil
(Environmental Science Program, University of California, Berkeley)

Pacific Institute for Studies in
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The Pacific Institute for Studies in Development, Environment, and Security is an independent, non-profit center created in 1987 to pursue research and policy analysis in the areas of envrionmental degradation, sustainable development, and international security. The Institute has three broad goals: (1) to conduct policy-relevant research on the connections between international security, global environmental change, and economic development; (2) to facilitate communication between individuals and institutions working on problems in these three areas; and (3) to educate plicy makers and the public on the nature of these problems and the need for long term strategies to address them. Underlying all of the Institute's work is the recognition that the pressing problems of environmental degradation, regional and global pverty, and political tension and conflict are fundamentally interrelated, and that these issues ultimately must be addressed in an interdisciplinary manner.

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SUMMARY

The Problem

Non-indigenous species (NIS) are those plants and animals that have been transported through human activities from their native ranges into new ecosystems where they did not evolve. While we use some non-native species for agricultural, ornamental and recreational purposes, resource managers and conservationists are increasingly concerned that many NIS are invading areas that our society has set aside for natural resource protection. In natural areas these biological invaders have threatened or eliminated native species and severely degraded ecosystem processes. 'Biological Invasions' are taking place worldwide, homogenizing the Earth's biota and reducing the biodiversity of the planet. Non-native species have already been implicated in the loss of more species than climate changes or most other human-related factors, except for habitat destruction and modification, justifying the consideration of plant and animal translocation as a fundamental component of Global Change.

California is among the most biologically diverse areas on the planet. At the same time, it includes more species listed under the Endangered Species Act as Threatened or Endangered than any other state in the U.S. Approximately one-tenth of its flora is estimated to be threatened with extinction or is already lost, and numerous animal species are similarly threatened. Nowhere are these threats more serious than in aquatic habitats where, for example, two-thirds of California fish species are threatened or gone. In California, fully half (37) of the animal species receiving special protection are directly tied to aquatic habitats. Non-native species play a critical role in threatening nearly all of these.

Our primary strategy for protecting native ecosystems and biodiversity has been to create natural reserves at great expense, where the role of NIS in threatening these ecosystems may be recognized, but we have no comprehensive overview of the extent of these threats. To address this concern, we conducted a survey of the managers of 52 natural areas in California to collect information on what non-indigenous species were present in the bioregions of the State, what impacts they were having and how these were being confronted. We focused upon invaders into aquatic and wetland habitats, given the degree to which these ecosystems have been affected and the importance they have to both the economy and ecology of the West.

Conclusions

Non-indigenous species of wetland plants and animals are present and causing detrimental impacts to threatened and sensitive species, to overall natural biodiversity, and to natural ecosystem processes in every bioregion of California. Resource managers in every 'natural area' surveyed described problems they confront with NIS, and in many cases management of these species demands a major component of reserve funds and staff time. Furthermore, every reserve has NIS problems that managers are unable to attend to, for reasons of inadequate funding, staff, information and/or mandate from their respective

agencies and the state or federal government. In many cases, the stretched budgets and time demands resulted in managers not being aware of some NIS present in or near their areas of jurisdiction that cause problems elsewhere. True costs were not possible to estimate accurately because of the limited nature of this analysis and because budgets could not be clearly broken down into NIS components by managers, but we estimate that NIS in natural areas cost the public in excess of tens of millions of dollars per year, including a variety of lost opportunity costs and intangible wildlife values, across California.

As a consequence of these many limitations, numerous NIS problems are increasing in magnitude or not even recognized at an early stage when control might be most effective. In general, those reserves with the most information available on local and regional biodiversity issues also put the most resources into attempting control of NIS. Some destructive aquatic and riparian NIS have only recently been identified as problems (e.g. Asian clam, perennial pepper-grass, tree-of-heaven, eupatory - a riparian shrub) while others are expanding ranges beyond previously assumed distributional limits (e.g. tamarisk, giant reed or arundo, red fox, brown-headed cowbirds). Many other NIS have been present and widespread for many years, but their destructive impacts on native species and ecosystems are just beginning to come to the attention of those citizens concerned about California's threatened biodiversity (e.g. bullfrogs and a vast array of fish, including trout, sunfish and bass, all of which prey on endangered amphibians; stocked northern California rainbow trout dilute the genetic integrity of southern populations; Himalayan blackberry and several other vine-like plants compete with and overwhelm native riparian plants).

NIS problems have often arisen from accidental or careless introductions; however, many of the most serious ones are species intentionally introduced for sport or cultural reasons. Some of these were imported into natural wetland areas and secondarily determined to be problems (stocked trout species, bullfrog, eucalyptus trees, European beach grass) and others have spread from developed sites into wild ecosystems (e.g. purple loosestrife and tamarisk were originally grown for shade, soil stabilization and/or landscaping; various sunfish and bass species escape from reservoirs into rivers and streams; livestock escaped to become feral). Furthermore, not all problem NIS are foreign. Some of the above examples are species native to North America, and even California, that are either spreading and displacing native species in new regions (e.g. red fox, cowbirds, cocklebur, the common reed *Phragmites*) or have been transplanted into water bodies where they did not historically occur (e.g. rainbow and golden trout, various crayfish).

It is generally recognized that human modifications of land and water resources have had the most destructive influences on natural biodiversity and ecosystems of California. This fact only highlights the critical need to protect biotic resources in the remaining areas dedicated for ecological protection from further declines, including impacts from NIS.

Following are additional specific conclusions about NIS, based on our surveys of California natural areas:

1. Broad-based behavior of the most threatening species:

Omnivorous predators, for example sunfish, crayfish and bullfrogs, are posing some of the most serious threats to sensitive and threatened species, many of which are present in

small, highly localized populations making them susceptible to extinction. Plants and some animals with broad ecological tolerances, able to spread rapidly by vegetative growth or abundant, easily dispersed propogules (e.g. seeds of arundo and tamarisk, or larvae of the corbiculid clams) are the biggest threats to aquatic ecosystems because they tend to form dense, monospecific stands that smother native species and modify the availability of resources (nutrients, water, food, shelter) within the ecosystem.

2. Where are the biggest problems:

Low elevation, coastal sites are threatened by the largest number of NIS, resulting, in part, from the array of species introduced in shipping ballast and through other port-of-entry factors. Also, these areas have mild climates and are highly populated, and therefore are more heavily disturbed by human activity. Both factors foster expansions of opportunistic NIS. Higher elevation areas are relatively free of multiple NIS problems, probably because of the climatic stresses present and the greater distances from sites containing potential escapees. Similarly, warm desert sites are affected by few species, but those NIS that tolerate stressful desert climates, like tamarisk, have enormous potential to multiply and dominate native species and ecosystems.

3. The role of disturbance:

As stated above, human disturbance of natural vegetation and underlying soils creates conditions that favor NIS expansions. Alteration of natural disturbance regimes (reducing stream flows, especially during floods, or interfering with natural drought and fire cycles) also appears to promote invasion by many accidentally and intentionally introduced species. Thus, management for native species protection should be directed towards maintaining natural disturbance regimes. Many 'weeds', both native and introduced, are actually fairly benign and/or drop out of the community as a system recovers from natural disturbances.

Recommendations

1. Rapid response to NIS based on sound science

Rapid responses have been effective in controlling or eradicating potentially huge problems in California (e.g. Asian tiger mosquito, purple loosestrife), illustrating the need for and value of frequent and vigilant monitoring to identify threats early. Furthermore, it is essential to maintain a high level of taxonomic and ecological expertise to recognize problems early because large numbers of NIS are related to recognized 'problem NIS' but do not tend to become invasive, or simply have not yet experienced conditions that would promote their expansion. It is important that managers recognize that initial entry of NIS may be subtle, particularly those occuring in water or wetlands where detection may be difficult. This requires rigorous foresight and adequate monitoring programs in order to prevent highly destructive outbreaks before they can occur, as well as a high degree of knowledge concerning biology of native and non-indigenous species, and processes within ecosystems. For all of these reasons, we encourage closer co-operation between management and academic institutions to deal effectively with NIS concerns.

2. Better supervision of NIS importation

Many NIS are those brought into the country or region for commercial purposes, such as ornamental plantings, the aquarium trade, aquacultural or other game stock. It is critical that vigilance be maintained in supervising the importation and maintenance of present and future ornamental and aquacultural trade species. Federal and State agencies are active in this regard to restrict the entry of potential agricultural pests, but their oversight procedures for 'ecosystem pests' must be greatly strengthened.

3. Legal and administrative frameworks for NIS management

To protect California's diverse ecosystems, we also need a more comprehensive legal or administrative approach to NIS throughout the state. Regulatory tools are needed that allow managers to identify problems early, delegate staff and funds to the problems, and conduct appropriate monitoring to ensure success in NIS entry, control and/or eradication. Existing laws and policy statements provide useful precedents for NIS control, but are generally inadequate to meet the specific needs of resource managers and do not provide them with a strong mandate for undertaking efforts they feel are required. Legal statutes are needed that explicitly address NIS concerns in areas dedicated for ecological protection. The most successful legislation would be co-ordinated among regional, federal and international agencies concerned with resource protection, given the nature of NIS problems to transcend political boundaries. An outline for a Model Law regarding nuisance NIS is presented here, is the subject of on-going discussion on how regulations may yield maximum effectiveness, and we anticipate will provide guidelines for developing adequate policy here and abroad.

4. Integrated ecosystem-based approaches to resource management

Aquatic habitats exhibit close interaction between reserve areas and highly-modified areas outside of reserves. The high probability of exchange of organisms or propagules through watercourses makes it essential to identify potential problems beyond reserve boundaries and to co-ordinate amongst agencies and interest groups on a regional or 'watershed' basis (as illustrated by the Arundo Donax Task Force in Riverside and Orange Counties). We further recommend taking a more comprehensive approach to biodiversity protection across the State (and beyond our borders), possibly along the lines of the Aquatic Diversity Management Areas program outlined by Moyle and Yoshiyama (1992). The Bioregion approach (California Resources Agency 1991) provides a useful step towards co-ordinating issues with regional relevance while recognizing the heterogeneity as well as similarities that exist both within and among regions.

5. Triage and resource management

Certain NIS have important recreational and economic values, so it is difficult or inappropriate to promote a general policy of eradicating all NIS. Furthermore, native species ares sometimes problems for valued recreational and wildlife purposes, and management must balance promoting purity of native biodiversity with sustaining recreational and other appropriate human values (but this should be weighted towards 'purity' in those ecosystems that are more highly protected, e.g. designated Wilderness Areas). Finally, the expense of NIS control may, in some cases, be prohibitive and should be considered before allocating

funds to specific programs. These realities suggest that resource management, now being called 'ecosystem management', is most effective when conducted as triage, balancing what is environmentally desireable, what is wanted by users, and what is possible (Vitousek 1994). Although triage is generally considered a political process, management must recognize the need for accurate scientific information, along with objective information from all interest groups. Our society must become better informed through public education programs of the real threats that NIS pose to ecosystems in order to promote an objective and balanced approach to resource management.

This study is designed to be a tool for land managers, policy-makers, and researchers to become more familiar with the scope and degree of the problems of NIS, and to serve as a means of focusing efforts towards a more co-ordinated approach to solving what we consider one of the most pressing problems in natural area and biodiversity protection.

INTRODUCTION

Non-indigenous species (herein abbreviated as NIS) are those plants, animals and other organisms that have been transported through human activities from their native ranges into new ecosystems where they did not evolve. Also known as 'exotic species', 'introduced organisms', or 'alien species' (Randall 1994), these transplanted species have recently become of great concern to resource managers and conservationists, and were the subject of a recent U.S. Office of Technology Assessment study (OTA 1993). According to that analysis approximately 4500 species in the U.S. are not native to the country, and 200 of these have invaded just during the last 10 years. Some NIS are beneficial, such as the crop plants we use for food and fiber, whereas most have little economic benefit, but many do have the potential to spread into areas of environmental concern where they can eliminate native species, severely degrade natural ecosystems and interfere with human needs.

Throughout the world these 'Biological Invasions' are occurring, with tremendous impact on natural processes and raising concerns that we are homogenizing the world's biota and losing the biodiversity of the planet (Lodge 1993, Vitousek 1994). Increasing public attention to the predicted impacts of Global Climate Change is critical to planning for our future, but the more subtle implications of widespread transplantation of organisms merits similar concern. Introduced organisms are directly implicated in threats to the majority of endangered species in California (Elias 1987, Steinhart 1990, Moyle and Williams 1990) and have been partly to blame for extinctions throughout the world (Welcomme 1984, MacDonald 1988, Savidge 1987, Miller et al. 1989, OTA 1993). Thus, scientists and conservationists are increasingly looking at biological invasions by non-native species as a fundamental component of Global Change resulting from human activities (Drake et al. 1989, D'Antonio and Vitousek 1992).

A well-documented example of the threats posed by non-indigenous species is the invasion of lakes and rivers in the eastern states by Zebra mussels (*Dresseina polymorpha*), a gastropod from eastern Europe that entered the Great Lakes through ballast water releases (Sprules et al. 1990, Garton et al. 1993). These invaders now clog water intakes, form destructive encrusting layers on top of endangered native mussel species, and feed on plankton and other life forms that form the basis for food webs of major lakes and rivers (Mackie et al. 1989). Zebra mussel damage to waterways and equipment is estimated to cost $1 to 10 billion over the next 10 years (O'Brien 1990, Strayer 1992, Czarnecki 1994)! While this species is not yet present in the Western states, biologists predict that because of the climatic similarity between the west coast of North America and the Caspian Sea where it naturally occurs, zebra mussels will colonize here within the next few years and will become a management problem in aquatic systems from British Columbia to Southern California (Strayer 1992).

The Zebra mussel is only one of many potentially damaging aquatic species that will eventually confront resource managers in California, and hundreds of others are already present, many causing extensive degradation of our landscapes (Mooney et al. 1986). Already the largest estuarine ecosystem on the west coast of North America, the San Francisco Bay/Sacramento River Delta, has experienced invasion by over 150 NIS, and their

impacts on the estuarine ecosystem are illustrated by a clam from Asia (Carlton et al. 1992, A. Cohen, pers. comm.). The Asian clam (*Potamocorbula amurensis*) feeds on small animals in the water column, and, by reducing the number of plankton in the Bay, threatens economically important Bay fisheries that are dependent on plankton resources. The Delta smelt was an abundant plankton-feeding fish in the Sacramento River Delta, but has recently been proposed as a Threatened species by the U.S. Fish & Wildlife Service because its numbers are also declining, in part as a consequence of competition from introduced clams (Moyle and Yoshiyama 1992). Invasive species in wetlands are often difficult to initially distinguish, and if past experience is any indicator, outbreaks are likely to be extremely difficult or impossible to control. Therefore the the importance of early detection and prevention before problem species get out of control cannot be overemphasized.

California is among the most biologically diverse areas on the planet, but approximately one-tenth of its flora is threatened with extinction or is already lost (Bakker 1984, Mooney 1988, Jensen et al. 1993). Sixty-two percent of the freshwater fishes native to California are in need of immediate, special protection (Moyle and Yoshiyama 1992), and nearly all native amphibians have suffered extraordinary declines in distributional ranges and population size (Hayes and Jennings 1986). The status of native invertebrates, particularly in aquatic habitats, is largely unknown (Mooney et al. 1986).

Our primary strategy for protecting native ecosystems and biodiversity for future generations has been to create natural reserves, at great expense and effort by many individuals, organizations and public institutions. However, it is critical to increase awareness that simply designating an area for 'wildland protection' and excluding most human impacts will be largely ineffective for providing long-term viability of most ecosystems because many NIS have the potential to invade so-called 'undisturbed habitats' (Vitousek et al. 1987, DiCastri 1990). The state of California is particularly vulnerable to NIS invasion because extensive human settlement and disturbance of coastal regions promotes the spread of NIS, ultimately into natural areas (D'Antonio and Dudley 1995), and the great diversity of habitat types results in numerous small populations of native species that are highly susceptible to local elimination and extinction (examples in Elias 1987). This susceptibility is accentuated by the small size of many protected areas, where edge effects from adjacent developed areas increase the risk to native species. *It is a paradoxical and revolutionary concept for many that simply leaving a natural area alone, or 'letting Nature take its course', would actually result in the loss of these species and ecosystems, along with wasting the efforts expended in the first place to designate them for protection.* Management, often intensive, is essential to maintain, let alone improve, many of the ecological reserves. Many protected communities and ecosystems have already been damaged, requiring managers to undertake extensive restoration efforts in order to retain substantial naturalness of these areas.

NIS are found in every ecosystem in the State, yet we have no comprehensive overview of the extent of NIS problems in California. Furthermore, the legal and administrative mechanisms to confront these threats to our native ecosystems are largely lacking, often consisting of ad-hoc responses once invasions have reached epidemic, emergency levels (Jackson 1993). There is a great level of concern within state and federal resource agencies about NIS problems, but the lack of a clear mandate on NIS policies from

higher administrative levels restricts their capacity to detect, respond to and assign funding to NIS threats early, when they would be more assured of success at lower costs.

This report is the first attempt to take a comprehensive approach to NIS problems in California, incorporating impacts of non-indigenous plants and animals to protected ecosystems, the costs they incur, and the legal and administrative mechanisms that facilitate response to biological invasions. We focus on aquatic and wetland ecosystems because in the semi-arid Californian region, these are the most imperilled and sensitive systems to both human and NIS impacts (CSLC 1993).

SURVEY APPROACH

This analysis is based on a survey of reserve managers across the State, representing State, Federal and NGO wildlands, and therefore largely represents the perspectives of the land managers and biologists in particular locations. We gathered information by telephone from 16 National Forests within California, 11 National Parks, Sea Shores and Recreational Areas, 9 Reserves of the University of California, 6 Wildlife Refuges, two Nature Conservancy Preserves and 3 State Parks (see map on p. 15). We rely heavily upon areas under federal jurisdiction. Federal lands are found in the same regions in which most State and local reserves are located and generally include much greater land areas, so that problems will generally be shared among the protected areas. We avoid discussing in detail every NIS that is recorded, and are considering primarily the actual problems currently posed by both plant and animal species that have been introduced either intentionally or accidentally into California's aquatic ecosystems. This is not an exhaustive survey, but is an attempt to consider some of the more important NIS in representative biogeographical provinces in the State.

The questions we posed in interviews of survey participants were as follows:

- What are the most problematic NIS in aquatic and wetland habitats in your area?
- What impacts to native species and ecosystem processes are known or suspected as a consequence of the presence of NIS?
- What efforts, both administrative and field-based, are currently taken to control NIS?
- How successful have control efforts been?
- What are the costs of maintaining such a program, or incurred as a consequence of NIS?
- What is not being done, or what are your needs, in controlling NIS?

We then used the answers to construct an overview of NIS concerns across the State, with emphasis on problem species in six broad biogeographical provinces, or Bioregions, of the State. Interested individuals in each of these bioregions can identify those species that are of potential concern in each area, as well as considering what types of habitats these species are likely to invade. Finally, we consider some of the present and possible approaches that activists and policy-makers could explore in developing a better response

system for dealing with problem invaders. We hope that this document will serve as a starting point, rather than a final statement, on the issue of non-indigenous species in wetlands and other natural areas of California and other states and provinces.

BACKGROUND

Aquatic Ecosystems of California

Aquatic ecosystems include a wide variety of habitats, including headwater streams, larger rivers, and terminal estuaries or land-locked basins (e.g. Mono Lake), as well as isolated springs, vernal pools, wet meadows and marshlands, natural lakes, and man-made reservoirs and water transport canals. These habitats are found throughout the State, from high, arid deserts to temperate coastal forests. Such aquatic and riparian ecosystems are recognized as critical for most wildlife species, and in arid regions approximately 90% of the organisms, both terrestrial and aquatic, depend directly on the aquatic environment for at least some stage of their lives (Carothers 1977). In many cases rivers, ponds and other aquatic systems provide the central feature for areas designated for wildlife protection, be they the 11 Wild and Scenic Rivers in California within National Forests or 25 out of 52 biodiversity preserves managed by The Nature Conservancy within California.

Aquatic habitats reflect land uses and conditions in their surrounding watersheds because the downhill flow of water means that waterbodies will incorporate impacts occurring throughout the surrounding landscape (Gregory et al. 1991). Erosion from road construction or timber cutting, for example, is often associated with degradation of spawning and feeding habitat for salmonids (trout and salmon) and other aquatic species (Murphy 1984). Aquatic organisms, and fish in particular, can often serve as surrogates for the rest of the associated biotic community (Moyle and Williams 1990), and the Environmental Protection Agency is moving towards the use of aquatic indicator species (mostly fish and aquatic invertebrates) as tools to indicate both water quality conditions and the status of surrounding terrestrial ecosystems (Plafkin et al. 1989). After more than a century of intensive development throughout the valleys of California, only about 10% of riparian habitats and probably less than 20% of estuaries remain essentially intact (State Lands Commission 1993). However, native species are present to a greater or lesser degree in nearly all waters, so a broad definition of what constitutes a natural ecosystem is warranted in developing protection and restoration guidelines for the region. Some of these habitats are considered in greater detail in subsequent sections, but we refer readers to other works for further information on these threatened ecosystems (e.g. Jensen et al. 1990, Moyle and Leidy 1992, CSLC 1993).

How do Non-Indigenous Species get to California?

Non-native species have been introduced into California wildlands by intentional and non-intentional pathways, or a combination of both. Intentional introductions involve the importation of desireable species into the State or counntry for economic and aesthetic purposes. Plants cultivated by nurseries for ornamental and cultural use subsequently escape

into adjacent wildlands (e.g. tamarisk or saltcedar to control erosion and as a windbreak, ornamental Tree-of-Heaven, highway iceplant, also to control erosion, and English ivy). Livestock and other useful animals such as pigs, sheep, horses and cats subsequently become feral via escape or relaxed owner control (Coblentz 1990). In addition, recreational and economic species are often planted directly into natural and semi-natural waters to create a food or sport fishery, or to augment depleted native stocks [e.g. bullfrogs, crayfish, brook trout and various sunfish (*Lepomis spp.* & *Micropterus spp.*) brought in from the eastern states, and German brown trout from Europe](Jennings and Hayes 1985, Moyle and Leidy 1992). All of these species are presently or potentially implicated in reducing populations of native species, and/or altering natural ecosystem processes such as nutrient cycling and disturbance regimes.

Intentional introductions also include the importation of biological control agents (usually pathogens or insects) to attack pest weeds and insects, but which occasionally become pests themselves on native species or valuable plants (Miller and Aplet 1993, Thomson and Huenneke 1992). For example, an herbivorous weevil in the genus *Rhinocyllus* was intentionally introduced into California to control weedy thistles, but subsequently expanded its host range to feed on native species of *Cirsium* thistle, several of which are legally protected (Turner et al. 1987). Another biocontrol introduction, the grass carp, *Ctenopharyndon idella*, effectively controls some aquatic weeds in canals, but prefers native plants and can thereby reduce native fish populations which utilize non-target plants (Wiley et al. 1987, Van Zon et al. 1978).

Unintentional invasions also occur by a great variety of methods. Many plants and animals arrived as 'stowaways' aboard ships, such as black and Norwegian rats that can then transmit infectious diseases, or annual grass seeds from the Mediterranean region adhering to fur of livestock or in their feed and have subsequently taken over much of the grassland areas of the West (McKnight 1961, Baker 1978). The Tiger mosquito is a major vector of dengue fever, and was accidentally brought into the southern states as larvae inhabiting the water trapped in used tires shipped from Japan to tire processing facilities in Houston and other cities (an infestation of Tiger mosquito has occurred in Oakland, California, but was eradicated by public health officers)(Craig 1992). Others came in ballast material, which in earlier years consisted of soil and rocks, and more recently shippers are using water for stabilizing ships, resulting in extremely high numbers of NIS found in waters and nearby lands around shipping ports (Carlton 1985, Garton et al. 1992).

Accidental introductions also occur when travelers inadvertently bring seeds, insects and pathogens from other parts of the globe, highlighting the need for adequate border inspections of both humans and products. A problem in many waters, particularly in severely threatened desert springs, is the release of aquarium fish and plants which then establish and create havoc with native species of pufpish and other natural communities (Courtenay and Williams 1992). This could only be considered unintentional because releases are done thoughtlessly by consumers, but importers must become more aware of the risks associated with releases into natural systems.

What Factors Promote Biological Invasions?

One of the basic conclusions by investigators concerned with NIS invasions is that their establishment is associated with some form of human-caused disturbance (Hobbs and Huenneke 1992). Such disturbances include road construction and maintenance, water pollution and eutrophication, livestock grazing, land clearing for vegetation management, and many other processes that open up space and physically disturb soils and other substrates. Disrupting the soil changes the availability of nutrients and water, and the removal of native plants reduces the potential for competition between them and the invaders. Many species that become problems are those which are also associated with natural or human disturbances in their home lands, particularly plants from the Mediterranean region where they were adapted to disturbance from human activities (Barbour and Majors 1988). Thus, they have traits which allow them to be dispersed easily (e.g. small seeds for wind dispersal, or seeds with bristles for attaching to migrating animals), and can grow readily in sites unsuitable for most native species on this continent (Baker 1978).

Repeated clearing of riparian vegetation for flood control or related purposes also increases the likelihood of fast-growing weedy plants, like the thistles, castor bean and giant reed or *Arundo*, to build up large populations that then compete with native riparian species (McIntyre et al. 1988). Channelization of natural streams, diversion of streamflows and construction of artificial impoundments further encourage invasions by exotic animals, especially those like sunfish, carp, mosquitofish, bullfrogs, and others which were associated in their native regions with slow-flowing, siltier conditions with elevated water temperatures. Such species thrive in the modified habitats created by western water projects, but there is some indication that relatively undisturbed streams are not easily invaded by these organisms, probably because they are unable to survive periodic floods and droughts to which native species are adapted (Baltz and Moyle 1993). However, NIS populations established at high densities in modified sites are often able to move into 'natural' streams quite readily during mild climate conditions, where they compete with and prey on native fish and amphibians, as well as transmitting diseases like *Saprolegnia* fungus (Moyle 1986, Ganzhorn et al. 1992 - in OTA 1993).

Roadways can be particularly problematic means of introducing NIS into natural areas (Tyser and Worley 1992, Wilcox 1990). Cutting and grading of roads, and periodic maintenance of the roadways, result in disturbed strips that are ideal for colonization by many opportuistic weedy species and once established, these weeds drop seeds that may invade into adjacent, less-disturbed habitats. This pathway for dispersal of NIS should be considered seriously when planning roads or other access methods into our natural areas. Livestock use in reserves, both for meat or fiber production, and stock animals used for recreation, also cause soil disruption which promotes NIS introductions (McClaren and Anable 1992, Fleischner 1994). Detrimental species associated with livestock, particularly brown-headed cowbirds (native to North America, but which are expanding into many new areas), also wreak havoc by parasitizing the nests of various threatened birds, including Bell's vireo, willow flycatcher, and many neotropical songbirds (Ehrlich et al. 1992).

Fire is an important factor in the evolution of many species in the California region, and changes in natural fire cycles can be additional factors promoting invasions by NIS

(D'Antonio et al. 1993). Suppression of fires can result in reduced recruitment of native species and consequently favor introduced species, such as exotic grasses in California prairie and other threatened communities (J. Randall & J. Bell, The Nature Conservancy, pers. comm.). Loss of the natural fire regime sometimes allows overly-vigorous plant growth, resulting in increased transpiration and consequent lowering of water levels in adjacent springs and streams (Busch 1994). Increased vegetation means more fuels, so that when fire does occur it can be much more destructive than if normal, periodic fires were to occur and will kill native species that would normally survive more moderate fires (M. Jorgensen, Anza-Borrego State Park, pers. comm.; Minnich 1989).

We must emphasize again, however, that environmental modification due to human disturbance is not always necessary for problematic invasions by NIS (Rejmanek 1989). The trout which have been introduced into, and reproduced, in many relatively undisturbed coastal and montane waters have compromised the genetic integrity of many local trout populations, and appear to have reduced or eliminated native invertebrates, amphibians and fish (Moyle 1986, Bradford et al. 1994). Natural flooding and associated disturbance also offers potential sites for colonization by plant species that are favored under disturbed conditions, for example tamarisk in desert riparian areas and giant reed in coastal watersheds (Griffen et al. 1989, Jackson 1993), and if colonization is successful they may reach population sizes at which they inhibit growth of native species and destroy habitat quality for native birds and other wildlife (Cohan et al. 1978).

Impacts of Non-Indigenous Species

The impacts that NIS can have on California ecosystems can be sub-divided into two general categories; direct impacts to individual native species, and impacts to ecosystem processes that, in turn, may affect native biodiversity and natural resources upon which we all depend. The direct impacts of NIS often involve predation on, or competition with, native species. Aquatic vertebrates, like sunfish and bass, trout and bullfrogs, may be particularly problematic because of their voracious feeding habits and great behavioural flexibility (Moyle 1986). They will occupy a wide range of habitats and tolerate both high and poor quality waters, reducing the likelihood that native species can find suitable refuge from their non-selective feeding, whether such feeding results in predator impacts to populations or increased competition for limited resources.

NIS are particularly detrimental to Species of Special Concern because such declining species generally have highly localized distributions and often suffer from other environmental stresses (e.g. pollution or habitat degradation), which makes them particularly susceptible to impacts from NIS. In reviewing Steinhart's (1990) overview of the 45 federally-listed Threatened and Endangered animal species in California, it appears that *NIS are important factors threatening at least 30, and probably closer to 37 of these, including a minimum of 1 of 2 mammals, 17 of 19 fish, 12 of 14 birds, 3 of 5 reptiles, and all 5 endangered invertebrates*. Similarly, Ehrlich et al. (1992) described the status of 116 species and sub-species of birds in North America that were either listed, or threatened but not yet officially listed; *non-indigenous birds, mammals or plants were primary threats to at least 33, or almost one-third of the at-risk birds*. Nine of the 16 sensitive bird species in

California were riparian-associated, and all experienced NIS impacts. We should note, however, that in many cases the impacts of NIS may be circumstantial, and further study with appropriate experimental protocols are desireable to establish true relationships among species (Hayes and Jennings 1986).

Other NIS primarily interact with native species by altering the ecological conditions found in their habitats. For instance, dense growth of saltcedar, iceplant, or a host of other invasive plant species will create excessive shading for native plants, deplete water availability to both plants and animals, and alter the chemistry of the soil, thereby discouraging the growth of native species (D'Antonio 1989, Busch et al. 1992). Choking of waterways may even inhibit organisms from natural migration routes, or reduce the likelihood of reproduction among remaining individuals. These and other impacts will be considered in greater detail in the survey portion of the text.

SURVEY RESULTS

Bioregion Approach

We consider some of the impacts by NIS species within bioregions of the State (Fig. 1), since such regions are based largely on the types of organisms, especially plants, found within the regions. The regions we use are generally those identified by botanists in the Jepson Manual (Hickman 1993) as the major floral provinces in the California region. Because of climatic and biological similarities, a NIS within a given bioregion has fair probability of being a current or potential problem at other sites in the bioregion. This allows interested parties to focus on those species likely to be of local or regional concern. The bioregion concept is being promoted by the State as a framework for considering a range of resource issues of common concern (Calif. Resources Agency 1991), both because issues will be similar among communities within the region, and because impacts at one location will often reverberate in other interconnected areas. NIS problems should be promoted as a major subject for consideration by the California Executive Council on Biodiversity which is the main network for communication on bioregion approaches to resource concerns.

The natural areas from which we received information are listed in Table 1, and illustrated in Fig. 2.

South Coast Bioregion

This area encompasses the Transverse and Peninsular Ranges of Southern California and their coastal plains, including the Channel Islands. The region is generally semi-arid, with most precipitation falling during the winter months and the summers experiencing a natural, warm drought period. The geology is highly complex and geographically dissected, including granitic and sedimentary substrates and large, coastal valleys composed of deep alluvium (Norris and Webb 1976). A large portion of the area is within National Forests, including Cleveland, San Bernardino, Angeles and Los Padres National Forests, which have responsibility for protection of wetland biodiversity. Other areas protected for natural biodiversity are Channel Islands National Park, Cabrillo National Monument for protection of marine communities near San Diego, Santa Monica Mountains National Recreation Area & Leo Carrillo State Park, and the University of California Motte Rimrock, San

Table 1. MAP LOCATION KEY

NORTH COAST

NC1	Redwood National Park
NC2	Six Rivers National Forest
NC3	Klamath National Forest
NC4	Shasta-Trinity National Forest
NC5	Klamath Basin National Wildlife Refuge
NC6	Lanphere Dunes U.C. Reserve

CENTRAL COAST

CC1	Pt. Reyes National Seashore
CC2	San Francisco Bay National Wildlife Refuge
CC3	Hastings U.C. Reserve
CC4	Landels-Hill Big Creek U.C. Reserve
CC5	Los Padres National Forest

SOUTH COAST

SC1	Los Padres National Forest
SC1b	Coal Oil Point U.C. Reserve
SC2	Channel Islands National Park
SC3	Angeles National Forest
SC4	Santa Monica Mts. National Recreation Area
SC5	Leo Carrillo State Park
SC6	San Bernardino National Forest
SC7	Motte Rimrock U.C. Reserve
SC8	James San Jacinto U.C. Reserve
SC9	San Joaquin Marsh U.C. Reserve
SC10	Cleveland National Forest
SC11	Elliott Chaparral U.C. Reserve
SC12	Cabrillo National Monument

CENTRAL VALLEY

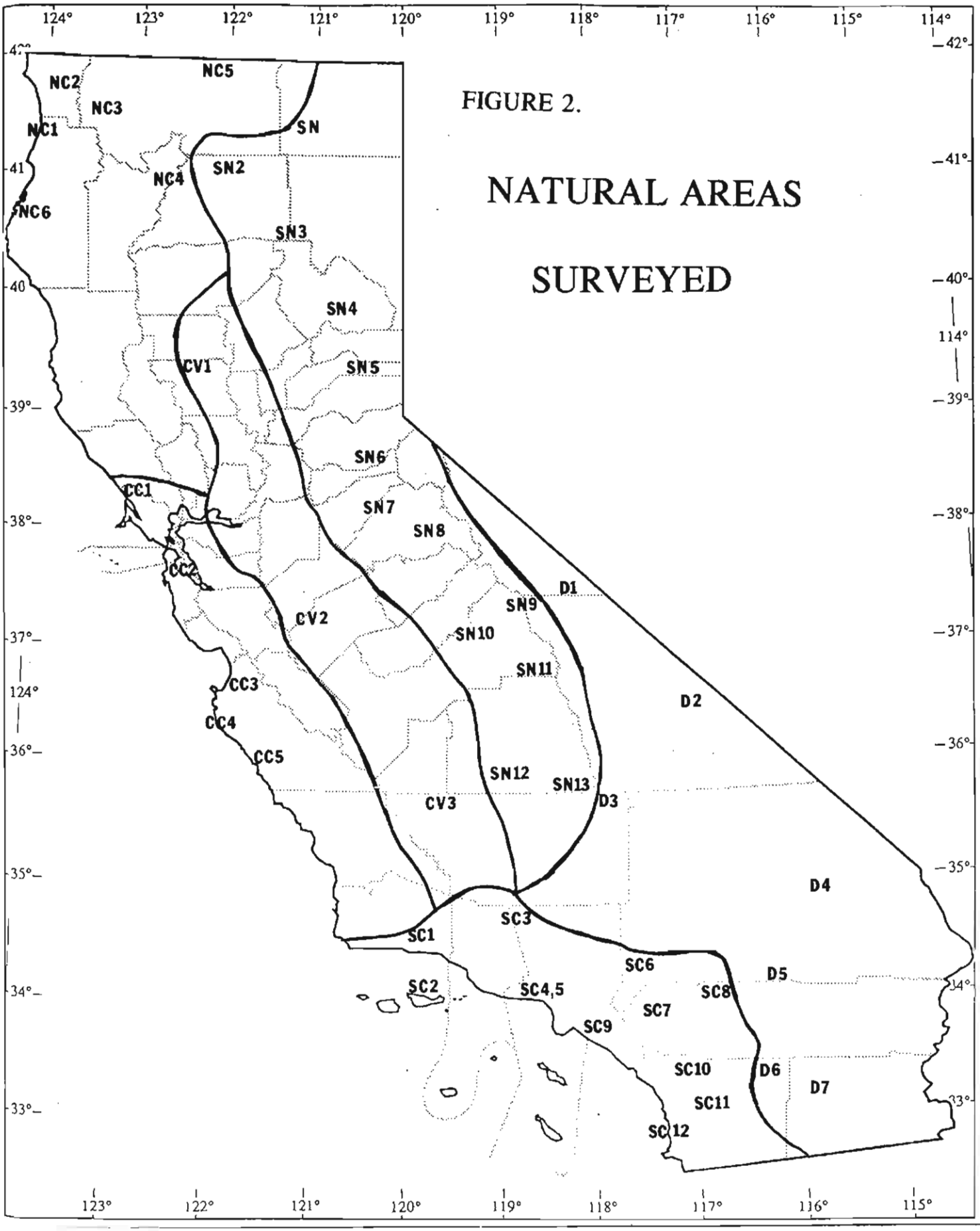
CV1	Sacramento National Wildlife Refuge
CV2	San Luis National Wildlife Refuges
CV3	Kern National Wildlife Refuge
CV4	Cosumnes River Nature Conservancy Preserve

SIERRA NEVADA

SN1	Modoc National Forest
SN2	Shasta National Forest
SN3	Lassen National Forest
SN4	Plumas National Forest
SN5	Tahoe National Forest
SN6	ElDorado National Forest
SN7	Stanislaus National Forest
SN8	Yosemite National Park
SN9	Inyo National Forest
SN10	Sierra National Forest
SN11	Sequoia-Kings National Park
SN12	Sequoia National Forest
SN13	Kern River Nature Conservancy Preserve

DESERT

D1	Inyo National Forest
D2	Death Valley National Park
D3	Red Rock State Park
D4	Granite Mt. U.C. Reserve
D5	Joshua Tree National Monument/Park
D6	Anza-Borrego State Park
D7	Salton Sea/Coachella Valley National Wildlife Refuges


NATURAL AREAS
SURVEYED
NC1
NC2
NC3
NC4
NC5
NC6
SN
SN2
SN3
SN4
SN5
SN6
SN7
SN8
SN9
SN10
SN11
SN12
SN13
CV1
CV2
CV3
CC1
CC2
CC3
CC4
CC5
D1
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D4
D5
D6
D7
SC1
SC2
SC3
SC4,5
SC6
SC7
SC8
SC9
SC10
SC11
SC12

FIGURE 2.

Joaquin Marsh and James Reserves in the Riverside/San Bernardino/Orange Counties area (Fig. 2).

Wetlands include major coastal rivers, for example the Santa Ana, San Gabriel, Los Angeles, and Santa Clara Rivers, and many hundreds of intermittent tributaries. These streamcourses flood on a regular basis in winter, except during drought years, opening new sites for natural riparian vegetation to re-colonize and form renewed wildlife habitat as well as posing flood risks to downstream communities. Many of these river systems have small or large estuarine areas at their coastal termini, however over 80% of these have been degraded by human activity (Kreissman 1991). Numerous vernal pools, temporary ponds which form where semi-impermeable geologic layers restrict percolation of rainwaters, are found in the San Diego and Riverside areas (and less commonlyelsewhere in the coastal plains). Development has destroyed 95% of these, threatening many annual plants and crustaceans that are restricted to these endangered wetlands (Bauder 1987).

Riparian-dependent species include several migrant birds which have experienced severe declines and are in various stages of consideration for federal listing, including least Bell's vireo (*Vireo bellii pusillus*), southwestern willow flycatcher (*Empidonax traillii extimus*), and western yellow-billed cuckoo (*Coccyzus americanus occidentalis*)(Faber et al. 1989). The California gnatcatcher (*Polioptera californica*) occupies the threatened sage-scrub/coastal chaparral vegetation that comprises much of the upland flora in the region. There are relatively few fish and amphibian species in the region (Swift et al. 1992, Stebbins 1966), but due to land clearing and development those here are also being considered for federal protection, such as southern steelhead (*Oncorhnychus mykiss*), Tidewater goby (*Eucyclogobius newberryi*), Unarmored Three-spine stickleback (*Gasterosteus aculeatus williamsoni*) Western pond turtle (*Clemmys marmorata*), Red-legged and Foothill yellow-legged frogs (*Rana aurora & R. boylei*), and Arroyo toad (*Bufo microscaphus*).

Non-indigenous riparian plant problems. Given the long history of non-indigenous human occupation, extensive land modification, and wide variety of environments, the South Coast Bioregion has been affected by an extremely large number of problem NIS's (Table 2, p. 31). One of the most serious botanical threats to remaining riparian areas is *Arundo donax*, or the giant reed, which was named as a problem throughout the bioregion (SC1,3,4,10, T. Bankamp, pers. comm.). Arundo can rapidly colonize denuded flood areas, inhibit re-establishment of native riparian species and maintain dominance in riparian areas (Bell 1994), even in small estuaries like at the mouth of the Ventura River (D. Magney, Cal. Nat. Plant Soc., pers. comm.). By competing with native willows, alders, and numerous other plant species, arundo poses a serious threat to all riparian-dependent species, including those considered threatened or endangered (Bell 1994). It may choke out true aquatic species like unarmored three-spine stickleback which have become relegated to very small sections of the Santa Clara and Los Angeles River watersheds (SC3). Arundo is also an extreme fire hazard. A recent project to clear arundo and restore native riparian plants in a riparian zone near the town of Riverside inadvertently saved the adjoining portion of the city from a major fire the following year (Jackson 1993). This success story was the impetus for forming a multi-agency *Arundo Donax* Task Force, or 'Team Arundo' to seek ways to jointly control the spread of the destructive weed (Jackson et al. 1994).

Other problem plants that invade riparian areas, irrigation canals, and isolated springs include saltcedar, castor bean, poison hemlock and tree tobacco (SC1,4,5,6,7). *Myoporum* was identified as a potential problem shrub invading the Santa Monica Mts. area (SC4); besides crowding out native riparian species, it and the previous species (except saltcedar) are highly toxic to humans and livestock, poison hemlock being the same European plant that brought the demise of Socrates. These are also considered problem species in similar ecosystems elsewhere in the world, suggesting that co-ordinated efforts to identify such problems and potential control efforts would be advisable (Drake et

al. 1989,). It was noted by one interviewee that, in the absence of other nectar bearing plants, especially the willows, tree tobacco can provide an alternate source of fuel for hummingbirds and other native pollinators (SC7). However, it was felt to be more desireable to promote the re-establishment of willows in these sites, and managers in other states have found that once established, native willows can maintain themselves fairly well against exotic competitors like saltcedar (J. Belknap, Arches National Park, pers. comm.). Blue gum *Eucalyptus* is another tree that has become common along streamcourses throughout coastal California (SC4,7,10). Several other species of eucalypts introduced from Australia are occasionally found near wetlands, and could present similar problems, although fortunately most species do not expand their population readily (D'Antonio and Dudley 1993). Volatile chemicals in eucalypt leaves inhibit germination of understory plants, leaving soils bare and susceptible to erosion, and once the leaves fall into the stream or pool they are very difficult for native fungi and invertebrates to decompose (Boulton 1991). Thus, leaves and other litter build up and clog the stream bottom, cause local de-oxygenation of the water and stream substrate, and reduce the abundance and diversity of organisms present which are important in providing the bulk of food for native fish.

A developing threat in the region is German ivy, which blankets and chokes riparian vegetation much as does the noxious vine, Kudzu (*Pueraria lobata*) in the southeastern U.S. German ivy and eupatory, a spreading shrub which creates a thatch that smothers native plants, have both been observed in riparian areas of Los Padres National Forest (SC1). Eupatory is also increasing in the San Gabriel and Santa Monica Mountains, where some biologists hope that its federal listing as a Noxious Weed will help facilitate agency response (T. Bankamp, pers. comm.). Harding grass is becoming a pest species in this area, where it dominates moist valley floors and competes with native grasses, such as in La Jolla Valley (SC4,5). Two plants which are not terribly invasive, yet are common mat-forming vines in previously inhabited areas that managers are trying to revert to natural communities, are periwinkle and garden nasturtium (SC1,4). Himalayan blackberry is a common vine which does invade seriously into many moist habitats (SC1), and provides refuge for non-indigenous rats that can subsequently destroy wildlife species and serve as vectors for pathogens. Pampas grass is becoming a problem at some sites, for example in the dune swale areas of Coal Oil Point U.C. Reserve (D. Magney, CNPS, pers. comm.). This plant is still sold as an ornamental species, but is increasingly seen as an invasive species colonizing disturbed sites and competing with native plant species (Madison 1994). In the San Joaquin Marsh Reserve, it was estimated that 50% of the plants on the reserve are non-native, and throughout the region many weeds are so common that they are considered essentially impossible to eradicate. Some that managers hope to address are fennel, artichoke thistle and *Myoporum*, along with ornamental palms that have been planted historically. Fennel is particularly pernicious, forming dense clumps (as does poison hemlock) in moist hillside sites (SC5,2).

Invasive aquatic plants. Aquatic plants have also been identified as problems in some water bodies, particularly ponds, reservoirs and other slower habitats. Mare's tail and water buttercup are both considered problems in a lake in the James Reserve, in which managers hope to maintain habitat for the Foothill yellow-legged frog, and possibly for the endangered stickleback which was extirpated from the area several decades ago (SC8). These aquatic plants clog the lake and promote its eutrophication and sedimentation. *Hydrilla* is another invasive aquatic weed which has inflicted millions of dollars of damage to waterways in the Southeastern U.S. (Kay 1992) and has been found in a stream in Cleveland National Forest where it escaped from a nearby residential area (SC10). In the warm climates of southern California, most of the aquatic plants that cause serious problems in the Southeast and throughout the world (Ashton and Mitchell 1989) are quite likely to fare well in our

reservoirs and other slow waters. Brass buttons and beard grass (*Polypogon monospeliensis*) occupy vernal pools in San Diego, threatening some of the most endangered species of plants, and possibly some of the recently listed fairy shrimp present in these rare habitats (Bauder 1987, Eng 1990).

Non-indigenous animal problems. Some of the most serious threats to aquatic biodiversity are from introduced fish, many of which were brought from the eastern part of the country for sport and food purposes. Various sunfish (*Lepomis* spp.) and bass (*Micropterus* spp.) have been indiscriminately planted for sport into most of the reservoirs and rivers in the South Coast area, where many have been successful in establishing populations in unregulated waters (Swift et al. 1991). Several species of catfish (Ictaluridae) and carp (Cyprinidae) have been similarly released to provide sport for fisherman in many of the same waters. In somewhat cooler waters and montane streams, non-native trout have been extensively stocked, in many cases in the same streams as those used naturally by anadromous Southern steelhead trout. These include stocked populations of more northerly rainbow trout (the non-migratory form of steelhead), brook trout from the eastern U.S. and German brown trout from Europe. Other small fish species, especially minnows (Cyprinidae: golden and red shiners, fathead minnow) have also been imported as baitfish or as forage for sustaining the introduced gamefish (Moyle 1976). It was noted that Pyramid Lake, in the Angeles National Forest (part of the California State Water Project and within the Piru Creek/Santa Clara River watershed) contained approximately 40 species of non-indigenous fish (SC3)!

These primarily carnivorous fish become a problem in sites supporting isolated populations of native aquatic species. They have been identified as serious threats to survival of two candidate species for federal listing in the San Bernardino Mountains, the Santa Ana sucker and the unarmored three-spined stickleback (SC6). Two closely related frog species, the mountain and foothill yellow-legged frogs, are seriously declining throughout their ranges. Yellow-legged frogs have been found in sites lacking exotic species, and it is considered that their absence elsewhere is, in part, due to predation from NIS (Bradford 1989). Wildlife managers in the San Bernardino National Forest are considering transplanting threatened populations in Baldwin Lake and nearby waters to sites lacking introduced predatory fish, and also without the introduced bullfrog, if such habitats can be found. Exotic vertebrates may be eradicated to re-create natural conditions, if funds and data to support the program can be obtained. Yellow-legged frog populations in wetlands at the nearby University of California James Reserve are also threatened by many of these predators, as well as by two unidentified species of non-indigenous crayfish [probably *Procambarus clarki* and *Orconectes rusticus*, two aggressive, omnivorous species that have been introduced into and causing problems in natural systems around the world (Hobbs et al. 1989)].

An isolated, remnant population of unarmored threespine stickleback is threatened in quiet waters of the upper Santa Clara River watershed (Angeles and Los Padres National Forests) by not only bullfrogs and other species mentioned above, but also by the African clawed frog (SC3). This predatory, aggressive frog is used for scientific and educational puporses, and its introduction probably resulted from the accidental or thoughtless release of individuals raised for scientific purposes (McCoid and Fritts 1989). While red-legged and yellow-legged frogs appear to be extirpated from the Santa Clara watershed, isolated, remnant populations of Arroyo toad (*Bufo microscaphus*, a candidate species for federal listing) in this watershed and in the Santa Ynez River system in Santa Barbara County are at risk fro both non-indigenous frogs and to a wide variety of introduced fish (SC1). In addition, two turtles (red-eared slider, painted turtle) have apparently escaped from captivity and threaten the native frogs, as well as the native southwestern pond turtle (*Clemmys marmorata pallida*), another species proposed for federal protection because of habitat losses and widespread declines in population sizes (SC1). In the San Joaquin Freshwater Marsh U.C.

Reserve (SC8) exotic amphibians such as African clawed frog, eastern snapping turtle, and red-eared slider turtle also threaten the native species. Introduced reptiles, especially turtles, are particularly dangerous because they carry a variety of pathogens, as anyone who has raised turtles at home knows, that also jeapordize the health and existence of small populations of native amphibians.

Southern steelhead/rainbow trout naturally migrated for spawning into large and small streams from Near Pt. Conception to areas as far south as Baja California, but are seriously declining throughout this range (Nehlsen et al. 1991). The introduction of northern populations of hatchery-reared rainbows threatens to destroy the genetic distinction of this endangered trout through hybridization. Introduced rainbows, and the German brown and brook trout, may compete with native populations and brown trout are important predators on other fish. While brook trout are no longer introduced on a regular basis, the other trout continue to be stocked into southern California waters (Moyle 1976, SC1, SC6), and this policy needs to be taken into question as their threats to native biodiversity becomes more widely known (Wilcove et al. 1992).

Finally, some NIS must be examined more closely for their impacts to estuarine and marine biodiversity. Mosquitofish, which are used throughout the state for 'environmentally benign' mosquito control, are not truly benign (Taylor et al. 1989). While mentioned as a problem in ponds far from the coast (SC6), a major concern is their impacts in coastal areas where they tolerate a wide range of salinities. There is little known about what impacts extensive release of mosquitofish has had on non-target native invertebrates, these fast-growing fish that tolerate an extremely wide range of environmental conditions could be severe competitors with declining brackish water and lowland stream fish, such as tidewater goby, sticklebacks and arroyo chubs (Myers 1965, Taylor et al. 1989). Biodiversity concerns, and questions regarding their effectiveness in controlling mosquitoes in many areas, suggest that we examine the potential of using native fish for such biological pest control purposes (Danielsen 1968).

In Channel Islands National Park, NIS problems in wetlands result primarily from their impacts on surrounding watersheds, where feral pigs and sheep have historically caused widespread vegetation removal, soil disruption and erosion with resulting siltation into intermittent and a small number of permanent streams (SC2).

Algae. Even in complete seawater circumstances, NIS are considered problems in maintaining nature preserves. In Cabrillo National Monument, 3 marine algae from Japan are considered potential threats to native species in the intertidal and sub-tidal zones (SC12). The red alga *Lomentaria hokadatensis*, a brown alga (*Sargassum munitum*) and a green alga (non-native subspecies of *Codium fragile*) were accidentally introduced through either shipping practices or in association with introduced oysters (to replace native oysters, which were collected to near extinction earlier in the century). Very little is known about their expansion and impacts, but the *Sargassum* species has also become a dominant species in the intertidal zone in the Channel Islands (SC2) and in the Santa Barbara area where it is potentially changing dynamics in this community and interfering with scientific studies (J. Connell, unpubl data; D'Antonio et al. 1986).

Central Coast Bioregion

This region encompasses the drainages of the Coast Range from near Pt. Conception in northern Santa Barbara County to the San Francisco Bay Area. This region is a transition zone between the semi-arid South Coast region and the mesic North Coast drainages, and is an overlap zone for many species that reach their northern or southern distribution limits in this region (Barbour and Majors 1988). This is clearly represented in, for instance, the Big Sur area where drier south-

facing slopes are covered with typical chaparral species like coastal sage (*Artemisia californica*), coyote bush (*Baccharis pilularis*), and several forms of manzanita (*Arctostaphylos spp.*) and California-lilac (*Ceanothus spp.*) while the north-facing slopes and canyons, which receive less direct sun but frequent coastal fog, will include dense redwood (*Sequoia sempervirens*) forests and associated wet-zone shrubs. Interior valleys away from the coast (e.g. the upper Salinas River region or the San Jose/San Benito area) will also be drier, again reflecting a Mediterranean rainfall pattern of wet winters and long, dry summers. San Francisco Bay habitats and the Marin County area are included in this region because of their floral similarities with coastal communities to the south.

Natural areas within this region where we received information on NIS were the Los Padres National Forest (northern portion), two University of California reserves, Hastings preserve near Carmel and Landel-Hills Big Creek Preserve near Big Sur, Pinnacles National Monument near Salinas, and the San Francisco Bay National Wildlife Refuge (Fig. 2). Aquatic habitats within these areas include primarily intermittent and some permanent streams, most relatively small coastal drainages such as the Little Sur River In Los Padres N.F. and Big Creek. Some springs and small ponds are present and include several sensitive species that have become rare or absent in southern California, for example yellow-legged and red-legged frogs, California tiger salamander (*Ambystoma tigrinum californiense*), and southwestern pond turtles. The fish fauna is considered part of the South Coast province, although both Steelhead/Rainbow trout and stickleback consist of the less-threatened northern genetic groups or sub-species. Tidewater goby is present, and declining here as well, and two species of sculpin not found further south (coastrange sculpin - *Cottus aleuticus*, riffle sculpin - *C. gulosus*) inhabit these coastal streams. A more extensive review of aquatic habitats in the region is desireable, but nearly all the NIS that are causing problems in southern California should be considered potential (or already present) problems here because of geographic and climatic similarities with some regions to the south.

Non-indigenous plants. Managers of these preserves were much more familiar with terrestrial than aquatic habitats, and in all these areas a variety of non-indigenous grasses, shrubs, vertebrates and even insects (European earwig, European honeybees) were particular problems. Although not part of the scope of this survey, the domination of upland areas by European grasses and other weeds, especially the broom species (Scotch broom, French broom, Spanish broom) will change the the nature of nutrient, water, and shading regimes, with subsequent impacts to riparian areas (D'Antonio and Vitousek 1992, Bossard and Rejmanek 1994). Erosion is exacerbated by altered vegetation in these highly erosive areas, depositing excess sediment into streams, pools and reservoirs and degrading both wildlife habitat and water quality (Gregory et al. 1991). European boar is a common feral invader throughout this region, and their rooting habits are particularly destructive to soils and native vegetation (CC3).

A federally-listed Noxious Weed which is becoming increasingly abundant in riparian areas is the eupatory, replacing native ferns and monkeyflowers in Big Sur stream areas by forming impenetrable mats over native vegetation (CC4). Eupatory is currently invading and overwhelming native riparian and redwood understory plants (e.g. *Oxalis* and *Stachys*) elsewhere in the Big Sur areas, including Julia Pfieffer State Park, and Park managers have not been able to develop plans for eradicating or coping with this recent invader (T. Bankamp, pers. comm., D. Gluesenkamp, pers. comm.). English ivy is another ornamental plant which has been observed invading riparian areas in many regions (Elliott 1993, Dudley unpub. data). This vine, along with the unrelated German ivy, overwhelm and ultimately displace native plants, resulting in depauperate wildlife communities because few insects and other forage organisms are associated with the nearly monospecific stands of ivy. Pampas grass is another plant that is increasingly abundant, especially along disturbed coastal

bluffs and hillsides where it is now entering some less disturbed natural areas (CC4,5).

In higher marsh areas and throughout the San Francisco Bay Area perennial pepperweed or peppergrass has become a prevalent nuisance, forming dense carpets and crowding out other plant species, presumably some which are threatened (e.g. *Arenaria paludicola, Cordylanthus palmatus, C. maritimus, Lilaeopsis masoni, Ranunculus lobbii, Suaeda californica*)(CC2, Trumbo 1994). Peppergrass and possibly other species could interfere with ecological restoration projects in the Bay as well, for example control efforts will drive up the cost of re-vegetation of the Montezuma salt marsh near San Rafael, where it could inhibit recovery of Mason's lileaopsis (S. Siegel, Levine-Friske Inc., pers. comm.).

Non-indigenous animals. The bullfrog was considered an important aquatic invader in Hastings Reserve, where it is a predator on native frogs and salamanders (CC3), and was noted as a probable factor in eliminating red-legged frogs from Jasper Ridge Biological Preserve near Palo Alto (MacDonald et al. 1988). A large variety of fish have also been introduced throughout the region (Moyle 1976), but their impacts on these reserves were limited or not presently known.

In San Francisco Bay and the Sacramento River Delta, an exceptionally large number of NIS species are present and profoundly changing whole biotic assemblages and ecosystem processes (Herbold et al. 1992). Most were introduced through ballast dumping but many others were introduced intentionally. The first such introduction was the Mexican oyster (*Ostrea chilensis*) during the gold rush, but greater success was achieved several years later with American oysters from the East coast (Skinner 1962). These have replaced the native California oyster (*Ostrea lurida*) which had been exceedingly abundant in the Bay previously (Nichols and Pamatmat 1988). American shad, common carp, largemouth bass, catfish, bullfrogs and many other species soon followed and support important sport and food fisheries in the region. Presently more than half of the fish in the Bay and Delta and most of benthic invertebrate assemblage is comprised of NIS compromising the ecological stability of this massive and critical ecosystem (Herbold et al. 1992). In particular, the two clams recently introduced in ballast waters from Asia (Asiatic clam - *Corbicula fluminea*, Asian clam - *Potamocorbula amurensis*) have already displaced native benthic organisms, and filter out plankton and larvae of both native and introduced species (Carlton et al. 1990).

The green crab, a species recently invading from Europe, is now present in the Bay and its predatory habits will further alter the natural ecosystem functioning of this world-class estuary. This species is also now present in Bodega Bay, where it threatens native Dungeness crab and economically important oyster beds, and is likely to spread more widely via longshore ocean currents (T. Grosholz, pers. comm.; Miller 1994). In mudflats near Pt. Reyes (CC1) the native snail, *Cerithidea californica*, is becoming displaced by an ecologically-similar introduced snail, *Ilyanassa obsoleta* (Race 1982). Another recent invader is the Chinese mitten crab, which is feared will damage levees by its burrowing activity and may carry a parasite that sickens humans (A.Cohen/M.McCabe, pers. comm.). The biology of the original Bay and Delta is scarcely even known at present, but the potential for expansion of many of these species into lakes, canals, rivers and other areas not presently invaded remains, particularly with the extensive transportation of water resources around the State.

In the Bay Area, aquatic NIS further threaten many terrestrial species. Asian clams appear to be eliminating both native and relatively benign exotic clams, and following a de-watering period in 1987, Asian clams increased while the native bivalves did not recover (CC2). This introduced clam is a poor food source for declining marshland birds, particularly the California clapper rail (*Rallus longirostris obsoletus*) which is listed as Endangered by the State Department of Fish and Game. This rail is also threatened by predation by a non-native red fox (CC2); a sub-species of red fox is native

to California, but this introduced sub-species is expanding its distribution throughout the state in association with human development (R.M. Jurek, Calif. DF&G, pers. comm.). The clapper rail population has been reduced from 200 birds to a present size of 8 individuals over the last 5-6 years, probably as a cumulative impact of predation, loss of preferred native food, and degradation of habitat resulting from the replacement of native tules and other marsh plants by European beach grass, which is difficult for birds to penetrate (CC2). The red fox preys on many other shorebirds, including the federally listed snowy plover, requiring extensive predator management by Refuge staff.

North Coast Bioregion

This region includes the relative narrow Coastal Range north of Marin County and west of the Sacramento Valley, and the more expansive Pacific drainages north to the Oregon border. Major river systems are the Russian, Eel and Mad Rivers, and the broad Klamath/Trinity River network. Much of the region is covered by mesic, coniferous forest and coastal grasslands, while the climate becomes increasingly arid with distance inland. The Upper Klamath Basin has an arid, seasonal climate with affinities to the high desert areas to the East. Natural lakes occur in some higher elevation areas, such as the Trinity Alps Wilderness, but most lakes here are formed from impounded rivers. There are, however, several important lagoons and estuarine areas such as those in and adjoining Redwood National Park and near Eureka at the mouth of the Eel River and other smaller streams. Interviews were conducted with officials from Shasta-Trinity, Klamath, and Six Rivers National Forests, Redwood National Park, Siskiyou County Agriculture Department, Klamath Basin Wildlife Refuge, and from Region III of the California Department of Fish & Game.

Non-indigenous animals. Most of the NIS of concern in the North Coast region are also present in the Central Coast region (Table 2, p. 31). A wide range of fish has been introduced into many waterways and many are considered threats to native fish and amphibians, such as brown trout that interfere with native rainbow trout in streams, and largemouth bass which prey on many native fish and amphibians in slower waters and reservoirs (NC2,4, CDF&G). In particular, bass threaten newly-hatched pond turtles, a species which is considered Sensitive by the Forest Service and is proposed for listing by the Fish and Wildlife Service. This declining turtle is also threatened by competition with painted turtles, which have been released from aquaria and are common in some lakes and streams in Humboldt County (NC2). Hatchery-reared rainbow trout are stocked into waters in the Shasta region and elsewhere, where they interbreed with red-band rainbow trout and are severely contaminating the genetic integrity of this Category 2 listed species (NC4). This is technically part of the Sacramento River drainage, but shares similar environmental characteristics with much of the coastal areas. Also, bullfrogs have spread widely and interfere with coho salmon and summer steelhead by competing for food and occasionally preying on juvenile fish (CDF&G). Bullfrogs compete with native Foothill yellow-legged frogs and appear to be a factor displacing this threatened species in the Eel River and in other waters (S. Kupferberg, UC Berkeley, unpub. data). In addition to all those listed above, exotic fish present and of concern in Redwood National Park include brown and black bullhead, eastern brook trout, black crappie, and golden shiner but Park managers lack the staff and mandate to undertake removal of these species. The introduced centrarchids, stocked rainbow trout, and bullfrogs are all considered important predatory threats to the California freshwater shrimp (*Syncaris pacifica*), a listed endangered species found only in a handful of small streams north of the Bay Area (CDF&G, TNC).

Mosquitofish planted for mosquito control have increased tremendously in brackish and

slower freshwaters, where they prey on amphibian eggs, and Japanese pond smelt are also present some bays, including Humboldt Bay (NC1). Organisms that are invading estuarine areas in the Central Coast region, e.g the snail *Ilyanassa obsoleta* in the Pt. Reyes area, are likely to be found iin similar habitats of Northern California and haven't yet been reported. Estuarine areas are further impoverished by non-indigenous plants, such as highway iceplant and European beachgrass, both introduced for erosion control and dune stabilization. They are now regarded as pests in the University of California Lamphere Dunes Reserve because they eliminate native dune species and alter natural erosional processes which are essential to maintaining the native community (NC6).

Non-indigenous riparian plants. Riparian areas in this region are not yet as badly invaded as many further to the south, but *Arundo* is now present and likely to expand in some valley bottoms (NC4). Tree-of-Heaven and black locust trees are also present and increasing in abundance (NC4). Himalayan blackberry is common throughout the region, where it grows profusely and crowds out many native forbs and shrubs (NC3,4). Although tamarisk is known from the North Coast region (Hickman 1993), it was not mentioned as being a problem as yet but certainly bears watching. There is concern that introduced bulrushes (*Scirpus spp. - S. mucronatus, S. setaceous*, and *S. tuberosus* are known from northwest California - Hickman 1993) are outcompeting and displacing a variety of native meadow species in low elevation valley bottoms (NC4). Other NIS plants (e.g. cocklebur, orchardgrass and several other grasses, common mullein, white sweetclover) are promoted in these wet meadow sites by soil disturbance resulting from livestock grazing (NC4). Not all invaders are non-indigenous, but sometimes native species can expand to the point of threatening sensitive species. The native mountain alder (*Alnus incana tenuiufolia*) is increasing into wet meadows where it may be crowding out a native plant species which are specialized to surviving only in these locales (NC3).

Aquatic plants. True aquatic plants have also caused concern. Purple loosestrife was recently discovered at Tule Lake and several years ago at Fall Rivers Mills, probably as escapes from cultivation. This species is extremely invasive, but knowledge of the severe problems it has caused in the eastern states convinced managers to eradicate it manually and with helicopter-applied herbicides early, before it could crowd native cattails and tules, and degrade wildlife habitat with its dense growth (Siskiyou Co. Ag. Dept.). Another species of exotic loosestrife is also present in Redwood National Park, but does not yet appear to be as invasive as its congener, the purple loosestrife (NC1). Water hyacinth may be the most serious aquatic plant invader in the world, and was similarly eradicated from the Pt. Reyes area by prompt identification of the plant and its potential damage (CC1). Aquatic species in the Redwood region also include Brazilian waterweed, Creeping bentgrass, Brass buttons and an introduced buttercup (*Ranunculus muricatus*), and these are being watched for potential expansion (NC1). In Redwood National Park, there are 181 species of non-indigenous plants identified so far, comprising about 20% of the total plant species known from the Park.

Terrestrial animals. Feral European boar or wild pigs are considered serious problems for both terrestrial and aquatic environments in the Humboldt area (and elsewhere) because they dig up bulbs and buried ampibians, and subsequent erosion causes degradation of aquatic habitats (NC2). Wild turkeys are also widely introduced for sport (they are originally native to parts of the region, but were themselves reduced in numbers by hunting), and are now implicated in amphibian declines through predation on sensitive, native frogs and salamanders (NC2). Along with disturbance from extensive cattle grazing, brown-headed cowbird populations are expanding into the Northwest, where they jeapordize nesting Neotropical migrant bird species. They parasitize nests of Willow flycatcher, vireo and several wood warblers in the vicinity of livestock activity (NC2).

Central Valley Bioregion

The Sacramento and San Joaquin River valleys comprise one of the largest and most extensive pre-European wetlands in North America. Half of the major rivers in the state funnel into this region, draining about 33.5 million watershed acres and including almost 1 million acres of riparian or wetland habitat on the valley floor before the waters empty into San Francisco Bay (Katibah 1984, Kreissman 1991 - in Cal Rivers 93). Alluvial material from the Sierra Nevada and the eastern portions of the Coast mountains have built up broad expanses that include a rich variety of wetland habitats. Natural wetlands include valley oak riparian gallery forests on the valley margins, cottonwood-sycamore riparian woodland in valley bottoms, seasonally flooded tule marshlands, and several areas with concentrations of vernal pools, particularly in the eastern portions of El Dorado County and western Contra Costa County (CNPS 1994). In addition, irrigation projects have created extensive shallow wetlands that provide habitat for migrating waterfowl, some of which are rice fields which are flooded during winter by agreement between landowners and wildlife agencies.

Valley riparian forests have been reduced to 11% of their former extent, two-thirds of vernal pools have been destroyed through agricultural and urban development; wetland losses since 1939 are almost one-third, and it is estimated that only 4% of original marsh wetlands remain in functioning condition (Frayer et al. 1989, Kreissman 1991). We received survey information concerning Central Valley NIS concerns from the San Luis, Sacramento and Kern National Wildlife Refuges, the Shasta-Trinity National Forest, and from California Department of Fish and Game officials in Sacramento.

Problem non-indigenous animals. As in the rest of the state, introduced fish are among the most serious NIS threatening aquatic ecosystems. As elsewhere, mosquitofish have been extensively planted throughout the Valley to reduce mosquito populations, which had been implicated with the spread of encephalitis and other communicable diseases (Usinger 1968). Now these omnivorous feeders reduce populations of native invertebrates and potentially compete with a variety of native fish and other insect feeders, but some biologists have suggested that mosquito abatement programs consider the use of native minnows instead of spreading these pests further (McGinnis 1984). Carp and black bullhead are widespread and their bottom feeding behavior results in increased turbidity in lakes and slow streams. Turbidity inhibits growth of some submerged aquatic plants that provide food and refuge to avian wlidlife, as well as game fish in Central Valley wildlife refuges (CV2). Large-mouthed bass are serious predators on juvenile snakes and turtles, including listed and proposed species (e.g. giant water snake - *Thamnophis couchi gigas*, southwestern pond turtle - *Clemmys marmorata pallida*). Refuge managers must regularly drain reservoirs and ponds to remove or reduce populations of non-desireable fish, and while these habitats are largely artificial, they remain essential for sustaining wildlife, particularly migratory aquatic birds.

In natural vernal pools and in canal systems, bullfrogs are often abundant and threaten sensitive amphibians such as California tiger salamander (*Ambystoma tigrinum californiense*), spadefoot toad (*Scaphiophus hammondi*) in the San Luis Refuge complex (CV2) and other endangered amphibians and reptiles like foothill yellow-legged frogs in the Sierra foothills and pond turtle throughout the Valley. The beaver is a native mammal to the Sacramento and San Joaquin River Systems but was greatly reduced by hunting. Following re-introduction, beaver have now expanded to many aquatic systems where it can interfere with manmade water control structures and re-forestation projects (CDF&G). Two other non-indigenous animals may be of concern in natural areas in the region, despite their not being mentioned by managers. The nutria is a large, South American aquatic rodent which disrupts canals in the Valley, but its impact on natural waterways appears to be largely unknown (Mooney and Drake 1988). On the other end of the size spectrum is the Argentine

ant, which invades semi-natural riparian areas and has adversely affected native ant species in Yolo and Solano counties (Ward 1986).

Non-indigenous plants. Aquatic plants considered problems in Central Valley wildlife refuges are Brazilian waterweed, which replaces native horned pondweed (*Potamogeton* sp.), and water milfoil and water hyacinth, both of which rapidly form extensive floating mats that choke waterways and reduce light penetration (CV2). Both hydrilla and purple loosestrife have been located at various sites in the Sacramento River system in recent years, but control has been undertaken rapidly when populations were still small (CV1). Control will be much less feasible and economic if larger outbreaks occur, as is foreseeable in backwaters and other less accessible areas of reservoirs and Valley rivers.

Because the Central Valley is so extensively modified by human activites, many weedy plants have established widely in the region. Perennial pepperweed is a highly invasive plant in shallow pond waters and adjacent moist uplands, and becomes think enough to displace other plants useful to wildlife (CV1,2). Knapweed can be an invasive pest in both agricultural and wildlife areas, such as in the southern part of the San Joaquin system where it competes with native vegetation critical to wildlife, such as the potentially threatened Buena Vista Lake shrew (CV3).

There is concern on the part of several natural area managers that cocklebur is another exotic plant detrimentally affecting native ecosystems; however, this may be a native species associated with disturbed areas throughout California (CV4). While rightfully considered a nuisance plant because of its invasive behavior and painful fruits, reduction in disturbance to some landscapes can reduce its numbers and as a pioneer species it probably drops out during natural vegetative succession. Such is not the case with arundo and saltcedar (tamarisk), which are present and expanding their populations along rivercourses, particularly regulated ones throughout the Central Valley (CV1,3). A fairly small infestation of saltcedar near the Kern Refuge erupted into an invasion of seasonal ponded areas during moderate flooding in 1983-84 and now covers several thousand acres. Because the infestation now encompasses both riparian and upland habitats, many listed and sensitive species are threatened by this species which alters both water availability and soil characteristics, and displaces native willows. Threatened species include Tipton kangaroo rat (*Dipodomys n. nitratoides*), Blunt-nosed leopard lizard (*Crotaphytus wislizenii silus*), kit fox (*Vulpes macrotis*), and the only population of Buena Vista Lake shrew (see above) under protection (CV3). At the other end of the Great Valley, it has been a surprise for many biologists that tamarisk has established well in the cooler regions of the Sacramento Valley (CV1,SN7, Moyle student unpubl data), implying that this invasive genus should be considered a serious potential problem throughout California. Finally, the edible fig has been identified as a potential problem invader into riparian areas in the Sacramento Refuge and at the Cosumnes River Preserve (J. Randall, The Nature Conservancy, pers. comm.). It spreads both asexually and probably by seed distributed by birds (CV1), presenting possible difficulties in tracking and controlling its spread.

Sierra Nevada Bioregion

It is difficult to present information on aquatic habitats for the entire Sierra Nevada, given its extreme variety of habitat and vegetation types, and climatic conditions (Barbour and Majors 1988). The northern portions share many affinities with the Cascade Ranges extending north into Oregon, with wet temperate coniferous forests on the western slopes and the high, arid basin and range province merging into the eastern slopes. The Modoc Plateau is ecologically similar to the Great Basin, but is included in this section for convenience. The southern parts of the Sierra Nevada are

drier, with chaparral vegetation on the lower western slopes, alpine and sub-alpine high country with numerous glacier-formed lakes, and grading into Mojave vegetation on the eastern escarpment. Aquatic habitats are diverse, including the lakes and alpine tarns, seasonal and permanent streams, wet sub-alpine and alpine meadows, major river systems, and a large number of important reservoirs that provide water resources, flood control and recreation.

The major biodiversity issues in aquatic ecosystems concern fish and amphibians; faunal diversity is not high when compared with lower elevation areas, but these areas are important nonetheless, primarily because of the genetic diversity presented by various trout and salmon species and sub-species (Behnke 1992, Moyle and Yoshiyama 1992). Few river systems are without major impoundments with associated negative impacts on anadromous fish populations (CSLC 1993). Mountain yellow-legged frogs present another critical concern because they are only found in high elevation ponds and lakes and are seriously declining (Bradford 1991), but are not yet federally protected. Aquatic ecosystems and communities of organisms are of concern because with short growing seasons and stressful climates, high elevation environments tend to be more sensitive to human impacts from livestock grazing, acid precipitation, timber and fire management and other factors. Given the large portion of the Sierra Nevada within National Forests or Parks, areal coverage for NIS problems is relatively good for this region.

Non-indigenous fish. Wildlife managers from every jurisdiction stated that some of their most important introduced species concerns were with fish introduced for sport (SN1-13). Several trout species have been stocked in nearly every major water body, with similar impacts to native species throughout the Sierra. Brook trout are probably the most widely distributed non-native trout, and on the western slope compete with native Rainbow trout populations (all respondents). Stocked rainbow populations also present continuing threats of genetic degradation of native populations, and biologists in the northern Sierra are especially concerned that the red-band form of rainbows is being steadily diluted to the point that soon no genetic distinctiveness will be present (SN3). The Paiute cutthroat (*Salmo clarki seleniris*) in Toiyabe National Forest is also in danger of loss due to hybridization with rainbows (commun. SN5). The Eagle Lake trout is another sub-species of rainbow that was designated recently for federal protection, and is threatened in its spawning stream and in several streams where its has been planted for species protection by genetic introgression with stocked rainbows, as well as by competition with brook trout introduced in the 1940's (SN3). Habitat degradation and water diversion further threaten its survival.

In the southern part of the Sierra, both forms of golden trout (*Oncorhynchus mykiss aguabonita, O. M. whitei*) are protected species that are also susceptible to hybridization with stocked rainbows (SN9). The golden trouts are also seriously threatened by predation and competition from German brown trout, and have been the subjects of long-term, costly efforts to exclude rainbows and brown trout from the Kern River tributaries (SN9, Fisk 1983, Pister 1994). Although endemic to the Kern drainage, golden trout are themselves widely stocked in high elevation waters in California, the western U.S. and on other continents, yet their impacts on native species are rarely mentioned. Having been re-distributed widely may additionally protect the geneotypes of these species, but raises another issue: the transplanting of rare species for their own protection should no longer be conducted without considering more substantively their potential effects on other sensitive species in these new habitats (Dudley et al. 1995).

Brown trout are considered the most voracious of the stocked trout, and Forest Service biologists generally felt that they were the most serious non-native trout threatening native species (SN3,4,5,6,7,10,11,12). Besides preying on native rainbow trout, in the Lake Tahoe area they and other exotic trout prey on Lahontan cutthroat trout (*S. c. henshawi*), Paiute sculpin (*Cottus beldingi*),

and Tahoe and Mountain sucker (*Catostomus tahoensis, C. platyrhynchus*) but do not yet appear to be threatening their existence (SN5). On the other hand, brown trout predation and competition probably were major factors leading to the extinction of the ecologically similar Bull trout (*Salvelinus confluentus*) from California and of the large Tahoe cutthroat trout (Moyle 1976, McGinnis 1984). Tahoe cutthroat formerly sustained a substantial fishery, and was driven further to extinction by introduction of Lake trout and Kokanee salmon (SN5). Kokanee, which are derived from lakes in Western Canada, reduce Lahontan cutthroat reproduction by depositing its eggs on top of cutthroat spawning sites, displacing the eggs of the native fish (SN5).

An additional game species which causes considerable concern is the northern pike from the midwestern states. It is highly aggressive and voracious, and has been planted illegally into Freshman's reservoir in Plumas N.F. (SN4). Managers have attempted to eradicate pike using chemical treatment before they could move downstream into the Central Valley and the Delta or be transported into the Truckee River drainage, where they would threaten many resident species as well as migrating trout (SN4,5). White bass and Striped bass are present in some west slope reservoirs, and are also considered potential problems for downstream fisheries if they migrate into free-flowing waters (SN10).

Non-indigenous trout also threaten several amphibian species where they share habitat. It appears that predation by trout, primarily brook trout, is the major determinant of widespread declines of the Mountain yellow-legged frog (*Rana muscosa*)(Bradford 1989) from previously fishless lakes and ponds. This relationship is now considered an important management problem throughout the higher elevation areas of the Sierra Nevada (all respondents). Less well-known is the possible role of trout predation in the decline of Yosemite toad (*Bufo canorus*) in the central High Sierra (SN7,8). At lower elevations the foothill yellow-legged frog (*R. boylei*) and red-legged frog (*R. aurora*) have suffered similar declines, possibly as a result of trout introductions, as well as stocking of bass and sunfish (all respondents). Centrarchids and bullhead are also present in many reservoirs of the Sierra, but their impacts on native species remain undetermined, in part because the reservoirs themselves have disrupted much of the natural biology of these sites (CSLC 1993). Red-legged frogs are primarily associated with ponds and slower stream waters on the western Sierra slope, where they also would experience competition and possibly predation by bullfrogs, which are present throughout the mid- and lower-elevation portions of the Sierra Nevada (SN3-8,11,12). The red-legged frog was recently proposed for federal listing and the foothill yellow-legged frog probably will be soon, once sufficient information can be gathered to document the need for listing. Almost all managers listed the bullfrog as a likely threat to both species because of similar habitat use, and included impacts to less similar species, such as juvenile pond turtle and newly-hatched ducks. The impacts of bullfrogs and introduced fish to other components of the ecosystem, such as aquatic invertebrates, is not at all well-known but recent taxonomic studies indicate that numerous aquatic species are distinct and localized, justifying listing as threatened or endangered species in the Sierra Nevada and consideration as possibly at risk to non-native predators (NDDB 1992).

Other non-indigenous animals. Introduced wild turkey was mentioned as a NIS present in parts of the Sierra Nevada, but does not appear to be a serious pest (SN6). Beaver is likewise a native species introduced widely and can play useful roles in meadow ecology, but managers caution that its potential effects on stream geomorphology and sediment dynamics should be considered prior to further introductions (SN6,12). Expanding populations of brown-headed cowbirds parasitize numerous species of migratory songbirds that nest in riparian vegetation, and are a major threat to the recently-listed Southwestern willow flycatcher (*Empidonax taillii extimus*)(SN6,7,9,12,13). Feral pigs/European boar and the opposum from the eastern U.S. both were identified as problems in

Sequoia National Forest (SN12) but occur broadly in the region at low elevations. Pigs disturb soil and feed on native invertebrates, and opposum is considered a problem because, while it is no longer an important game species, it was said to destroy eggs of many ground-nesting birds.

Problem plants. Non-indigenous plants tend to be constrained by higher elevations, so they appear not to be as serious in wetlands of the National Forests in the Sierra Nevada as in lower regions. Some common weedy plants invade disturbed riparian sites, including bull and Canadian thistles (SN7,8,9,10,12), scotch broom and medusa head (SN5,6). Others are in moist habitats, such as bur chervil and poison hemlock (SN10), but none of these appear to be cause for great alarm. As in other regions, some native species in disturbed habitats are considered problems, and may even be incorrectly assumed to be non-native, like cocklebur (SN8) and durango root (SN79), but toxicity of the latter, and poison hemlock should still be considered management issues if their distributions are expanding. Himalayan blackberry is common in mid-to-low elevation riparian areas and was noted to outcompete several native riparian plants, such as dogwood and hazelnut (SN5,8). Tree-of-heaven or *Ailanthus* is found in several riparian areas throughout the mid-elevations of the Sierra, often in association with historic Chinese settlements where it was planted as a shade tree (McClintock 1981). *Ailanthus* can be highly invasive because it sends out underground runners that sprout numerous new trees some distance from the parent plant, and is very difficult to eradicate because of this resistant growth form.

Some aquatic plants receive attention, although growth rates in higher elevations are relatively slow so problem invasions may not be as difficult to eradicate as at lower sites. Plants mentioned were common waterweed, or *Elodea*, and duckweed, both native to the state but potential problems found occasionally in Plumas National Forest and in Sequoia/Kings National Park (SN4,8). More seriously, purple loosestrife has been found a 'couple of times' near Lake Tahoe but was quickly eradicated (SN5) and a small population is established in a private pond near Inyo N.F., where it could potentially expand to the South Fork Kern River and Lake Isabella (SN13). A less-known NIS is cutleaf water-parsnip which was found in a stream in El Dorado National Forest (SN6) and is of additional concern due to its apparent toxicity to livestock.

Desert Bioregions

This is a large area encompassing a broad range of elevations and climatic conditions. For our purposes we are combining three general types of desert, Great Basin, Mojave and Colorado. The Great Basin province includes the areas east of the Sierra Nevada and north of approximately the Kern-Inyo county line. The Great Basin is generally above 4000 feet in elevation, with highly seasonal, severe climatic extremes. Most precipitation falls during cyclonic conditions in the summer months, and long periods of natural drought greatly restrict the types of vegetation, and associated fauna, that can survive. Where there is water, however, rich communities establish and the high productivity of both lakes and riparian areas during warmer periods provide important food and nesting resources for neotropical birds. These wetlands are associated with streams flowing from more mesic mountain to the west, and several land-locked, often saline lakes are present in the region but subject to considerable human modification (e.g. Mono L., Owens L.).

The Mojave and Colorado Deserts occupy most of southern California east of the Coast Range, and differ primarily in precipitation patterns, the Mojave receiving its meager rainfall in the winter and the Colorado, which is a floristic extension of the Sonora Desert, usually receives both winter and summer monsoonal rains. Much of the drainage is internal, as represented by the Mojave River system which flows into Death Valley, while other areas drain into the Colorado River when

there is sufficient waterflow. Numerous dry lakes fill irregularly and posses active biological communities for relatively short periods. Many perennial springs are scattered throughout the region, and contain several fish and invertebrate species found nowhere else.

The Klamath and Modoc regions in the northeast corner of California are somewhat anomalous, in that they have ecological affinities with the Great Basin but the major rivers either drain into the North Coast or the Sacramento systems. Here we treat the Modoc Plateau as a northern extension of the Sierra Nevada because of similar biodiversity concerns and the relatively little reporting done there, and the Klamath as part of the North Coast region; however, many of the NIS issues for the region are similar to those in the high Desert ecosystems and some will be mentioned here as well.

Information was gathered from Death Valley National Monument (now National Park), Inyo National Forest which includes extensive areas of Great Basin habitat, Red Rock State Park near Mojave and Anza-Borrego State Park in the Colorado Desert east of San Diego, Joshua Tree National Monument, Granite Mountain University of California Reserve, and from the Salton Sea and Coachella Valley National Wildlife Refuges.

Non-indigenous problem desert plants. Probably the most widespread NIS endangering desert aquatic habitats is the saltcedar (*Tamarix spp.*)(D1-7). Reported from below sea level in Death Valley to over 4000 feet in the Owens Valley, tamarisk pumps large amounts of water out of the ground and has lowered or eliminated surface water in many sites, eliminating habitat for migrant waterfowl, threatened Desert bighorn sheep, and several wet area plants that are unable to penetrate as deeply with their roots (Soltz and Naiman 1978, Loope et al. 1988). Several endemic species of pupfish (*Cyprinodon spp.*) in isolated springs and streams are potentially threatened by such water reduction in Death Valley (*C. nevadensis* - Saratoga Springs pupfish), the Owens valley (*C. radiosus* - endangered Owens pupfish in Fish Slough U.C. Reserve), Anza-Borrego State Park (*C. macularius* - endangered Desert pupfish maintained artificially) and the Mojave tui chub (*Gila bicolor mohavensis*) is at risk to tamarisk invasion in the Mojave River (D2,4,6,7). Tamarisk has been able to outcompete willow and other riparian plants in many locations, greatly diminishing the quantity and quality of riparian habitat for migrant songbirds and vegetation dependent birds like the endangered Yuma clapper rail (*Rallus longirostris yumanensis*) at the Salton Sea and elsewhere. It has very small seeds which disperse easily by wind and water so spreads widely and easily. Tamarisk can cause soil salinization, inhibiting recruitment of native riparian species (D3,5,7) and threatening endangered plant species, like the mojave tarweed (*Hemezonia arida*) in Red Rock State Park (D3).

Two species of palm are considered problems in Death Valley, where date palms and fan palms have been planted adjacent to streams within the Park. Besides reducing water availability, eliminating native riparian growth, clogging waterways with their leaves, and changing the flow and morphology of the habitat, palm seeds are transported by birds, coyotes and other wildlife species that could readily disperse the trees to more distant, isolated sites (D2). This fan palm is native to several isolated oases, particularly near Joshua Tree State Park, where potential recruitment is likely to be inhibited by many of the following weeds that are widespread in moist sites. Bermudagrass is present here and in several other moist sites in lower desert areas (D3) where its dense mats change aquatic communities and can promote other non-indigenous species like fathead minnows (Dudley and Grimm 1992). It and several other wetland species (e.g. alkali bulrush, Canada thistle - D7) probably should be excluded whenever possible because of their capacity to dominate wetland sites. Even plants like purple loosestrife and perennial peppergrass are recorded in unlikely locations such as the Modoc Plateau, and are possible invaders throughout the deserts. The aquatic hornwort is an aquarium plant which is found crowding out native pupfish and invertebrates in Death Valley and is only one of

many aquatic plants that are likely to thrive if introduced into stable springs and ponds (D2). Carrizo, more usually known as common reed or *Phragmites*, is a native plant found beside streams and ponds, but is considered a problem where it (and alkali bulrush) appears to displace native cattail and result in poorer habitat for Clapper rails (D7). Madagascar periwinkle is a medicinal herb present in Borrego Springs, surrounded by Anza-Borrego State Park, and is a potential invader in other warm desert springs (D6, Hickman 1993).

Problem animal species. Pupfish and other endemic spring species, including highly localized spring snails (Hydrobiidae) are also threatened by introduced fish (mosquitofish, sailfin molly, goldfish, red shiners) and even crayfish, all of which are occasionally dumped by humans into springs and require exhaustive efforts to remove (D2,5, Loope et al. 198, Steinhart 1990, Minckley and Deacon 1992). These fish, particularly goldfish, threaten amphibians in Joshua Tree National Monument, where habitat is extremely limited for 2 pupfish species in the reserve (D5). Springs are further endangered by feral burro and escaped livestock which cause enormous disturbance and loss of vegetation in isolated wetlands (D2,4,SN1). Feral horses similarly destroy streambanks and riparian vegetation in Anza-Borrego State Park (D6), but these problem livestock are paradoxically protected by federal law, highlighting the need for a more comprehensive approach to feral animal management.

Brown trout and several centrarchids are present, but not native in, the Owens River and potentially pose a risk to three other endemic fish (endangered Owens tui chub - *Gila bicolor snyderi*, Owens sucker - *Catostomus fumeiventris* (but is common in Crowley reservoir), and the local form of speckled dace (*Rhinichthys osculus*)(D1). Bullfrogs have scattered populations throughout the desert where permanent water is found, and pose future threats to native aquatic fauna if their expansion continues. Crayfish are also widely introduced, and in Anza-Borrego State Park *Procambarus sp.* (probably *P. clarki*, which has been introduced throughout the West from the southeastern states - Hobbs et al. 1991) has established huge populations in a permanent stream, and has eliminated the vast majority of invertebrates that shared the habitat (D6). Crayfish are omnivorous, and will decimate aquatic plants and algae, invertebrates, frogs and even fish from streams and pools where they are thoughtlessly stocked (Hobbs et al. 1991). Finally, the European honeybee is abundant in wet sites throughout the warm deserts, and its aggressive behavior towards other insects, and even songbirds, reduce visitation to thee critical water sources by native species (D2,6).

Ecological Generalizations for NIS in California

As the previous sections have shown, non-indigenous species of wetland plants and animals are present and causing detrimental impacts to threatened and sensitive species, to overall native biodiversity and to natural ecosystem processes in every bioregion of the State. These problems, however, are not evenly distributed across the state, nor are NIS all equal in their impacts. The list of species in Table 2 summarizes the locations of problematic NIS in the nature reserves we investigated, and attempts to rank the degree of threat they pose.

In general, omnivorous predators like sunfish, crayfish and bullfrogs appear to pose some of the most serious threats to sensitive or endangered species. Such species are able to survive in many types of aquatic habitats because their behavioral flexibility allows them to take advantage of whatever prey types are available, including use of non-animal food when prey are sparse or unavailable. Similarly, plants and some animals with broad ecological

Table 2. PROBLEM NIS IN CALIFORNIA WETLANDS

TAXON	COMMON NAME	THREAT**	REGION*
ALGAE			
Lomentaria hokadatensis	Japanese red alga	4	SC
Sargassum munitum	Sargasso weed	2	SC
Codium fragile subsp.	deadman's fingers	4	SC
PLANTS			
Ageratina(=Eupatorium) adenophora	eupatory	1	SC,CC
Agrostis stolonifera	creeping bent grass	2	SC,CC
A. tandilensis, A. viridis	bentgrass	4	J
Ailanthus altissima	tree of heaven	2	NC,SN
Ammophila arenaria	European beachgrass	1	SC,CC,NC
Andropogon virginicus	broomsedge bluestem	4	J
Anthriscus caucalis	bur chervil	3	SN
Aponogeton distachyon	Cape pondweed	4	J
Arundo donax	giant reed	1	SC,CC,NC,CV
Berula erecta (N)	cutleaf water parsnip	2,t	SN
Catharanthus roseus	Madagascar periwinkle	4,t?	D,J
Cardaria draba	hoary cress	2	CC,E
C. chalepense, C. pubescens	lens-pod hoary cress, white-top	4	CV,E,J
Carpobrotus edulis	highway iceplant	1	SC,CC,NC,
Ceratophyllum demersum (N)	aquatic hornwort	4	D
Cirsium arvense	Canada thistle	2	SN,D
Cirsium vulgare	bull thistle	2	SN
Conium maculatum	poison hemlock	2,t	SC,CC,
Cortaderia jubata	pampas grass	2	SC,CC,
Cotula coronopifolia	brass buttons	2,3	SC,CC,NC
Cynara cardunculus	artichoke thistle	2	SC,CC,CV
Cynodon dactylon	bermuda grass	2	SC,D
Cytisus scoparius	Scotch broom	1	SC,CC,NC,SN
Datisca glomerata (N)	Durango root	4,t	J
Eichhornia crassipes	water hyacinth	1	NC,CV
Egeria densa	Brazilian waterweed	1	CV
Eleagnus angustifolia	Russian olive	1	D,E

(N) = Native in California, possibly from another region of the State

**Threat Levels:
1 = Serious, documented threat to sensitive species or ecosystems
2 = Moderate threat to native species or ecosystems, not special status spp., or poisonous
3 = Benign, low risk NIS (but may be problem in certain areas), or too common for control
4 = Potential threat undocumented, related to problem NIS
t = Toxic to livestock or humans

* Region is the Bioregion, according to our boundaries, in which the NIS occurs; SC=South Coast, CC=Central Coast, NC=North Coast, CV=Central Valley, SN=Sierra Nevada, D=Desert; J=from Jepson Manual (Hickman 1992) and potentially problematic, E= information primarily based on Calif. Exotic Pest Plant Council list of problem exotics; M=Moyle 1976 and Mc=McGinnis 1984 for fish. Occurrence is based on information provided by natural area managers, and does not equate with actual distributions or complete coverage of the NIS in California; see CalEPPC 1994 listing, Mooney et al. 1986, Moyle 1976 for additional species and distribution information.

Elodea canadensis (N)	common waterweed	4	SN
Eucalyptus globulus	blue gum	3	SC,CC
Ficus carica	fig	4	CV
Foeniculum vulgare	fennel	2	SC,CC
Gunnera tinctoria	gunnera	4	CC,J
Hedera helix	English ivy	4,t	SC,CC
Hippurus vulgaris (N)	mare's tail	4	SC
Hydrilla verticillata	hydrilla	1	SC,NC,CV
Lactuca serriola, L. spp.	prickly lettuce, wild l.	4,t?	SC,J
Lepidium latifolium	perennial peppergrass	1	CV,D,E
Lythrum salicaria	purple loosestrife	1	NC,SN,D
L. hyssopifolium, L. spp.	loosestrife	4	NC,J
Melilotus alba	white sweet clover	3	SC,CC,NC
Mentha pulegium	pennyroyal	4	CC,E
Mesembryanthemum crystalinum	crystalline iceplant	1	SC
Myoporum laetum	myoporum	2	SC
Myriophyllum aquaticum	parrot's feather	4	J
M. spicatum	Eurasian milfoil	1	CV
Nereum oleander	oleander	4,t	E
Nicotiana glauca	tree tobacco	2,t	SC
Ottelia alismoides	ottelia	4	CV,J
Parentucellia viscosa	parentucellia	4	NC,E
Phalaris aquatica	Harding grass	2	SC
Phoenix dactylifera	date palm	3	D
Phyla (=Lippia) nodiflora	lippia	4	E
Phragmites australis(=communis)(N)	common reed	3	SN,D
Piptatherum miliaceum	smilo grass	2	SC,E
Pistia stratiotes	water lettuce	2	J
Poa pratensis	Kentucky bluegrass	2	NC,SN,D
Ricinus communis	castor bean	2,t	SC
Ranunculus muricatus	buttercup	4	J
R. aquatilus aquatilus (N?)	aquatic buttercup	3	SC
Robinia pseudoacacia	black locust	2	NC,SN
Rorippa nasturtium-aquaticum (N?)	water-cress	3	SC
Rubus discolor (=procerus)	Himalayan blackberry	2	SC,CC,NC,SN
Salix alba	white willow	4	SN
Salsola tragus, S. soda	Russian thistle, tumbleweed	2	CC,CV,D
Scirpus spp. (incl. S. setaceous, S. mucronatus, S. tuberosus)	bulrush, alkali bulrush	2	NC,SN,D
Senecio mikanioides	German ivy	1	SC,CC
Spartina alternifolia	saltwater cord grass	1	SC,CC,NC,CV
S. densiflora, S. patens	cord grass	4	E
Tamarix spp. (T. chinensis, T. ramosissima, T. gallica, T. parviflora, etc.)	saltcedar, tamarisk	1	SC,CC,CV,SN,D
T. aphylla	athel	3,4	D
Tropaeolum majus	garden nasturtium	3	SC
Verbascum spp.	mullein	3	SN,D
Veronica spp. (V. anagallis-aquatica, V. beccabunga, V. catenata)	speedwell, brooklime	4	NC,D
Vinca major	periwinkle	2	SC
Washingtonia filifera (N)	California fan palm	3	SC,D
Xanthium spinosum, X. strumarium (N?)	cocklebur	3	SC,NC,CV,SN
Zantedeschia aethiopica	calla lily	2,t	CC

ANIMALS

INVERTEBRATES (partial list)

Mollusca			
Corbicula fluminea	Asian clam	1	SC,CC,CV
Ilyanassa obseleta	mud snail	2	CC,NC
Ostrea spp.	oysters	3	CC
Potamocorbula amurensis	Asiatic clam	1	CC,CV
Arthopoda			
Aedes albopictus	Asian tiger mosquito/dengue fever	1	CC
Apis mellifera	European honey-bee	3	SC,D
Carcinus maenus	green crab	2	CC
Eriocheir sinensis	Asian mitten crab	2	CC
Forficula auricularia	European earwig	3	SC,CC
Iridomyrmex humilis	Argentine ant	3	SC,CC,NC,CV
Orconectes spp. (rusticus?)	crayfish	2	SC,CC
Procambarus spp. (clarki)	crayfish	2	SC,D

AMPHIBIANS

Chelydra serpentina	snapping turtle	4	SC
Chrysemys picta	painted turtle	4	SC
C. scripta	red-eared slider (turtle)	4	SC
Rana catesbeiana	bullfrog	1	SC,CC,NC,CV,SN,D
Xenopus laevis	African clawed frog	1	SC

FISH

Atherinidae - Menidia beryllina	inland silverside	3	CC,CV,Mc
Centrarchidae			
Lepomis spp.	sunfish (incl. green sunfish, red-ear sunfish, pumpkinseed, bluegill)	1,3	SC,CC,NC,CV,SN,D
Micropterus spp.	bass (incl. largemouth, smallmouth, spotted, redeye)	1,3	SC,NC,CV,SN
Pomixis spp.	crappie (white, black)	2	SC,SN
Cichlidae Tilapia zillii	redbelly tilapia	1	D
Clupeidae Dorosoma petenense & Alosa sapidissima	threadfin & American shad	2,3	M
Cyprinidae (minnows and carps)			
Carrasius auratus	goldfish	2	SC,D
Cyprinus carpio	carp	2	SC,CV
Gila orcutti (N)	arroyo chub	2,4	D
Notemigonus crysoleucas	golden shiner	1	D
Notropis lutrensis	red shiner	1	SC,D
Ptychocheilus grandis (N)	Sacramento squawfish	3	NC
Pimephales promelas	fathead minnow	2	SC,D
Tinca tinca	tench	2	M
Cyprinodontidae Lucania parva	rainwater killifish	2,4	M
Gobiidae Acanthogobius flavimanus	yellowfin goby	2	CC
Ictaluridae (catfish - all introduced)			
Ictalurus melas	black bullhead	1,4	SC,CV,SN,D
I. nebulosus	brown bullhead	1,4	SN
I. punctatus	channel catfish	3	SC
Osmeridae Hypomesus nipponensis	wakasagi/pond smelt	4	CC,NC,M
Percidae Perca flavescens & Percina macrolepida	yellow perch, bigscale logperch	2,4	CV,M

Gasterosteidae			
Gasterosteus aculeatus a. (N)	three-spine stickleback	1,4	SC
Percichthyidae - Morone saxitilis & M. chrysops	striped & white bass	1,3	SC,CV,SN
Poeciliidae (livebearers, guppies - all introduced)			
Gambusia affinis	mosquitofish	1	SC,CC,NC,CV,D
Poecilia latipinna, P. mexicana	sailfin & shortfin molly	1	D
Salmonidae			
Oncorhynchus mykiss (N)	steelhead, rainbow trout	1,3	SC,CC,NC,SN,D
O. m. aguabonito (N)	golden trout	4	SN
O. nerka (N)	sockeye salmon, kokanee	1,4	SN
Salmo trutta	German brown trout	1	SC,NC,SN,D
Salvelinus fontinalis	eastern brook trout	1	SN
S. namaycush	lake trout	1,4	SN
Thymallus arcticus	arctic grayling	4	SN
Esocidae Esox lucius	northern pike	1	SN,CV

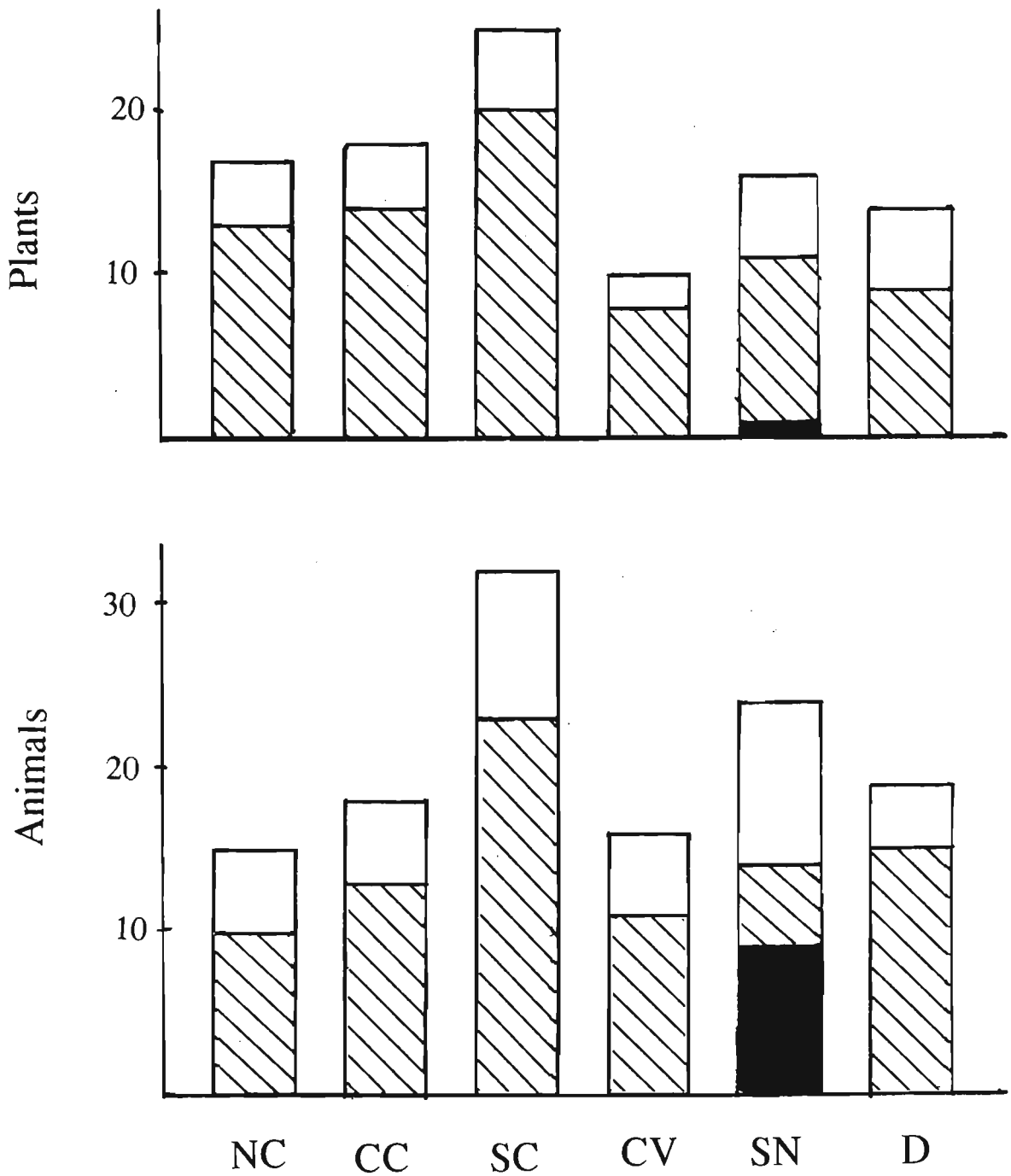
MAMMALS

Castor canadensis (N)	beaver	3,4	CV,SN
Didelphus virginiana	oppossum	3,4	SN
Equus cabullus	feral horse	2	D
Equus asinus	feral burro	1	D
Myocaster coypus	nutria, coypu	4	CV
Rattus rattus, R. norvegicus	black rat, Norway rat	1	SC,CV
Sus scrofa	European boar, feral pig	1	SC,CC,NC,SN
Vulpes fulva (N)	red fox	1	SC,CC,CV
(domesticated stock)	feral sheep, goats & cattle	1	SC(esp. islands),NC,SN,D

BIRDS

Bubulcus ibis	cattle egret	3	SC,CV
Meleagris gallopavo (N)	wild turkey	2	NC,SN
Molothrus ater (N)	brown-headed cowbird	1	SC,NC,CV,SN,D
Sternus vulgaris	European starling	2	SN

Figure 2. Number of problem NIS in the 6 bioregions of California. NC = North Coast, CC = Central Coast, SC = South Coast, CV = Central Valley, SN = Sierra Nevada, D = Desert regions; Bars indicate the number of NIS mentioned by managers, and cross-hatching indicates those judge to be of primary concern (Level 1 and 2 of Table 2; darkened portions of SN indicate those species occurring above 2000 m., primarily salmonids. The true number of NIS, even problem ones, may be substantially higher than is shown here.



tolerances, able to spread rapidly by vegetative growth or abundant, easily dispersed propogules (e.g. seeds of tamarisk, underground runners of arundo, or larvae of the corbiculid clams) are the biggest threats to aquatic ecosystems because they tend to form dense, monospecific stands which smother native species and modify the availability of resources (nutrients, water, food, shelter) within the ecosystem. Nearly all of thesesuccessful invaders also have the physiological ability to tolerate a wide variety of often-stressful environmental conditions. The ability to occupy many habitats and utilize many types of resources allows these NIS to move into many sites where they are difficult to detect and can remain for long periods. They may subsequently take advantage of environmental opportunities to expand into many other habitats, making control exceptionally difficult.The relationship between broad ecological and behavioral capabilities and success as an invadingspecies is well-known, although not absolute in explaining which species will cause problems. This subject deserves detailed study to determine which species presently, and potentially, pose a risk of invasion (Elton 1958, Ehrlich 1986, Bazzaz 1986, Pimm 1989).

Low elevation, coastal ecological reserves are threatened by the largest number of NIS (Fig. 2). The South Coast bioregion is particularly hard hit by NIS, with more species of both plants and animals reported than in any other bioregion. The concentration of NIS in coastal areas results, in part, from the array of species introduced in shipping ballast and through other ports of entry. The environmental conditions are also important, and a combination of mild coastal climates and the frequency and extent of human disturbance in these natural areas near larger populations foster expansions of opportunistic NIS. Higher elevation areas are relatively free of multiple NIS problems (Fig. 2), probably because of the climatic stresses present and the greater distances from sites containing potential escapees. Although the Sierra Nevada includes quite a large number of exotic species, nearly all are found below about 2000 meters where the habitats are more closely allied with Central Valley habitats downstream. Only trout species are common NIS at the higher elevations, which incidentally receive a higher degree of protection as Wilderness or National Parks, yet many of the impacts are in the less protected, mid- and lower elevation areas. Similarly, warm desert sites are affected by relatively few species (Fig. 2), but those which tolerate stressful desert climates, like tamarisk, often have enormous potential to multiply and dominate native species and ecosystems. The number of NIS in an area, alone, may be a fairly poor indicator of the threats they pose if these include a few, highly invasive species.

Both natural and human disturbance are factors fostering invasion by many NIS, but as pointed out in the Introduction, disturbance is not necessarily a pre-requisite for successful invasion. Particularly in riparian areas in which native species experience cyclical disturbances from natural flooding and drought, the lack of such natural disturbance, as occurs when dams restrict floods and may even create dependable, benign streamflows, will favor expansion by both plant and animal invaders (Baltz and Moyle 1993). These include many of the 'warm-water' fishes, like catfish, carp, bass and sunfish, and plants like tamarisk, arundo, bermuda-grass, and probably others which have not yet received study. Management for native species protection should be directed towards maintenance of natural disturbance regimes. It is interesting to note that many 'weedy species' identified as management problems (e.g. cowbirds, cocklebur, the common reed *Phragmites*, etc.) are, in fact, native to California but have expanded, often as a consequence of disturbance. Many

native and exotic 'weeds' are fairly benign and/or drop out of the community as the system recovers from disturbance, which again emphasizes the need for, and cost-effectiveness of, understanding the ecological context of NIS problems.

NIS CONTROL PROGRAM COSTS AND NEEDS

Control Programs

Invasions of NIS can be controlled by limiting their introduction, eradicating species once they are present in the environment but before infestations are epidemic, or controlling the spread of recognized problem species. Effective programs should address all three angles of control, but natural area managers were nearly unanimous in pointing out that there is insufficient discussion at the state or federal levels to address suitable methods for controlling entry of new NIS into the environment. Furthermore, insufficient research information exists to know the true extent of infestations of species not already identified as major problems in wetlands. This lack of monitoring and basic survey information, especially for aquatic organisms, was listed as a serious concern by managers throughout the state, in National Forests, State Parks and NGO reserves (D1,5,6, CV1,3, NC1,4, CC3,4, SC1,6,7,11, SN1,3,4,7,8,12).

In addition to this basic information, managers expressed great need for ecological studies to characterize the types of problems presented by exotic species, both to understand which deserve greatest attention, as well as to justify the nature of problems so that funds could be requested from agency authorities. One natural area had a full-time staff person dedicated to NIS problems, and this is where the best program of early detection has provided good information on NIS that are potential problems; still, attention to terrestrial problems takes precedence over wetland NIS (NC1). Virtually all reserves have experienced recent cutbacks in funding and/or staff, increasing the likelihood that NIS problems will go unrecognized or not receive adequate attention.

It is not our purpose here to describe detailed methodologies for controlling NIS invasions, although many managers said there was a need for a general set of guidelines that can be applied to management of NIS. Biologists active in control efforts stated, however, that some methods useful in some locations may not be appropriate elsewhere. For example, herbacides used to control many plant species cannot be used in some reserves for general environmental protection reasons or because NIS co-occur with sensitive non-target species that could be harmed (e.g. SN3,4, NC5, SC1,3). Furthermore, reliable control methods are established for a few well-known species [e.g. using the glyphosate-related herbacides on cut tamarisk stems (Neill 1993), or antimycin, rotenone or other rapidly-decomposing chemicals for fish eradication], but there has been little research done on how to control infestations of lesser known species.

Biological control methods using herbivores or pathogens putatively specific to the target organisms is considered important for future NIS control, but has not been developed or tested to the point where successful control can be achieved for most species (Randall 1993) or has various potentially destructive side effects (Miller and Aplet 1993). Mammal

control by several hunting methods has been applied to varying degrees of success in some California locations, particularly in the Channel Islands with feral pigs, goats, cats and rats (SC2), and with red foxes in San Francisco Bay wetlands (CC2) but application of vertebrate control in other places or with other animal species is likely to be more difficult. Mechanical removal of a non-desired plant species involves hand-pulling of small infestations of non-indigenous plants (many reserves) or gill-netting of introduced fish or bullfrogs from ponds and small lakes (SN 8,9). Larger infestations are less cost-effective with labor-intensive efforts and require more severe measures, such as bull-dozing of expanses of tamarisk (CV3) or draining reservoirs to eliminate non -indigenous fish (SC6). The Nature Conservancy is in the process of developing guidelines for treatment of several problem NIS in North America, but most of these are terrestrial plant species.

It was interesting to note several interviewees felt that improved land management could reduce the influences of some of the NIS problems they face. In particular, many felt that livestock grazing was a major factor promoting the invasion of NIS because of the associated removal of native vegetation, disturbance of soils, and erosion of streambanks that favored expansion of several opportunistic NIS plant species (NC4, SN1,9). Improved maintenance, or elimination, of roadways and paths within and adjacent to reserves to reduce roadside infestations of weedy NIS and to reduce erosion was also felt to be an important management action to improve NIS control. Such measures, which have many other beneficial attributes such as improving water quality and creating better habitat for native species, offer some of the best approaches to confront the many NIS that depend on human disturbance to successfully invade natural areas.

Economic Impacts of NIS

As part of our survey of natural areas, we asked about the economic implications of NIS problems resource managers confront. This concern was secondary to the ecological information we gathered, and further, there had been little analysis within agencies of the actual economic costs related to NIS problems. Thus, quantitative estimates were generally unavailable, and in fact impossible by our surveying methods. An accurate consideration of these concerns should be part of further studies.

There was, however, broad support for the fact that expenditures in time and funds were often significant, and far too little to adequately address the problems. In some cases expenditures were relatively small, and the main concern was that valuable time had to be taken from other activities, reducing the effort that could be expended on upgrading other aspects of reserves or improving information. This was particularly true at many of the University of California Natural Reserves, where managers estimated that the staff time expended on NIS could often demand 10-20% of their duties, and this was considered inadequate for the problems (CC3,4, SC8,9, D4). Necessary control for maintaining native grasslands was estimated to cost $30,000 at one Central Coast reserve (CC3), and needs were similar elsewhere just to maintain the present level of native species composition. They depended upon volunteer and student assistance for most of the control work. Roughly 200 to 600 person-hours of volunteer time was often spent on NIS control per year (CC3, D5, SC9), such time representing opportunity costs which could otherwise have been assigned to

improving other features of the reserves. The lack of funds has meant that some NIS simply remain unattended, for example at a reserve in the San Bernardino Mts. perennial peppergrass and castor bean are problem species but cannot be eradicated without additional funds to do the job correctly (SC7).

Volunteer work was essential at many other areas, including National Forests and Wildlife Refuges and NGO reserves (SC1, CC3, SN13 and many others). Again, this means substantial time must be expended by staff to train non-professional workers, purchasing equipment and keeping it in working order, and such volunteer programs have been stopped in some areas due to the risks inherent in using agrichemicals and dangerous equipment (SC3, SC6). Tamarisk control at Joshua Tree National Monument costs over $10,000 expenses per year, 3 months of full-time activity by 2 staff, and includes upwards of 20 volunteers working for 2-day periods. In Death Valley, tamarisk control is costing an initial $75,000 for the first 2 years, and will require an annual $20,000 follow-up program for several years. Saltcedar control efforts during 1993 were approximately $6000 at Coachella Valley Wildlife Refuge, but full costs were much greater because 535 hours of staff, Youth Conservation Corps and volunteer time were expended and major problems remain (D7). Fish & Game Non-game funds were used to conduct a pilot removal of 300 acres of invading saltcedar at the Kern Refuge near Bakersfield. Three full-time staff and 9 California Conservation Corps workers expended 72 person-days for this project, but there were no funds to conduct the essential follow-up treatment of re-sprout plants, nor to carry out the whole job of tamarisk removal from the over 5,000 acres infested. Thus, the infestation remains. A minimal estimated cost of $15,000 for labor alone are used for giant reed control in Los Padres National Forest, but tamarisk control will require even greater funding once it has moved from the scoping and planning phase into active programs; again, managers are dependent upon volunteer labor because of inadequate funding for a adequate, continuing program.

The giant reed infestation in the Santa Ana River has prompted a major co-operative effort by resource and urban agencies, NGO's and citizens to address risk presented to urban and rural areas by arundo-sustained fires (SC3,6, Jackson 1993). This interagency effort was only established after a small clearing project in Riverside County secondarily provided a buffer zone which protected urban areas from wildfire, and will require expenditures of over $60,000/year just to conduct removals from a fairly small area. Reducing the impacts of shorebird predation by red fox and other mammals, using barriers, loud charges, and non-lethal traps, costs well over $40,000 per year, but this expenditure must be maintained indefinitely because eradication is not presently feasible; invasion of beachgrass into the reserve cannot be treated at present, except in small trials (CC2).

One manager suggests that in the future, modified flood-water diversion programs could reduce the potential impacts for the massive invasions they experienced, highlighting the need for early prevention and detection, rather than treatment of NIS epidemics (CV3). Control of incipient loosestrife invasions could be achieved at relatively low costs, for instance its eradication near Lake Shasta and in the Plumas area cost approximately $5000 in each case because detection for the officially listed Noxious Weed was early (NC4, SN4). Similarly, a small invasion of perennial peppergrass at Sacramento and Delevan Refuges only cost about $3,000 to eradicate, but the larger infestations at Sutter and Colusa Refuges

simply haven't been attacked for lack of funds (CV1). . Later attempts at controlling invasions of NIS would be much more expensive, and a Department of Fish & Game official estimated that northern pike, if not eliminated quickly from Lake Pillsbury, could result in losses for established fisheries of over $1.5 million. The elimination of predacious German brown trout from headwater streams of the Kern River was only possible because they threatened the only endemic populations of golden trout, the official State fish and one sub-species has federal protection. Eradication involved large-scale (non-lethal) electrofishing removal of all trout, followed by poisoning to eliminate stragglers, and construction of gabion barriers to restrict upstream re-colonization by undesireable fish, at a cost of over $1 million, and a follow-up program in 1994 may be equally expensive (SN9, SN12).

Many interviewees stated that funds are probably available if they receive a mandate, and monitoring information, to justify control of NIS (NC4, SC4,6,10, SN1,3,7,12). This creates a Catch-22 in which the lack of funds to enable identification of threats makes it difficult to allocate funds for taking action until the situation has gotten out of hand. The National Forests, in particular, are in a position that, if they can show that NIS are detrimental to biodiversity concerns, the protection of which is mandated through the National Forest Management Act, then they can justify requests for NIS control expenditures. As elsewhere, funding and staff limitations inhibit the collection and development of information to make this case. The National Parks appear to be in a better position to close this gap, because their central mandate to protect natural ecosystems has provided some justification for full-time hiring of specialists in developing NIS programs (NC1, SN8, SC2). At one Park, it was estimated that staff salaries related to NIS control amounted to approximately $90,000 per year, with about 5000 volunteer-hours involved in their efforts. In this case, staff have now identified over 170 exotic plant species alone within the Park, representing approximately 20% of the flora (NC1). Thirty-eight mostly terrestrial species are highest management threats, in that they either displace rare or endangered native species, or can hybridize with native species, thereby compromising their genetic integrity. The rest are considered innocuous at present. A valuable product of such work in these reserves is that their research may be useful for justifying monitoring programs and actions elsewhere, and this strengthens the case for developing broader-based information systems on NIS issues. Even in National Parks resource officers are strictly constrained by lack of funds; in Yosemite National Park approximately $9000 is being spent per year to promote natural species in popular meadows, when effective recovery would cost far in excess of $100,000, with an additional $50,000 per year to promote recovery of the yet unlisted mountain yellow-legged frog (SN8).

Finally, managers are limited in what eradication programs they can conduct by public perceptions. In many cases the public pressure to maintain recreational fisheries for species that threaten native fish and invertebrates will be difficult to overcome, while public education programs are also essential to instill the attitude that some species which are perceived to be attractive (fan palms in some desert springs, purple loosestrife, tree-of-heaven, etc.) are, in fact, serious threats to welfare of native species and even to their own welfare when exotics threaten water sources or promote fires (NC2, CC2, SC3,6 SN1,4,7,11).

REGULATIONS CONCERNING NIS INVASIONS

Agricultural Codes

The State of California has a major interest in controlling NIS which threaten the agricultural industry, and the State Department of Food and Agriculture is legislatively mandated to 'promote and protect the agricultural industry of the State ... [by preventing] the introduction and spread of injurious insects or animal pests, plant diseases, and noxious weeds' (Food and Agriculture Code). Such NIS are classified with respect to their threat: Class A must be eradicated and monitored until the species is not detected for three years with no treatment, while Class C species may be economically detrimental, yet are so widely distributed that control would be impossible. Listing of a species as a Noxious Weed allows agricultural officials to allocate funds and develop action plans relatively quickly to respond to NIS threats. The California Administrative Code and the State Seed Law provide related mechanisms for dealing with recognized agricultural threats. Similar mandate is provided at the federal level by the Noxious Weed Act and the Lacey Act (for interstate and foreign transport of organisms) to provide for abatement, eradication, and control of entry of listed weeds, but harmful species can continue to be imported legally unless officially listed, and the listing process is long and cumbersome (OTA 1993).

Environmental or Biodiversity Pest Species

Lacking the clear economic impacts posed by agricultural pests, pest NIS in natural areas do not foster as strong a lobby towards developing legislation for environmental protection against them. Nonetheless, economic and other interests are at stake in natural areas, and because of the similar goal of removing the threats posed by NIS in 1975 a section was added to the Agricultural Code that states 'plants growing in native stands ... contribute to the environmental and public health and welfare needs of the people of the state... [and] such plants shall be considered as a part of the agricultural industry for the purpose of any law that provides for the protection of the agricultural industry from pests (Agric. C. Sect. 24.5). Thus, environmental pests may be listed as Noxious Weeds, and some, such as purple loosestrife, have been so-classified because of their known threats elsewhere. Loosestrife was eradicated in California on several occasions as a consequence of such listing (Siskiyou Co., NC5, SN4). However, very few of the present and potential threats have generated sufficient concern to justify this listing (Mooney et al 1984). One of the major concerns of natural area managers is that both the state and federal Noxious Weeds laws should be amended to, first, address 'weeds' that threaten natural areas and not just agricultural crops, and secondly, to make the listing process more rapid and accessible to a broader cross-section of resource interests.

A similar form of legislation at the federal level which specifically addresses NIS is the Nonindigenous Aquatic Nuisance Species Prevention and Control Act, passed in 1990 as a consequence of economic and environmental damage resulting from invasions of eastern waterways by zebra mussel (Czarnecki 1994). Although useful in a symbolic manner, this bill can authorize programs directed towards problem aquatic NIS but the lack of

appropriation authority limits its implementation (OTA 1993). It was not mentioned as a legislative tool managers utilize, nor were they aware of this legislation.

Some regional NIS concerns have been addressed, particularly in the San Francicso Bay/Sacramento Delta area. The San Francisco Estuary Project is an EPA-sponsored co-operative effort, with input from agencies, industries and NGO's, to develop a Management Plan to protect Estuary resource (SFEP 1993). It includes several objectives concerning (1) prohibition of exotic species introductions into the Bay and Watershed, (2) control of exotic species already present, and (3) development of programs to educate the public about exotic species problems. These do not yet have the force of law, but such a mutual plan coulod be invaluable in providing more comprehensive protection thatn is currently available in the region.

Although NIS are not specifically addressed, the Endangered Species Act (ESA) provides an additional vehicle for controlling NIS that pose threats to native species that have been listed, or are candidates for listing, as Threatened or Endangered. This is the primary tool that the natural area managers interviewed have used to justify their efforts to control problem NIS (D2,4, NC4, SC3, SN7, and others). The State of California has a similar protected species list, administered by the California Dept. of Fish and Game, and many other species of plants and animals receive some degree of protection, especially in National Forest areas, that have been identified as being in need of species protection by conservation organizations (primarily the California Native Plant Society; Elias 1992). The latter protection is essentially 'de facto' based on opinions developed by natural area planners, and largely lacks legal justification.

An additional mechanism available for protecting our natural areas from NIS invasions is an policy statement (Executive Order 11987) announced by President Carter in 1977 at the beginning of his term in office. It explicitly deals with the need to control or eradicate introduced organisms that threaten economic AND environmental resources in the U.S. This Order has not been rescinded, but has been largely forgotten in the administration of natural areas. At least two reserve managers were aware that such policy statement existed (SC6, SN7). We have included a copy of this Order because it may still prove to be a useful educational and administrative tool (Appendix 1).

Ecosystem Management and NIS Control

While the original intent of the Endangered Species legislation was to protect unique and threatened ecosystems, in reality it has been extremely difficult to incorporate ecosystem protection into the ESA mandate (Seligsohn-Bennett 1991). In some of the most important reserves, there are actually few officially listed species, compounding the difficulty in justifying the use of this Act for NIS control (D2,4). Furthermore, a serious drawback of the ESA is that species only become listed once they have declined to the point of emergency action, and under such circumstances introduced environmental or biodiversity pests are likely to have expanded to the point that adequate control is infeasible.

Ecosystem management is a focus of the National Forest Management Act (NFMA), which guides the development of Forest Plans on a Forest by Forest basis and provides that there should be 'no net loss of biodiversity'. This language does not resolve concerns over

protection of 'ecosystems' vs. 'single species', but recognizes the need to incorporate both concepts into resource planning. Giving special attention to the protection and enhancement of riparian areas, this is one of the more effective tools for developing NIS control plans and was mentioned as the primary means of doing so by nearly all National Forest managers we spoke with. In some Forest Plans there are even stipulations that no new introductions of NIS will take place, unless no native species can perform the desired purpose (NC3). Reserve Plans can also incorporate specific mandates to improve land uses such as livestock grazing or fire management so as to reduce threats posed by NIS, and special status resources like Wild and Scenic River designation further advance such progressive management within public lands (NC4, SN1,8). Still, the NFMA process also suffers from serious drawbacks in that each Forest Plan is developed on an 'ad hoc' basis with differing levels of input from outside interests and scientists. It is difficult to modify these plans once passed through the NEPA guidelines so new information is not readily incorporated, and there is no clear authority for budget allocations if a new need is recognized within or outside the agency.

State Parks and National Parks have similar processes for determining resource protection policies, policies more strict than those used in multiple-use National Forest lands (D5,6,7, SN8). The National Park Service is mandated to conserve the scenery, natural historic objects, and wildlife inside the Parks so that they can be enjoyed now and by future generations (USDI 1994). Natural resources are to be maintained, rehabilitated and perpetuated in the inherent integrity (USDI 1991). Control programs for exotic plant and animal species are to be undertaken wherever such species threaten Park resource or public health and when control is 'prudent and feasible' (USDI 1988). This policy is explicit, but again is without the specific mechanisms to initiate control programs and provide the resources and funds necessary to carry them out.

Need for New Legislation

All of the above legislative and administrative mechanisms provide some basis to justify responses to problem NIS. They do not, however, explicitly provide effective tools necessary for rapid identification of, and response to, problems. It seems that the Nonindigenous Aquatic Nuisance Species Act should be the most important mechanism for confronting invaders in the aquatic and wetland habitats we have been concerned with in this study. Its procedural limitations, however, compromise it usefulness and there has been discussion of amending the ANSA when it is due for renewal in 1995. Many experts feel that it may be better to let this Act run out, and develop new regulations that address the specific and general concerns regarding all NIS, rather than remaining encumbered by problems associated with the present law (Miller and Aplet 1993).

A recent international conference on Biological Invasions as a Global Change reached this last conclusion and participants have constructed the first phase of a Model Law that could provide a vehicle for developing legislation or policies at any level (Local, State, Federal, International) that would address NIS problems. Such a law could encompass both economic and environmental pests, because the mechanisms of introduction, invasion and control are often similar for pests of crops and natural ecosystems, and this would enhance

the capacity to integrate detection and eradication programs with minimal overlap in jurisdiction. We propose that such a law be developed for the State of California, with co-operative participation by all relevant interest groups. An outline of this Model Law is provided in Appendix 2.

CONCLUSIONS

The Problem

Non-indigenous species of wetland plants and animals are present and causing detrimental impacts to threatened and sensitive species, to overall natural biodiversity and to natural ecosystem processes in every bioregion of the state of California. Resource managers in every 'natural area' surveyed described problems they confront with NIS and in many cases these species demand a major component of reserve funds and staff time. Furthermore, every reserve has NIS problems that managers are unable to attend to, for reasons of inadequate funding, staff, information and/or mandate from their respective agencies and the state or federal government. In many cases, the stretched budgets and time demands resulted in managers not being aware of some NIS present in or near their areas of jurisdiction that cause problems in other natural reserves in California or elsewhere in the world.

As a consequence of these many limitations, numerous NIS problems are either increasing in magnitude or not even recognized at an early stage when control might be most effective. An example of a severe problem 'waiting to happen' is Russian olive, an invasive tree present in California and causing damage to springs and small streams in arid regions throughout the western states (Olson and Knopf 1986 - they also note that it inexplicably continues to be planted by resource agencies), but was not listed as a concern in the desert reserves we surveyed. In general, those reserves with the most information available on local and regional biodiversity issues were also those able to put the most resources into attempting control of NIS.

Some destructive aquatic and riparian NIS have only recently been identified as problems (e.g. eupatory, perennial peppergrass, Asian clam, tree of heaven) while others are expanding ranges beyond previously assumed distributional limits (e.g. tamarisk, giant reed or arundo, red fox, brown-headed cowbirds). Many other NIS have been present and widespread for many years, but their destructive impacts on native species and ecosystems have only recently come to the attention of the general public (e.g. bullfrog and a vast array of fish, including trout, sunfish and bass that prey on endangered amphibians, stocked northern California rainbow trout that dilute the genetic integrity of southern populations, Himalayan blackberry competition with native riparian plants).

Although most NIS problems may arise from accidental or careless introductions, many of the most serious cases are, in fact, of species intentionally introduced for sport or cultural reasons. Some of these were imported into natural wetland areas and secondarily determined to be problems (stocked trout species, bullfrog, eucalyptus trees, European beach

grass) and others have spread from developed sites into wild ecosystems (e.g. purple loosestrife and tamarisk originally grown for shade, soil stabilization and/or landscaping, various sunfish and bass species escaping from reservoirs into rivers and streams, feral livestock). While we typically think of NIS as those originating from other countries, some of the above examples are native species that are either spreading and displacing native species in new regions (e.g. red fox, cowbirds, cocklebur, the common reed *Phragmites*) or have been transplanted into water bodies where they did not historically occur (e.g. rainbow and golden trout, *Pacifastacus* crayfish). It is generally recognized that human modifications of land and water resources have had the most destructive influences on natural biodiversity and ecosystems of California, which only highlights the critical need to protect biotic resources in the remaining areas dedicated for ecological protection from further declines, including impacts from NIS.

Solutions

Aquatic and wetland habitats tend to exhibit close interaction between reserve areas and highly-modified areas outside of reserves. The physical and biological linkages within watersheds yield a high probability of exchange of organisms or propagules, making it essential to identify potential problems beyond reserve boundaries and to co-ordinate amongst agencies and interest groups on a regional or 'watershed' basis (as illustrated by the Arundo Donax Task Force in Riverside and Orange Counties). This inter-connectedness, plus the facts that NIS are often difficult to initially detect and, once established, are exceedingly difficult and costly to control, put a premium on maintaining frequent and vigilant monitoring programs, coupled with a in-place mechanisms for rapid responses once invaders are detected.

In order to protect California's diverse ecosystems, we also need a more comprehensive legal or administrative approach to NIS throughout the state. Regulatory tools are needed that allow managers to identify problems early, delegate staff and funds to the problems, and conduct appropriate monitoring to ensure success in NIS entry, control and/or eradication. Existing laws and policy statements are inadequate to provide the rapid responses we deem essential, and it has become clear that legal statutes are needed that explicitly address NIS concerns in areas dedicated for ecological protection. The most successful legislation would be co-ordinated among regional, federal and international agencies concerned with resource protection, given the nature of NIS problems to transcend political boundaries. An outline for a Model Law regarding nuisance NIS is presented (Appendix 2), is the subject of on-going discussion on how regulations may yield maximum effectiveness, and we anticipate will provide guidelines for developing adequate policy here and abroad.

Certain NIS have important recreational, ornamental and economic values, so it is difficult or inappropriate to promote a general policy of eradicating all NIS; instead, balances should be found in natural area management between promoting human values and maintaining ecological purity. Thus, ecosystem management may be most effective when it is conducted as triage, balancing what is environmentally desireable, what is wanted by users, and what is possible (Vitousek 1994). We further suggest taking a more

comprehensive approach to biodiversity protection across the whole state, such as the Aquatic Diversity Management Areas program proposed by Moyle and Yoshiyama (1992). The Bioregion approach (CRA 1993) also provides a useful step towards co-ordinating issues with regional relevance, but much heterogeneity exists within regions, and many NIS issues do not strictly abide by 'bioregion boundaries'. Thus strict adherence to any fixed 'management boundary', even restricting management to a single State, limits the effectiveness of promoting biodiversity protection. As reiterated above, we need the administrative flexibility and inter-agency communication, coupled with a more uniform and decisive legislative mandate, to deal with all administrative levels and spatial scales of this and other threats that confront our badly damaged natural ecosystems.

WHERE TO GO FOR MORE INFORMATION

A variety of publications, books and conference proceedings examine the theory, ecology and management of invasive non-indigenous species around the globe, many of which are listed in the References section. We particularly suggest that readers interested in further information consult the Congressional report on harmful NIS (OTA 1993).

Several non-governmental organizations conduct NIS studies, public education programs, and volunteer work trips to eradicate NIS, and two of the most active in California are The Nature Conservancy (information available from the San Francisco office) and the California Native Plant Society (916-447-2677 in Sacramento). Another statewide organization for researchers, practitioners and conservationists was recently formed to deal specifically with NIS problems, the California Exotic Pest Plant Council (CalEPPC - they can be contacted at P.O. Box 26523, San Diego, CA 92196). On the national level, the Environmental Defense Fund (1875 Connecticut Ave., NW, Washington, D.C., 20009) has a program concerning impacts of NIS and other threats to aquatic biodiversity, and the Endangered Species Coalition (202-547-9009) provides a network for promoting legislation to protect biodiversity.

Further information is also available by contacting the authors through the Pacific Institute in Oakland (510-251-1600).

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Appendix I. 1977 Executive Order 11987.

Text of Executive Order 11987

Title 3 - The President

Executive Order 11987 May 24, 1977

EXOTIC ORGANISMS

By virtue of the authority vested in me by the Constitution and statutes of the United States of America, and as President of the United States of America, in furtherance of the purposes and policies of the Lacey Act (18 U.S.C. 42) and the National Environmental Policy Act of 1969, as amended (42 U.S.C. 4321 et seq.), it is hereby ordered as follows:

Section 1. As used in this Order:

(a) "United States" means all of the several States, the District of Columbia, the Commonwealth of Puerto Rico, American Samoa, the Virgin Islands, Guam, and the Trust Territory of the Pacific Islands.

(b) "Introduction" means the release, escape, or establishment of an exotic species into a natural ecosystem.

(c) "Exotic species" means all species of plants and animals not naturally occurring, either presently or historically, in any ecosystem of the United States.

(d) "Native species" means all species of plants and animals naturally occurring, either presently or historically, in any ecosystem of the United States.

Section 2.

(a) Executive agencies shall, to the extent permitted by law, restrict the introduction of exotic species into the natural ecosystems on lands and waters which they own, lease, or hold for purposes of administration; and, shall encourage the States, local governments, and private citizens to prevent the introduction of exotic species into natural ecosystems of the United States.

(b) Executive agencies, to the extent they have been authorized by statute to restrict the importation of exotic species, shall restrict the introduction of exotic species into any natural ecosystem of the United States.

(c) Executive agencies shall, to the extent permitted by law, restrict the use of Federal funds, programs, or authorities used to export native species for the purpose of introducing such species into ecosystems outside the United States where they do not naturally occur.

(d) This Order does not apply to the introduction of any exotic species, or the export of any native species, if the Secretary of Agriculture or the Secretary of Interior finds that such introduction or exportation will not have an adverse effect on natural ecosystems.

Section 3.

The Secretary of Interior, in consultation with the Secretary of Agriculture and the heads of other appropriate agencies, shall develop and implement, by rule or regulation, a system to standardize and simplify the requirements, procedures and other activities appropriate for implementing the provisions of this Order. The Secretary of the Interior shall ensure that such rules or regulations are in accord with the performance by other agencies of those functions vested by law, including this Order, in such agencies.

(signed by the President)

THE WHITE HOUSE,
May 24, 1977

[FR Doc.77-14120 Filed 5-24-77; 1:41 pm]

FEDERAL REGISTER, VOL. 42, NO. 101 -- WEDNESDAY, MAY 25, 1977

Appendix II.

PREVENTION OF HARM BY NON-INDIGENOUS SPECIES ACT** CHAPTERS

I. STATEMENT OF PURPOSE
II. DEFINITIONS
III. PREVENTION AND EXCLUSION OF NIS INTRODUCTIONS
- Prevention (Country of Origin)
  - Raising international awareness
  - Preventing undesireable imports
  - Screening facilities
  - Sanctions
- Exclusion (Importing Country)
  - Authority
  - Intentional importation
  - Unintentional introductions
  - Permits
  - Fees

IV. INTERSTATE AND INTRASTATE SHIPMENTS; SPECIAL PATHWAYS
V. INTENTIONAL RELEASE REVIEW
- Review of Intentional Introductions
- General Principles for Release
  - Reasons for proposed introductions
  - Record of prior releases and outcomes
  - Prediction of possible impacts
- Criteria & Assessment
- Levels of Approval
- Assessment and Follow-up Requirement of Proposed Introductions

VI. RESPONSE TO BIOLOGICAL INVASIONS
- Concerns/Shortcomings of Existing System
- Biological Invasion Response Task Forces
- Determination of NIS Priority Level or Risk

VII. DISPUTE RESOLUTION
- Conflicts of Interest Between Jurisdictions
- Conflicts Between Public Interests
- Disputes Over Use of Indigenous Label

VIII. RESEARCH & DATA
- Non-Indigenous Species (NIS) Database
- Monitoring and Detection
- Support for Research

IX. EDUCATION
- General Public Education about NIS Impacts and Prevention
- Local Involvement in Monitoring and Response
- Support for K-12+ Education on NIS
- Training for Agency Employees

NON-INDIGENOUS SPECIES ACT, CONT.

X. LIABILITY FOR RELEASES
XI. SUPPORT FOR STATE AND LOCAL INITIATIVES
XII. INTENTIONAL EXPORTS
XIII. FUNDING
- Principles
- Recommendations - User fees, Excise taxes, General funds
- Immediately Available, Modest Changes
- Status of Current Law

XIV. GENETICALLY ENGINEERED ORGANISMS
XV. AGENCY ASSIGNMENT OF RESPONSIBILITY

** Drafted by participants, Aspen Global Change Institute Session on Biological Invasions as a Global Change - Organizer John Katzenberger, August 21-September 2, 1994. Chairs: Dr. Peter Vitousek (Stanford U.), Dr. Carla D'Antonio (U.C. Berkeley), & Dr. Lloyd Loope (U.S. Park Service); Chapter drafters include, but not limited to: Greg Aplet (Wilderness Soc.), Faith Campbell (Natural Resource Defense Council), John Dennis (U.S. Park Service), Tom Dudley (Pacific Institute), Jack Ewel & Katherine Ewel (U.S. Forest Service), Wm. Hammond (Flor. Water Mgt. District), Marc Miller (Emory U.), John Randall (The Nature Conservancy), David Wilcove (Environmental Defense Fund), Phyllis Windle (Office Tech. Assess.). Full text in review for public dissemination.

Appendix III. Alien Species (Reprinted from Pacific Discovery 46(Summer 1993):8-11.

Alien Species

The insidious invasion of ecosystems by plants and animals from around the world has become a major environmental threat.

by CARLA D'ANTONIO & TOM L. DUDLEY

IN 1958, OXFORD ecologist Charles Elton outlined the ecologically devastating effects of invading species in his book, *The Ecology of Invasions by Plants and Animals.* Elton stated that "we are living in a period of the world's history when the mingling of thousands of kinds of organisms from different parts of the world is setting up terrific dislocations in nature. We are seeing huge changes in the natural population balance of the world." Although he warned that invasions were increasingly widespread, the threats they pose to natural ecosystems did not come to the full attention of the scientific community and the general public until the last decade.

Even today, 35 years after Elton's warning, we have not taken the gravity of the situation to heart; while major environmental threats such as global climate change attract more and more of our national attention and research dollars, the invasion of our ecosystems by plants and animals from around the world is every bit as insidious and important.

It is almost impossible to find communities that have not been affected by invading organisms. In the western United States, we have been almost overrun by grasses and herbs from Europe and Africa, clams from Asia, or even less distant immigrants from the eastern United States such as bullfrogs, cowbirds, and sunfish. Exotic organisms are proving to be costly threats to private enterprise, taxpayers, and natural ecosystems. As urban and agricultural development expand, the value of wildlands as repositories of biological diversity and as symbols of our natural heritage has increased. Along with land-use change and habitat fragmentation, introduced species present another front on which these wildlands are being attacked.

For instance, throughout coastal California, the Hottentot fig, a succulent more commonly known as highway iceplant (*Carpobrotus edulis*), with its brilliant pink or yellow flowers, carpets roadsides, suburban gardens, and ocean bluffs. This attractive and seemingly useful groundcover plant introduced into California from South Africa about 70 years ago is actually anything but innocuous, and has become a major frustration for land managers and biologists.

The iceplant has become a problem species in wild dune, grassland, and scrub communities on the Pacific Coast from Baja California to the Oregon border. It invades natural habitats far away from where it was planted because rabbits and deer eat the fruits and disperse its seeds. When the iceplant takes hold it can outcompete the native species, acidify the soil beneath it, and is difficult (and costly) to eradicate. Without amendment or modification, the decline in soil fertility is slow to reverse even after the iceplant's removal. Similar stories are repeated throughout the world with different complexes of introduced and native species.

MOST PLANTS AND ANIMALS can disperse naturally into new habitats, and still today, invasions, such as the colonization of North America by cattle egrets from Africa, occur without human intervention. But the most destructive invasions are invariably those facilitated by people, and they have been going on around the globe for centuries. The builders of empires were accompanied by other species from the lands of the conquerors, imposing what historian Alfred Crosby calls "ecological imperialism." Native ecosystems have been subjected to oppression similar to that experienced by indigenous peoples.

Many introductions were intentional. Sheep and swine were released onto islands in the New World to provide food for returning colonists. Eucalyptus and tamarisk trees were introduced for lumber and windbreaks, while European and African grasses were brought for livestock fodder. And there are many cases of biological control projects gone awry, such as the mongooses which were brought to Hawaii to control introduced rats but instead became predators of native birds.

Other introductions have been accidental. These are particularly common around trade centers where ships release their ballast along with cysts and seeds of foreign species. This was the source of the Eurasian zebra mussel (*Dreissena polymorpha*), which now clogs water facilities in the Midwest and the Great Lakes, as well as many of the weeds we now pull from our gardens. The chestnut blight fungus, which has caused the near-extinction of American chestnut trees throughout the eastern United States, was a hitchhiker on Asian chestnut plants brought to this country around the turn of the century.

Not every introduced species is pernicious. Agriculture in the United States, as elsewhere, depends on introduced

DICK VAN NOSTRAND/BAY CITY TIMES

Above: The Eurasian zebra mussel (Dreissena polymorpha)*, has overrun much of the Great Lakes's native biota and caused millions of dollars of damage in blocked water pipes and fouled boats and harbor structures.*

Opposite: Two exotic species that have come to characterize the Marin County landscape are French broom (foreground) and the Australian eucalyptus (background). French broom spreads quickly, overrunning coyote bush and other native plants, and its seeds can remain dormant but viable for decades. Eucalyptus, originally brought here as a lumber tree, spreads slowly, but it profoundly alters the ecosystems it occupies.

species, and in gardens, parklands, and managed natural areas it is common to find introduced species that do not spread into wildlands. So, what qualities make an introduced species a pest? First, if it reduces biological diversity by affecting the survival of native species, either through predation, or from competition or disease. Second, if it causes a change in the resource supply and so influences the composition of the community at large. Third, if it alters the rate or type of disturbances, such as changing the frequency and severity of fires.

In addition, for an introduced species to be a real danger, it must reproduce and spread on its own. For instance, eucalyptus trees clearly inhibit the growth of other plants, and to many people they are a nuisance. Yet because they spread little from their original planted areas they are not difficult to control in California. Scotch broom (*Cytisus scoparius*), on the other hand, does invade widely and illustrates why many exotics reproduce and disperse so successfully: it lacks the natural controls found in its native lands. There are 38 known herbivores that eat broom in Europe and only eight broom eaters in the United States.

Sometime in the 1940s or early 1950s brown tree snakes (*Boiga irregularis*) from Australia or New Guinea were accidentally transported to Guam. Free from both predators and competitors, these snakes flourished. Today Guam has tens, perhaps hundreds of thousands of these snakes. They have destroyed almost the entire native avifauna. Nine native forest bird species have become extinct, and others are likely to follow.

Likewise, on Santa Catalina Island grazing by introduced goats and sheep caused the elimination of an estimated 48 native plant species, several of which were endemic to the Channel Islands. Work by Berkeley graduate student Sarah Kupferberg suggests that the introduced bullfrog competes with native frogs and may be a primary cause of their decline in northern California rivers.

Cases of invaders altering resources often involve plants which reduce the quality or supply of nutrients and water to native assemblages. In addition to the highway iceplant species, the crystalline iceplant (*Mesembryanthemum crystallinum*) alters soil resources by taking up salts from deeper soil levels and concentrating them in leaf tissue. When these annuals die, they deposit salt on the soil surface leading, over successive years, to its salinization.

Salt cedar or tamarisk, native to the Mediterranean, was planted as a windbreak throughout the arid western United States. At least one species, *Tamarix ramosissima*, has proved extremely invasive and now infests many stream and river corridors. This tree transpires enormous quantities of water. It draws the water table so far down that previously permanent ponds and desert streams disappear, and the plant communities and the animals that depend on them are jeopardized.

Both plant and animal invaders can alter the abundance of other species indirectly by modifying the natural rate of disturbances. Throughout western U.S. rangelands and in dry tropical forests of the Hawaiian islands, Central America, and Australia, introduced grasses primarily of European or African origin have increased the frequency and intensity of fire. Before the invasion of Idaho rangeland by European cheatgrass (*Bromus tectorum*), fires burned through this Great Basin desert every 60 to 110 years. Since the grass invasion, these same sites burn every three to five years, decimating native woody species which do not recover well from frequent fire. Grass-fueled fires typically encourage even more abundant growth of introduced grasses at the expense of native plant species and the animals that have depended on them. In Hawaii, fires fueled by alien grasses have converted thousands of acres of native dry forest to exotic-dominated savanna.

Helix aspersa, *the common garden snail, was brought to Santa Rosa from Europe in the 1840s. Now, though it is a highly prized delicacy in France, it is the curse of gardeners throughout California. In the late 1800s, there was a mysterious population explosion of the snails, which almost destroyed the citrus farm in the Central Valley. Authorities were forced to close roads that were alive with snails. Today, a Santa Rosa entrepreneur is exporting snails back to France, where the wild population is nearly gone.*

In many cases we see not a single problem species, but an "invasion complex." One invader takes hold, alters the physical habitat, and soon other exotic species are finding a new home. The European wild boar, which now roams over much of the United States including Hawaii, rototills the soil in native communities in search of bulbs and insects. It can destroy native understory vegetation and opens up space for invasion by introduced plants. Also in Hawaii, introduced fruit-eating birds disperse seeds of the introduced fire tree *Myrica faya*. This nitrogen-fixing tree is enhancing the rate of nitrogen accumulation and altering plant and animal succession in young volcanic soils.

While invasions do occur in intact ecosystems, more often it is human land-use changes, such as livestock grazing, forest practices, fire suppression, and regulation of stream flows which create the conditions that allow large-scale invasion. Once invaders are established, it is difficult, if not impossible, to recreate the natural processes that supported the original biota.

Below: The brown tree snake (Boiga irregularis), *a native to Australia and New Guinea, has no predators or competitors on Guam, where its exploding population has extirpated nine of the island's eleven native forest birds.*

DAVID LIEHMAN

Top: This Australian tree, Melaleuca quinquenervia, *threatens to take over the Florida Everglades, encroaching on new territory at a rate of more than 15,000 acres each year. Above: The hearty iceplant, imported from South Africa, lines highways and borders gardens all along the west coast. Unfortunately, it spreads far and fast, causing problems for native scrub, dune, and grassland communities. It is a fierce competitor, far outpacing most of the native plants that share its habitat requirements.*

THE ECONOMIC CONSEQUENCES of invaders can be far-reaching and costly. In Hawaii Volcanoes National Park, where over 66 percent of the plant species are introduced and wild pigs disrupt many of the native ecosystems, the Resources Management Division spends 80-90 percent of its annual budget on eradication efforts, according to park vegetation specialist Tim Tunison. Channel Islands National Park in California has spent more than $725,000 to eradicate feral pigs from Santa Rosa Island. To date 1,200 pigs have been removed. "These were very expensive pigs," points out wildlife biologist Carmen Lombardo, "but eradication was essential to the ultimate restoration of these sites."

Mainland parks and reserves also suffer from alien species problems. Everglades National Park spent $16,500 an acre eradicating the aggressive Christmas berry (*Schinus terebinthifolius*) from a 60-acre site. They had to remove every inch of the rich topsoil left over from past farming operations. Only the native plants could take root in the sterile soil below.

Habitat restoration projects frequently become mired down by introduced species problems. After a pipeline was installed in Santa Barbara County, California in the mid-1980s, introduced plants soon dominated the disturbed land, preventing the regrowth of native species. Removing these weeds absorbed a large part of the restoration budget.

In some parks, reserves, and agricultural habitats, introduced species have been controlled through manual, chemical, and biological techniques. To simulate the elements which regulate populations in native landscapes, both state and federal agriculture departments have long been involved in introducing predators or pathogens to control earlier-introduced pests. A European weed, tansy ragwort (*Senecio jacobaea*), was successfully controlled on range and agricultural lands in northern California and Oregon and in Redwood National Park using two insect species from Europe, a flea beetle and the cinnabar moth. Scale insect pests on citrus fruit in California are also controlled with host-specific parasitoid wasps from Asia.

Unfortunately, very little biological control research has been done on plants and animals that are not agricultural pests. Control of ragwort in Redwood National Park was only pursued because it also threatened nearby rangelands. The research is expensive, time-consuming, and complex and is not within the budgets of most parks and reserves. Consequently, wildland managers have had to rely on manual and chemical removal methods.

Their success has been proportional to the degree of the invasion at the time when removal began. At Channel Islands National Park, invasion by pampas grass and yellow star thistle, introduced plants that are serious problems elsewhere, was kept in check relatively easily because removal and subsequent monitoring began while populations of the invaders were still limited. Other exotic plants that already covered large areas and had built up extensive seed banks have yet to succumb to control.

In the last decade, citizen groups and public agencies have begun to combine their efforts to identify and control problem species. Concern over the spread and negative impacts of the Australian tree *Melaleuca quinquenervia,* which has been estimated to be spreading through the Florida Everglades at a rate of 15,000 acres per year, led to the formation of the Exotic Pest Plant Council. This group is funded by several state and federal agencies and has members educating the public and land managers about threats posed by exotic species. In west Marin County, California, a number of groups, including the Friends of the Coyote Bush, are systematically tearing out the French broom which has engulfed hillsides once covered with wildflowers. A chapter of the Exotic Pest Plant Council has now formed in California and is in the process of identifying the introduced species that pose the greatest threats to our wildlands.

In southern California, local, state, and federal agencies have banded together to form the *Arundo donax* Task Force to control the spread of this invasive and fire-promoting giant reedgrass. Because wildland and reserve boundaries are not obeyed by introduced species, this type of multi-agency and public cooperation is essential to long-term control of exotic organisms. Throughout California and the West, The Nature Conservancy and other volunteer organizations also sponsor programs in which citizens assist with exotic species eradication.

These are encouraging signs, but the rate of human-caused invasions continues to far exceed efforts to stem them. Unless there is a popular awakening to the seriousness of the problem, local and regional diversity will continue to shrink, and the world's biota will become increasingly homogenized, threatening our economies and irreversibly impoverishing our natural heritage. □

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Source: California Invasive Plant Council

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Invasive Plants of California's Wildland

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Foreword >

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Invasive Plants of California's Wildland

Foreword

The heart of this book is the species accounts, which provide detailed information about the biology and control of seventy-eight non-native plant species that are listed as Exotic Invasive Plants of Greatest Ecological Concern as of 1996 by the California Exotic Pest Plant Council (Cal-IPC). We decided to cover only the species on this list because it is the best effort to date1 to determine which of the non-native plants already growing wild in California cause or have the potential to cause serious damage in the state's parks, preserves, and other wildlands. We are convinced that non-native invasive plants pose one of worst threats, perhaps the worst of all, to the state's remaining populations and communities of native species. We hope the information on the pages that follow will be used to help promote the survival and growth of native plants and animals threatened by these invaders.

Cal-IPC was established in 1992 in response to growing concern about invasive non-native plants in the state's wildlands. In 1994 Cal-IPC canvassed its members and other land managers and researchers around the state for information about non-native plants that invade California's preserves, parks, and other wildlands. This information was used to develop a list of Exotic Invasive Plants of Greatest Ecological Concern in California. The species were grouped into several categories to indicate how severe and/or widespread they are. List A-1 includes the most invasive and damaging species that are widespread in the state. List A-2 includes highly damaging species that are invasive in fewer than five of the geographic subdivisions designated in The Jepson Manual: Higher Plants of California. List B includes less invasive species that move into and degrade wildlands. The Red Alert List includes species whose ranges in California currently are small but that are believed to have the potential to spread explosively and become major pests. Species for which there was insufficient information to determine their ability to invade and degrade natural areas were placed on a Need More Information list and only a few for whom strong evidence is mounting are included in this book. As the list was being compiled and categorized it was reviewed, re-reviewed, and finally approved by a group of respected researchers. In 1996 the Cal-IPC list was updated based on new information and expanded to include a total of seventy-eight species.

We begin this book with a brief overview of the impacts of invasive plants and what we know about the characteristics of plant species most likely to invade and the habitats and communities most likely to be invaded. This is followed by a discussion of strategies and methods appropriate for the control of invasive plants in parks, preserves, and other wildlands. The remainder of the book consists of species accounts for seventy-eight invasive non-native species. Each account helps readers to identify the species and understand important aspects of its biology and lists specific control methods that are regarded as relatively effective, as well as some found to be ineffective.

[1] We acknowledge that several non-native invaders that have caused severe damage to wildlands in California are not on the 1996 edition of the list, as does Cal-IPC. As we write this Cal-IPC is preparing an updated version of the list, but it will not be ready in time for us to include newly listed species.

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Invasive Plants of California's Wildland

California Wildland Invasive Plants

John M. Randall and Marc C. Hoshovsky

The focus of this book is non-native plants that invade parks, preserves, and other wildlands in California, but our real concern is the survival and growth of the native plants and animals these invaders threaten. Unfortunately, some non-native invasive plant species inflict so much damage that, unless they are controlled, it will be impossible to preserve viable populations of many native species or many of the state's natural communities and ecosystems.

The good news is that many plant invasions can be halted or slowed, and, in certain situations, even badly infested areas can be restored to relatively healthy communities dominated by native species. Weed control and restoration are now widely regarded as necessary in many wildlands across the state and around the world. We hope this book will help land managers, volunteer stewards, and others to recognize some of California's most damaging wildland in vad ers, to better understand their impacts, and to minimize the damage they do to native biological diversity.

Invasive species are now widely recognized worldwide as posing threats to biological diversity second only to direct habitat loss and fragmentation (Pimm and Gilpin 1989, Scott and Wilcove 1998). In fact, when biological invasion by all types of organisms is considered as a single phenomenon, it is clear that to date it has had greater impacts on the world's biota than have more notorious aspects of global environmental change such as rising CO2 concentrations, climate change, and decreasing stratospheric ozone levels (Vitousek et al. 1996). Compared to other threats to biological diversity, invasive non-native plants present a complex problem that is difficult to manage and has long-lasting effects. Even when exotics are no longer actively introduced, these plants continue to spread and invade new areas. Effective control will require awareness and active participation of the public as well as natural resource managers and specialists.

California's invasive plant problems are widespread and severe. The state's varied topography, geology, and climates have helped to give rise to the state's extraordinary native biological diversity and high levels of endemism. However, these varied conditions also provide suitable habitat for a wide variety of non-native plant species, many of which have readily established and rapidly spread in the state. Fewer than ten percent of the 1,045 non-native plant species that have established in California are recognized as serious threats (Randall et al. 1998), but these have dramatically changed California's ecological landscape. They alter ecosystem functions such as nutrient cycles, hydrology, and wildfire frequency, outcompete and exclude native plants and animals, harbor dangerous animal invaders, and hybridize with native species. Some spread into national parks, preserves, and other wildlands and reduce or eliminate the species and communities these sites were set aside to protect.

Rare species appear to be particularly vulnerable to the changes wrought by non-native invaders. For example, the California Natural Diversity Database indicates that 181 of the state's rare plant species are experiencing threats from invasive weeds (California Department of Fish and Game, Natural Heritage Division). Habitats for rare animals such as the San Clemente sage sparrow and the Palos Verde blue butterfly are also being invaded. Even more common species could be driven to rarity or near extinction by particularly disruptive invaders, as evidenced by the fate of the American chestnut (Castanea dentata) in the eastern hardwood forest following introduction of chestnut blight, Cryphonectria parasitica (National Academy of Science 1975).

IMPACTS OF INVASIVE PLANTS ON WILDLANDS

Non-native plant invasions can have a variety of effects on wildlands, including alteration of ecosystem processes; displacement of native species; support of non-na tive animals, fungi, or microbes; and alteration of gene pools through hybridization with native species.

Ecosystem Effects

The invasive species that cause the greatest damage are those that alter ecosystem processes such as nutrient cycling, intensity and frequency of fire, hydrological cycles, sediment deposition, and erosion (D'Antonio and Vitousek 1992, Vitousek 1986, Vitousek and Walker 1989, Vitousek et al. 1987, Whisenant 1990). These invaders change the rules of the game of survival and growth, placing many native species at a severe disadvantage (Vitousek et al. 1996). Cheat grass (Bromus tectorum) is a well studied example of an invader that has altered ecosystem processes. This annual grass has invaded millions of acres of rangeland in the Great Basin, leading to widespread increases in fire frequency from once every sixty to 110 years to once every three to five years (Billings 1990, Whisenant 1990). Native shrubs do not recover well from more frequent fires and have been eliminated or reduced to minor components in many of these areas (Mack 1981).

Some invaders alter soil chemistry, making it difficult for native species to survive and reproduce. For example, iceplant (Mesembryanthemum crystallinum) accumulates large quantities of salt, which is released after the plant dies. The increased salinity prevents native vegetation from reestablishing (Vivrette and Muller 1977, Kloot 1983). Scotch broom (Cytisus scoparius) and gorse (Ulex europaea) can increase the content of nitrogen in soil. Although this increases soil fertility and overall plant growth, it gives a competitive advantage to non-native species that thrive in nitrogen-rich soil. Researchers have found that the nitrogen-fixing firetree (Myrica faya) increases soil fertility and consequently alters succession in Hawaii (Vitousek and Walker 1989).

Wetland and riparian invaders can alter hydrology and sedimentation rates. Tamarisks (Tamarix chinensis, T. ramosissima, T. pentandra, T. parviflora) invade wetland and riparian areas in southern and central California and throughout the Southwest, and are believed to be responsible for lowering water tables at some sites. This may reduce or eliminate surface water habitats that native plants and animals need to survive (Brotherson and Field 1987, Neill 1983). For example, tamarisk invaded Eagle Borax Spring in Death Valley in the 1930s or 1940s. By the late 1960s the large marsh had dried up, with no visible surface water. When managers removed tamarisk from the site, surface water reappeared, and the spring and its associated plants and animals recovered (Neill 1983). Tamarisk infestations also can trap more sediment than stands of native vegetation and thus alter the shape, carrying capacity, and flooding cycle of rivers, streams, and washes (Blackburn et al. 1982). Interestingly, the only species of Tamarix established in California that is not generally regarded as invasive (athel, or T. aphylla) is regarded as a major riparian invader in arid central Australia.

Other wetland and riparian invaders and a variety of beach and dune invaders dramatically alter rates of sedimentation and erosion. One example is saltmarsh cordgrass (Spartina alterniflora), native to the Atlantic and Gulf coasts and introduced to the Pacific Coast, where it invades intertidal habitats. Sedimentation rates may increase dramatically in infested areas, while nearby mudflats deprived of sediment erode and become areas of open water (Sayce 1988). The net result is a sharp reduction in open intertidal areas where many migrant and resident waterfowl feed.

Coastal dunes along the Pacific Coast from central California to British Columbia have been invaded and altered by European beachgrass (Ammophila arenaria). Dunes in infested areas are generally steeper and oriented roughly parallel to the coast rather than nearly perpendicular to it as they are in areas dominated by Leymus mollis, L. pacificus, and other natives (Barbour and Johnson 1988). European beachgrass eliminates habitats for rare native species such as Antioch Dunes evening-primrose (Oenothera deltoides ssp. howellii) and Menzies' wallflower (Erysimum menziesii ssp. menziesii). Species richness on foredunes dominated by European beachgrass may be half that on adjacent dunes dominated by Leymus species (Barbour et al. 1976). Changes in the shape and orientation of the dunes also alter the hydrology and microclimate of the swales and other habitats behind the dunes, affecting species in these areas.

Some upland invaders also alter erosion rates. For example, runoff and sediment yield under simulated rainfall were fifty-six percent and 192 percent higher on plots in western Montana dominated by spotted knapweed (Centaurea maculosa) than on plots dominated by native bunchgrasses (Lacey et al 1989). This species is already established in northern California and the southern Peninsular Range and recently was found on an inholding within Yosemite National Park (Hrusa pers. comm.).

Some invasive plants completely alter the structure of the vegetation they invade. For example, the punk tree (Melaleuca quinquenervia) invades marshes in southern Florida's Everglades that are dominated by sedges, grasses, and other herbaceous species, rapidly converting them to swamp forest with little or no herbaceous understory (LaRoche 1994, Schmitz et al. 1997). Such wholesale changes in community structure may be expected to be followed by changes in ecosystem function.

HABITAT DOMINANCE AND DISPLACEMENT OF NATIVE SPECIES

Invaders that move into and dominate habitats without obviously altering ecosystem properties can nevertheless cause grave damage. They may outcompete native species, suppress native species recruitment, alter community structure, degrade or eliminate habitat for native animals, and provide food and cover for undesirable non-native animals. For example, edible fig (Ficus carica) is invading riparian forests in the Central Valley and surrounding foothills and can become a canopy dominant. Invasive vines are troublesome in forested areas across the continent. In California, cape ivy (Delairea odorata) blankets riparian forests along the coast from San Diego north to the Oregon border (Elliott 1994).

Non-native sub-canopy trees and shrubs invade forest understories, particularly in the Sierra Nevada and Coast Ranges. Scotch broom (Cytisus scoparius), French broom (Genista monspessulana), and gorse (Ulex europaea) are especially troublesome invaders of forests and adjacent openings and of coastal grasslands (Bossard 1991a, Mountjoy 1979). Herbaceous species can colonize and dominate grasslands or the ground layer in forests. Eupatory (Ageratina adenophora) invades and dominates riparian forest understories along California's southern and central coast. Impacts of these ground-layer invaders have not been well studied, but it is suspected that they displace native herbs and perhaps suppress recruitment of trees.

Annual grasses and forbs native to the Mediterranean region have replaced most of California's native grasslands. Invasion by these species was so rapid and complete that we do not know what the dominant native species were on vast areas of bunchgrasses in the Central Valley and other valleys and foothills

around the state. The invasion continues today as medusa-head (Taeniatherum caput-medusae) and yellow starthistle (Centaurea solstitialis) spread to sites already dominated by other non-natives. Yellow starthistle is an annual that produces large numbers of seeds and grows rapidly as a seedling. It is favored by soil disturbance, but invades areas that show no sign of being disturbed by humans or livestock for years and has colonized several relatively pristine preserves in California, Oregon, and Idaho (Randall 1996b).

In some situations invasive, non-native weeds can prevent reestablishment of na tive species following natural or human-caused disturbance, altering natural suc ces sion. Ryegrass (Lolium multiflorum), which is used to reseed burned areas in southern California, interferes with herb establishment (Keeley et al. 1981) and, at least in the short term, with chaparral recovery (Schultz et al. 1955, Gautier 1982, Zedler et al. 1983).

Hybridization with Native Species

Some non-native plants hybridize with natives and could, in time, effectively eliminate native genotypes. The non-native Spartina alterniflora hybridizes with the native S. foliosa where they occur together. In some Spartina populations in salt marshes around south San Francisco Bay, all individual plants tested had non-native genes (Ayres et al. in press).

Promotion of Non-Native Animals

Many non-native plants facilitate invasions by non-native animals and vice versa. Myrica faya invasions of volcanic soils in Hawaii promote populations of non-native earthworms, which increase rates of nitrogen burial and accentuate the impacts these nitrogen-fixing trees have on soil nutrient cycles (Aplet 1990). M. faya is aided by the non-native bird, Japanese white-eye (Zosterops japonica), perhaps the most active of the many native and non-native species that consume its fruits and disperse its seeds to intact forest (Vitousek and Walker 1989).

EARLY INVASIONS BY NON-NATIVE PLANTS

The first recorded visit by European explorers to the territory now called California occurred in 1524, but people of Old World ancestry did not begin to settle here until 1769. Available evidence indicates that the vast majority of non-native plants now established in California were introduced after this time. There is compelling evidence that red-stem filaree (Erodium cicutarium), and perhaps a few other species, may have established even earlier, perhaps after being carried to the territory by roaming animals or by way of trading networks that connected Indian communities to Spanish settlements in Mexico (Hendry 1931, Hendry and Kelley 1925, Mensing and Byrne 1998). Once settlers began to arrive, they brought non-native plants accidentally in ship ballast and as contaminants of grain shipments and intentionally for food, fiber, medicine, and ornamental uses (Frenkel 1970, Gerlach 1998).

The number of non-native species established in California rose from sixteen during the period of Spanish colonization (1769-1824) to seventy-nine during the period of Mexican occupation (1825-1848) to 134 by 1860 following American pioneer settlement (Frenkel 1970). Jepson's A Manual of the Flowering Plants of California (1925), the first comprehensive flora covering the entire state, recognized 292 established non-native species. Rejmnek and Randall (1994) accounted for taxonomic inconsistencies between the 1993 Jepson Manual and earlier floras and found that Munz and Keck's 1959 A Flora of California included 725 non-native plants species and their 1968 A California Flora and Supplement included 975. The 1993 Jepson Manual recorded 1,023 non-natives, and subseqent reports in the literature have brought the number up

to 1,045 (Randall et al. 1998). Rejmnek and Randall (1994) remarked that, although non-native species continue to establish in California, the rate of increase in their number appears to be slowing after roughly 150 years of rapid growth.

Most non-native plants introduced to California in earlier times first established at coastal sites near ports and around missions and other settlements. In recent times, first reports of new non-native species have come from every major geographic subdivision of the state (Rejmnek and Randall 1994). Apparently, the great speed and reach of modern transportation systems and the increasing global trade in plants and other commodities have enabled non-natives to spread to sites throughout the state. A variety of human activities continue to introduce new species to California and to spread those that have established populations in only a few areas. For example, land managers still introduce non-native species to control erosion or provide forage for livestock. New ornamental plants and seeds are imported and sold. Movement of bulk commodities such as gravel, roadfill, feed grain, straw, and mulch transport invasive plant propagules from infested to uninfested areas (OTA 1993). The rate of spread is often alarming. For example, within California, yellow starthistle has expanded its range at an exponential rate since the late 1950s, increasing from 1.2 to 7.9 million acres by 1991 (Maddox et al. 1996, Thomsen et al. 1993).

Problems caused by invasive plants in California were recognized by Frederick Law Olmsted in 1865 in a report he filed on the newly set-aside Yosemite Valley, noting that, unless actions were taken, its vegetation likely would be diminished by common weeds from Europe. The report pointed out that this had already happened in large districts of the Atlantic States. Botanists and other students of natural history noted the establishment of non-native species in the state in published papers, and by the 1930s natural area managers in Yosemite and scattered parks and preserves around the state began controlling invading non-native species that were recognized as agricultural pests (Randall 1991). The issue was brought into mainstream ecology in the late 1950s with the publication of Charles Elton's book, The Ecology of Invasions by Animals and Plants (1958). Concern and interest among both land managers and researchers have grown since that time, particularly since the mid-1980s.

SPECIES MOST LIKELY TO BE INVASIVE

Many people have wondered if certain traits distinguish species that become invasive. Despite a great deal of study, no single answer presents itself, and researchers have been surprised by the success of some species and the failure of others. Studies conducted in 1980 in central California on Peruvian pepper (Schinus molle) and its close relative Brazilian pepper (Schinus terebinthifolius) failed to determine why the former was spreading in California (Nilsen and Muller 1980a, 1980b). Instead the studies suggested Brazilian pepper was the more invasive species. Recently, Brazilian pepper has been found to be invasive in southern California, so perhaps studies of this type do have some predictive power.

Despite these puzzling cases, recent work has pointed to several factors that may help to predict which species are likely to be invasive. In two studies the best predictor was whether a species was invasive elsewhere (Panetta 1993, Reichard and Hamilton 1997). For example, if a species native to Spain is invasive in Western Australia, it is likely to be invasive in California and South Africa as well. Rejmnek and Richardson (1996) analyzed characteristics of twenty species of pines and found that the invasive species were those that produce many small seeds and that begin reproducing within their first few years. When they extended the analysis to a group of flowering trees, these same characters usually discriminated between invasive and non-invasive species. This study and several others also found plants with animal-dispersed seeds, such as bush honeysuckles or ligustrums, are much more likely to be invasive in forested communities (Reichard 1997, Reichard and Hamilton 1997). It has also been suggested that species capable of reproducing both by seed and by vegetative growth have a better chance of spreading in a new land (Reichard 1997).

Self-compatible species, with individuals that can fertilize themselves, have been thought more likely to invade, since a single plant of this type could initiate an invasion (Baker 1965). However, many self-incompatible species are successful invaders, including some with male and female flowers on separate plants. It is also thought that plants dependent on one or a few other species for pollination, fruit dispersal, or the uptake of nutrients from the soil are less likely to invade new areas unless these organisms are introduced at the same time. As a group, figs may be relatively poor invaders because, with few exceptions, each species is pollinated by a distinctive species of wasp that is in turn dependent on that species of fig. However, the edible fig's pollinator was introduced to promote fruit production, and now the species is invasive in parts of California. Other plant invasions may be promoted by introduced animals as well. For example, honeybees boost seed production of invaders whose flowers they favor (Barthell pers. comm.). In Hawaii feral pigs promote the spread of banana poka (Passiflora mollissima) and other species by feeding voraciously on their fruits and distributing them in their scat, often in soil they have disturbed while rooting for food.

It has also been suggested that species with relatively low DNA contents in their cell nuclei are more likely to be invasive in disturbed habitats (Rejmnek 1996). Under certain conditions, cells with low DNA contents can divide and multiply more quickly, and consequently these plants grow more rapidly than species with higher cellular DNA content. Plants that germinate and grow rapidly can quickly occupy such areas and exclude other plants following disturbance.

It is generally agreed that a species is most likely to invade an area with a climate similar to that of its native range, but some non-native species now thrive in novel conditions. An analysis of the distribution of non-native herbs of the sunflower and grass families in North America indicated that species with a larger native range in Europe and Asia are more likely to become established and to have a larger range here than species with small native ranges (Rejmnek 1995). It is thought that species with large native ranges are adapted to a variety of climate and soil conditions and are more likely to find suitable habitat in a new area. This ability to cope with different conditions can be attributed in part to genetic plasticity (genetic differences among individuals of a species) or to phenotypic plasticity (the ability of any given individual of some species to cope with a variety of conditions). Another factor that may help to determine whether a plant will invade a site is whether it is closely related to a native species (e.g., in the same genus). Plants without close relatives appear more likely to become established (Rejmnek 1996).

A species may be more likely to become established if many individuals are introduced at once or if they are introduced repeatedly. Introductions of many individuals may help to ensure that they will mate and produce offspring and that there will be sufficient genetic variability in the population for the species to cope with a wider variety of conditions. In addition, if sites where the species can successfully germinate and grow are limited in number, the chance that at least one seed scattered at random will land on an appropriate site increases with the number of seeds dispersed. Chance may be important in other ways. For example, species that happen to be introduced at the beginning of a drought may be doomed to fail, although they might easily establish following a return to normal rainfall. An early introduction may by chance include no individuals with the genetic makeup to thrive in an area, while a later introduction may include several.

There is often a time lag of many decades between the first introduction of a plant and its rapid spread. In fact, some species that rarely spread today may turn out to be troublesome forty, fifty, or more years from now. This makes it all the more urgent that we find some way of determining which species are most likely to become invasive so that we can control them while their populations are still small.

HABITATS AND COMMUNITIES MOST LIKELY TO BE INVADED

Another question that has long intrigued ecologists is why some areas appear more prone to invasion than others. Again, many hypotheses have been advanced, but we have few solid answers. There is even some question about which areas have suffered the highest numbers of invasions, since this may differ depending on the type of organism considered and which species are regarded as firmly established. A given area may be highly susceptible to invasion by one type of organism and highly resistant to another, while the situation might be reversed in other areas.

It is generally agreed that areas where the vegetation and soil have been disturbed by humans or domestic animals are more susceptible to invasion. In North America disturbed sites are commonly invaded by species native to the Mediterranean region and the fertile crescent of the Old World where the plants had millennia to adapt to agricultural disturbances. Changes in stream flows, the frequency of wildfires, or other environmental factors caused by dam building, firefighting, and other human activities may also hinder survival of native plants and promote invasion by non-natives. Nonetheless, reserves and protected areas are not safe from exotic species. In a 1996 poll, sixty-one percent of National Park Service supervisors throughout the United States reported that non-native plant invasions are moderate to major problems within their parks. In more than half (fifty-nine percent) of The Nature Conservancy's 1,500 preserves exotic plants are considered one of the most important management problems (TNC 1996a, 1997).

It is also safe to say that remote islands in temperate and tropical areas appear to be highly susceptible to invasions by non-native plants and animals. For example, nearly half (forty-nine percent) of the flowering plant species found in the wild in Hawaii are non-native as are twenty-five percent of plants on California's Santa Cruz Island (Junak et al. 1995). Most remote islands had no large native herbivores, so pigs, cattle, sheep, and other grazers introduced by humans found the native plants unprotected by spines or foul-tasting chemicals. Introduced grazers often denuded large areas of native vegetation, leaving them open to colonization by introduced species adapted to grazing. There is also speculation that islands, peninsulas such as southern Florida, and other areas with low numbers of native species or without any representative or distinctive groups are more prone to invasion. For example, there are no rapidly growing woody vines native to the Hawaiian Islands, where several introduced vines have become pests. Some researchers theorize that where such gaps exist, certain resources are used inefficiently if at all. Such open niches are vulnerable to invasion by non-native species capable of exploiting these resources. Other researchers reject this concept, maintaining that open niches are impossible to identify in advance and that when new species move in they do not slip into unoccupied slots but instead use resources that would have been used by organisms already present.

History likely also plays a large role in determining the susceptibility of a site to invasion. Busy seaports, railroad terminals, and military supply depots are exposed to multiple introductions. People from some cultures are more likely to introduce plants from their homelands when they migrate to new regions. In fact, colonization of much of the Americas, Australia, and other areas of the world by western Europeans and the plants and animals from their homelands may go hand in hand, the success of one species promoting the success of others. European colonists were followed, sometimes preceded, by animals and plants with which they were familiar and that they knew how to exploit. The plants and animals benefited in turn when these people cleared native vegetation and plowed the soil.

DEFINITIONS OF TERMS USED IN THIS BOOK

Native plants are those growing within their natural range and dispersal potential. They are species or subspecies that are within the range they could occupy without direct or indirect introduction and/or care by humans. Most species can be easily classed as either native or non-native using this definition, but

there are some gray areas. Natural ranges should not be confused with political or administrative boundaries. Bush lupine (Lupinus arboreus), for example, may be thought of as a California native, but its native range is only along the central and southern coasts of the state. It is not native along the north coast, where it was intentionally planted outside its natural range (Miller 1988, Pickart this volume). All hybrids between introduced or domesticated species and native species are also non-native.

Non-native plants are those species growing beyond their natural range or natural zone of potential dispersal, including all domesticated and feral species and all hybrids involving at least one non-native parent species. Other terms that are often used as synonyms for non-native include alien, exotic, introduced, adventive, non-indigenous, non-aboriginal, and naturalized. With rare exceptions, conservation programs are dedicated to the preservation of native species and communities. The addition of non-native species rarely contributes positively to this unless these plants alter the environment in ways that favor native species as do some grazers and biological control agents.

Natural areas are lands and waters set aside specifically to protect and preserve undomesticated organisms, biological communities, and/or ecosystems. Examples include most national parks, state and federally designated wilderness areas, and preserves held by private organizations such as The Nature Conservancy and the National Audubon Society.

Wildlands include natural areas and other lands managed at least in part to promote game and/or non-game animals or populations of native plants and other organisms. Examples include federal wildlife refuges, some national and state forests, portions of Bureau of Land Management holdings, including some areas used for grazing, and some lands held by private landowners.

Pest plant and weed are used interchangeably in this book to refer to species, populations, and individual plants that are unwanted because they interfere with management goals and objectives. Plants regarded as pests in some wildlands may not be troublesome elsewhere. For example, the empress tree (Paulownia tomentosa) is a pest in deciduous forests of the eastern United States, particularly in the southern Appalachians, but it is not known to escape from cultivation in California, where it is used as an ornamental landscape tree. Some species that are troublesome in agricultural or urban areas rarely, if ever, become wildland weeds. The term environmental weeds is used by many Australians (Groves 1991, Humphries et al. 1991b) to refer to wildland weeds, but few North American land managers or researchers use this term.

Invasive species are those that spread into areas where they are not native, according to Rejmnek (1995), while other authors define as invasives only species that displace natives or bring about changes in species composition, community structure, or ecosystem function (Cronk and Fuller 1995, White et al. 1993). Most wildland weeds are both invasive and non-native, but not all non-native plants are invasive. In fact, only a small minority of the thousands of species introduced to California have escaped cultivation, and a minority of those that have escaped spread into wildlands.

Management of Invasive Species >

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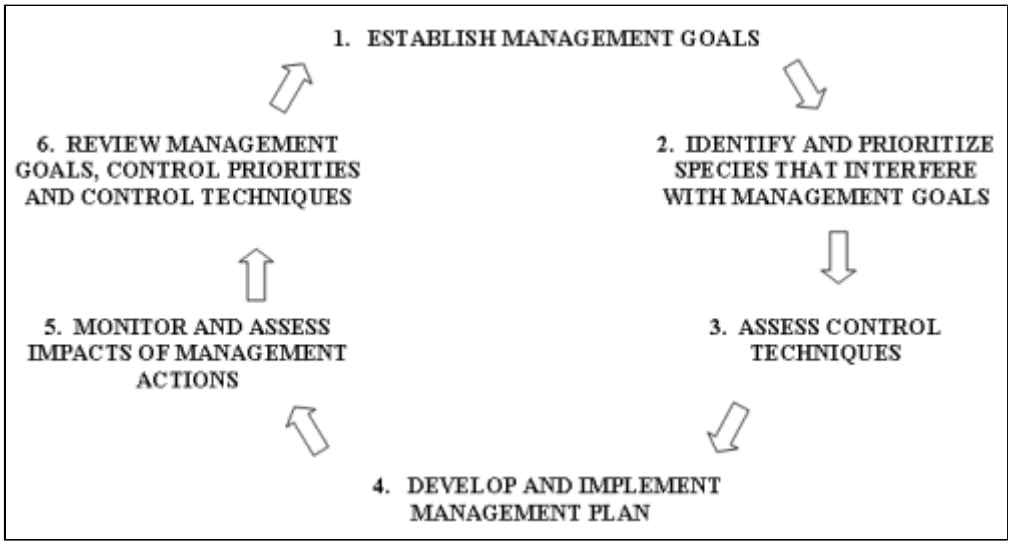
Invasive Plants of California's Wildland

Management of Invasive Species

Marc C. Hoshovsk and John M. Randall

Before embarking on a weed management program, it is important to develop a straightfor-ward rationale for the actions you plan to take. We believe this is best accomplished using an adaptive management approach as follows: (1) establish management goals and objectives for the site; (2) determine which plant species or populations, if any, block or have potential to block attainment of management goals and objectives; (3) determine which methods are available to control the weed(s); (4) develop and implement a management plan designed to move conditions toward management goals and objectives; (5) monitor and assess the impacts of management actions in terms of effectiveness in moving toward goals and objectives; and (6) reevaluate, modify, and start the cycle again (Figure 1). Note that control activities are not begun until the first three steps have been taken.



It is vital to establish management goals before embarking on any management activities. What is it you want to protect or manage? Is your objective to protect or enhance a certain species or community, preserve a vignette of pre-Columbian America, preserve certain ecosystem attributes, or preserve a functioning ecosystem? A weed control program is best viewed as part of an overall restoration program, so focus on what you want in place of the weed, rather than simply eliminating the weed. Keep in mind that the ultimate purpose of a weed control program is to further the goal of preserving a species, community, or functioning ecosystem.

In many cases it will be easy to identify species that degrade the site or threaten to do so. If impacts of a

species are not clear, you may need to monitor its abundance and effects on the natural community. Set priorities to minimize your total, long-term workload. This often means assigning highest priority to preventing new invasions and to quickly detecting and eliminating any new invasions that occur. High priority should also be assigned to the species with the most damaging impacts, to infestations that are expanding rapidly, and to infestations that affect highly valued areas of the site. Also consider the difficulty of control. It is of little use to spend time and resources to attack an infestation you have little hope of controlling.

Consider all control options available: manual, mechanical, encouraging competition from native plants, grazing, biocontrol, herbicides, prescribed fire, solarization, flooding, and other, more novel techniques. Each of these methods has advantages and disadvantages, and often the best approach is to use a combination of methods. Frequently, one or more methods will not be appropriate for a given situation because they do not work well, their use is objectionable to people in the area, or they are too costly. Herbicides may kill important non-target plants. Mechanical methods often disturb soil and destroy vegetation, providing ideal conditions for establishment of weedy species. It will often be best to employ two or more methods. For example, cutting and herbicides or prescribed fire and herbicides have been used successfully in combination in many weed control programs.

Biological control can be an extremely selective control tool, but there is some risk that control agents may attack desirable species. The best known example of a biocontrol agent attacking desirable species is that of Rhinocyllus conicus, a beetle first released to control non-native thistles in North America in the 1960s that was recently found attacking native thistles and reducing their populations at some sites (Louda et al. 1997).

Some native animals use invasive non-native species for food and cover and may have difficulty finding replacements if infestations are removed and not replaced with non-invasive native or introduced species. For example, huge numbers of monarch butterflies (Danaus plexippus) roost in some groves of Eucalyptus globulus in coastal California. In addition, elimination of plants in a natural area can be alarming to some people, particularly when herbicides are used, so it is important to explain the threats posed by the pest and the reasons why you chose the methods you did.

There is much room for improvement in control methods for many of the species described in this book. Readers may want to experiment with methods that may more effectively and efficiently control these invaders and promote native species.

The Bradley Method is a sensible approach to weed management (Bradley 1988, Fuller and Barbe 1985). In this approach, weed control is begun in portions of the site with the best stands of desirable native vegetation (those with few weeds) and proceeds slowly to areas with progressively worse weed infestations. This is similar to Moody and Mack's (1988) advice to attack outlying satellite weed populations first rather than larger, denser source populations. They based this advice on modeling work that indicated that the rate of spread of small satellite poplations is generally significantly higher than that of older, larger populations and that containing or eliminating the outliers saves time and effort in the long run. The Bradley Method dictates that the area under control should expand at a rate that allows previously treated areas to be monitored and kept in satisfactory condition. It also advocates the use of techniques that minimize damage to native plants and disturbance to the soil so that the natives can thrive and defend against reinvasion. This approach is particularly promising for small preserves or sites with access to large pools of volunteer labor. More detailed information on the Bradley Method is contained in Fuller and Barbe (1985).

PREVENTION

The most effective and efficient weed control strategies are preventing invasions by new plants species and quickly detecting invasions that occur so weeds can be eradicated or contained before they spread. The California Department of Food and Agriculture (CDFA) has long recognized this, and the state's Noxious Weed List gives highest priority to species that either are not yet established in the state or whose populations are not yet widespread. The state's native species will be better protected if new invaders are detected quickly and word of their discovery is communicated to those who can take action to prevent their spread, such as the staff at the CDFA Control and Eradication Branch or Plant Pest Diagnostics Branch.

There are already at least 1,045 non-native plant species established in California (Randall et al.1998), and more continue to arrive and become established. If allowed to spread, some of these new species could impact native species and communities as severely as yellow starthistle and tamarisk do now. Preventing or stopping just one new invasive weed would be of greater conservation benefit in the long run than far more costly and difficult efforts to control an already widespread pest.

Taking precautions in normal resource management activities can halt or slow the establishment and spread of weeds in a given area. Wise precautions include: removing seed sources from roads, trails, rights-of-way, watercourses, and other dispersal routes; closing unnecessary roads and trails where possible; planning work projects to minimize soil disturbance and reestablish vegetation as quickly as possible where disturbance does occur; limiting the use of construction materials such as gravel, fill, mulch, straw, and seed mixes that may carry weeds or buying from suppliers who guarantee their products are weed-free; washing vehicles and equipment to remove weed seeds and other propagules before they are used in another area; follow-up monitoring of work sites to detect new weed populations while they are still small and easily controlled; and public education and outreach regarding the importance of weed detection and prevention of invasion.

ERADICATION

Eradication is the complete elimination of a species from a given area. The great appeal of eradicating a weed is, of course, that once the project achieves success no more work is required and the species cannot spread unless it is re-introduced. Unfortunately, it is rarely possible to eradicate an established weed from a large area. In fact, the history of CDFA's eradication projects indicates that there is little likelihood of eradicating a species from California once it has spread to a few tens of acres in the state.

It may be possible to eradicate a weed from a given area, such as a preserve or national park if it has not yet become widespread there, but it is likely to re-invade from adjacent lands unless there is some barrier that will prevent it from doing so. Eradication is most likely when the species has just begun to establish in a new area, which underscores the importance of efforts to detect new invaders at national, state, and local levels.

PHYSICAL CONTROL

Physical methods of weed control generally are labor intensive and often are used for small populations or where other control methods are inappropriate, such as near sensitive water supplies. Nonetheless, physical methods have been used successfully by volunteer groups and paid workers to control weed infestations on several large sites in California (e.g., Pickart and Sawyer 1998). Physical methods can be highly selective, targeting only the pest species, but they can also disturb the soil or damage nearby vegetation, thereby promoting germination and establishment of weedy species. Physical control methods may also produce large amounts of debris, disposal of which is sometimes difficult.

Physical control methods range from manual hand pulling of weeds to the use of hand and power tools to uproot, girdle, or cut plants. Two companies produce tools specifically for pulling shrubs such as scotch broom, tamarisk, and Russian olive. The Weed Wrench (see Resources section) and the Root Jack (see Resources section) are lever arms with a pincher or clamp at the bottom that grips the plant stem. Once the stem is secured, the user leans back, tightening the clamp in the process. After a little rocking, the entire plant comes up, roots included (Hanson 1996). Other tools for weed control, including girdling knives, axes, machetes, loppers, clippers, chainsaws, and brush cutters, are available from hardware stores and gardening and forestry supply companies. Various attachments are available for bulldozers and tractors to clear and uproot woody plants. Brush rakes or blades may be mounted on the front of the bulldozer, and brushland disks or root plows may be pulled behind. Mowing can prevent seed formation on tall annual and perennial weeds and deplete food reserves of shoots and roots. Unfortunately, repeated mowing can favor low-growing weeds or damage desirable native species (Ashton and Monaco 1991).

Prescribed Fire

Fire can be an effective means of reducing weed infestations, particularly for shrub by weeds and in native communities that evolved with fire. Fire may sometimes be the only element necessary to give native species a chance to recover. Fire may also be used to eliminate old vegetation and litter in areas infested with perennial herbs such as fennel (Foeniculum vulgare) or leafy spurge (Euphorbia esula) prior to treating the area with herbicide. This allows more herbicide to reach the living leaves and stems of target plants, potentially enhancing its effectiveness. Fire can also be used to induce seeds of some species to germinate so the seedbank can be flushed and the resulting seedlings can then be killed with another fire or some other method (e.g., Bossard 1993).

Conducting a prescribed burn is not a simple or risk-free operation. Managers considering prescribed burning should be trained and certified and should work close ly with the local office of the California Department of Forestry and Fire Protection to ensure safe, effective, and legal burns. Good logistical planning, coordination of work teams, careful timing with respect to weather (winds, moisture conditions), co or di na tion with air quality agencies, and attention to other details are required to carry out an effective and safe burn. In most parts of California it is necessary to address air quality concerns and to obtain permission from the regional air quality board. Escaped fires are costly and can be disastrous.

Prescribed fires may promote certain invasive, non-native species, and so should be used with caution. Non-native annual and biennial species, such as cheat grass (Bromus tectorum) and bull thistle (Cirsium vulgare), are most likely to be favored in the years immediately following a burn and in repeatedly burned areas. Hot fires can also sterilize the soil, volatilizing important nutrients and killing microorganisms on which native plants rely. Removal of vegetation by fire can also increase soil erosion and stream sedimentation. Construction of firebreaks and associated soil disturbance can increase erosion and provide a seedbed for invasive weeds.

Blowtorches and flamethrowers can also be used to burn individual plants or small areas. This method has been used with some success on thistles in several areas. Flamethrowers have also been used to heat-girdle the lower stems of shrubs such as scotch broom (Cytisus scoparius). This technique has the advantages of being less costly than basal and stem herbicide treatments and suitable for use during wet weather. On the other hand, it is time-consuming and not viable in areas where wildfire is a danger.

Flooding and Draining

Prolonged flooding can kill plants that infest impoundments, irrigated pastures, or other areas where water

levels can be controlled. This method may be even more effective if plants are mowed or burned before flooding. Spotted knapweed (Centaurea maculosa) is sensitive to flood ing, and its populations can be reduced by flood irrigation in pastures. Flooding may also help to control non-natives by promoting the growth and competitive ability of certain native species in some situations. Unfortunately, flood ing will not kill the seeds of many target species.

Draining water from ponds and irrigation canals may control aquatic weeds such as reed canary grass (Phalaris arundinacea) (Schlesselman et al. 1989). Drainage can be conducted in different ways, including seasonal, intermittent (within-season), or par tial draw downs (McNabb and Anderson 1989).

Mulching

Mulching excludes light from weeds and prevents them from photosynthesizing. Commonly used mulches are hay, manure, grass clippings, straw, sawdust, wood chips, rice hulls, black paper, and black plastic film. The most effective mulches are black paper or plastic because of their uni form coverage. Particle mulches cannot prevent all weeds from breaking through (Schlesselman et al. 1989). Mulch materials and application can be expensive and may be suitable only for small infestations. Particle mulches should be weed-free to avoid introduction of other weeds.

Soil Solarization

Soil solarization is a technique for killing weed seeds that have not yet germinated. A clear polyethylene plastic sheet is placed over moist soil and kept in place for a month or more. The incoming solar radiation creates a greenhouse effect under the plastic, increasing soil temperatures. High temperatures kill some seeds outright and weaken others, making them more susceptible to attack by pathogens (Schlesselman et al. 1989).

BIOLOGICAL CONTROL

Biological control, or biocontrol, involves the use of animals, fungi, or other mi crobes that prey upon, consume, or parasitize a target species. Target species are fre quent ly non-natives whose success in new environments may be due in part to the absence of their natural predators and pathogens.

Classical biological control involves careful selection and introduction of one or more natural enemies to the target species' new habitat to reduce target populations. Successful control programs of this kind result in permanent establishment of the control agent or agents and permanent reduction in target species populations. Such programs are not designed to eliminate the target species completely, and it may take repeated releases to ensure the establishment of an agent. It may take years or decades before their effects are obvious. Some of the greatest strengths of classical biological control are that once an agent is established it will last indefinitely and it may spread on its own to cover most or all of the area infested by the weed, generally without additional costs. On the other hand, these strengths can become liabilities if the agent begins to attack desirable species as well as the pest it was introduced to control. Biocontrol researchers take great pains to locate and use agents that are highly specific to the targeted weed. This contributes to the high cost and long time required for development and approval of new biological control agents. Several of the species covered in this book are the subjects of ongoing classical biological control programs.

As opposed to classical biocontrol, inundative or augmentative biocontrol involves mass releases of pathogens whose effects on the target are normally limited by their inability to reproduce and spread. Inundative biocontrol agents that are non-native and/or not target-specific may be sterilized or otherwise

rendered incapable of establishing permanent populations before they are released. Because they do not become established, they must be reared and released again each time weed populations erupt. There have, however, been instances in which mistakes or back mutations allowed some of these species to establish permanent wild populations.

The USDA must approve biocontrol agents for use. Approved biological control agents have been studied, and their host specificity determined. Accidentally introduced species have unknown host species, are not permitted for distribution, and should not be redistributed. If you have questions about any potential biocontrol agents, contact the CDFA Biological Control Program (see Resources section).

Competition and Restoration

The use of native plants to outcompete alien weeds is a frequently overlooked but potentially powerful technique. Sometimes the natives must be planted into the habitat and given some care until they are well established. This may be appropriate where a native forest community is to be reestablished in an old field currently occupied by a thick cover of alien grasses and forbs. Reseeding with native species also works well in some grasslands. In other cases all that may be required is time; the native community may reestablish itself once human-caused disturbance ceases. Even in these cases, it may be important to locate and remove certain weeds capable of hindering succession. You can also enhance other weed control methods by encouraging competition from native species.

Ideally, seeds or cuttings used in restoration should be collected on the site or from adjacent properties. Unfortunately, in many cases the only available or affordable seeds and plants are from distant or unidentified populations. Potential impacts of using seeds and plants collected at distant sites include project failure if genotypes used are unable to survive conditions on the site, introduction of diseases, and loss of genetic diversity through overwhelming or contaminating locally adapted genotypes.

Grazing

Grazing animals may be used to selectively control or suppress weeds, but grazing is also known to promote certain invaders in some circumstances. Cattle, sheep, goats, geese, chickens, and grass carp have been used to graze undesirable species at sites around the nation. Often grazing must be continued until the weed's seedbank is gone, as the suppressed plants may otherwise quickly regain dominance. Another drawback to using grazing animals is that they sometimes spread weed seeds in their droppings.

CHEMICAL CONTROL

Herbicides are chemicals that kill or inhibit plant growth. They can be extremely effective tools when used to eliminate certain species. They can also be dangerous and should be used only after careful consideration of other options and only with extreme care. Each species treatment in this book provides specific information on the herbicides, rates, and times that have been found most effective against that species. However, the effectiveness of a given treatment may vary with climate and environmental conditions, and some populations of a given species may be more tolerant of, or even resistant to, a particular herbicide than other populations of the same species. It may be necessary to conduct trials to identify the most effective techniques for controlling a particular problem species.

The most important safety rule for herbicide use is to read the label and follow the directions. Applicators must wear all protective gear required on the label of the herbicide they are using. It is also important to adopt or develop protocols for storing, mixing, transporting, cleaning up, and disposing of herbicides and for dealing with medical emergencies and spills.

California's programs to regulate pesticides and pesticide applicators are regarded as the most stringent in the nation and as such are the standard against which many other states measure their programs. California's Department of Pesticide Regulation reviews health effects of pesticides independently of the federal Environmental Protection Agency and has more stringent registration requirements. California also has the most stringent pesticide use reporting requirements. Agricultural pesticide use is broadly defined and includes applications made in nature preserves, parks, golf courses, and cemeteries and along roadsides. Such applications are regulated by the CDFA, and county agricultural commissioners' offices enforce the regulations. Pest control businesses, agricultural pest control advisors, and pest control aircraft pilots must register in each county where they operate. Anyone who wants to buy a restricted pesticide must have a permit from the commissioner's office. All agricultural pesticide use must be reported monthly to the commissioner's office. Home-use pesticides (those purchased over-the-counter in small volumes) are exempt. There are also more detailed requirements for applicator training and protective gear. Inspectors from county commissioners' offices conduct thousands of compliance inspections every year and have the authority to halt pesticide applications if they believe an applicator's safety is in danger or the pesticide is likely to drift off-site. Contact your county agriculture commissioner's office for details on training and other regulations before purchasing or applying herbicides. County agricultural agents can answer questions about both wildland and agricultural uses of herbicides, as can certified herbicide applicators.

Environmental risks posed by herbicide use include drift, volatilization, persistence in the environment, groundwater contamination, and harmful effects on animals. Drift and resulting death or damage to non-target plants may occur when herbicides are applied as a spray; chances of drift increase with decreasing size of spray droplets and increase with increasing wind speeds. Volatilization and subsequent condensation on non-target plants resulting in their death or damage is another risk of herbicide use. Some herbicides are much more likely to volatilize than others, and likelihood of volatilization increases with increasing temperature. Some herbicides are more persistent in the environment and thus have a greater opportunity for harmful effects. Most herbicides will decompose more rapidly with increasing temperature and soil moisture, and some are decomposed by ultra-violet light. Chances of groundwater contamination generally increase with increasing solubility and persistence of the herbicide, increasing porosity of the soil, and decreasing depth to the water table. Herbicides with potential to cause direct harm to animals (e.g., diquat) are rarely used in natural areas. Animals may, however suffer from indirect impacts if, for example, their food plants are killed.

In order to minimize these environmental risks, look for compounds that can be used selectively (to kill one or a few species); that degrade rapidly under conditions found at the site; that are immobilized on soil particles and unlikely to reach groundwater; that are non-toxic to animals; and that are not easily volatilized.

Also choose an application method that minimizes risks of harming non-target plants and environmental damage. Possible application methods include: spraying on intact, green leaves (foliar spray); spot application (usually from backpack or handheld sprayer); wick application; boom application (from a boom mounted on a vehicle or aircraft); single spot or around the circumference of the trunk on intact bark (basal bark); cuts in the stem (frill or hack and squirt); injected into the inner bark; cut stems and stumps (cut stump); spread in pellet form at the plant's base; and sprayed on the soil before seeds germinate and emerge (pre-emergent).

Mix a dye with the herbicide so applicators can see which plants have been treated and if they have gotten any on themselves or their equipment. Some pre-mixed herbicides include a dye (e.g., Pathfinder II® includes the active ingredient triclopyr, a surfactant and a dye). Ester-based herbicides such as Garlon4® require oil-soluble dyes such as colorfast purple, colorfast red, and basoil red (for use in basal bark

treatments), which are sold by agricultural chemical and forestry supply companies. Clothing dyes such as those produced by Rit® will work in water-soluble herbicides such as Garlon3A®, and they are inexpensive and available at most supermarkets and drugstores.

Detailed information on herbicides is available in the *Weed Science Society of America's Herbicide Handbook* (Ahrens 1994) and *Supplement* (Hatzios 1998). This publication gives information on nomenclature, chemical and physical properties, uses and modes of action, precautions, physiological and biochemical behavior, behavior in or on soils, and toxicological properties for several hundred chemicals (see Resources section). Critical reviews of several common herbicides are available at a small charge from the Northwest Coalition for Alternatives to Pesticides (see Resources section).

Beyond this book, additional information and training on weeds and their control can be found by contacting local universities, extension agents, county weed and pest supervisors, and the California Department of Food and Agriculture. The California Exotic Pest Plant Council can direct readers to other local experts on weeds. The Bureau of Land Management offers an Integrated Pest Management and Pesticide Certification course in Denver, Colorado, and the Western Society of Weed Science offers a Noxious Weed Management Short Course in Bozeman, Montana.

View plant list by:
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Arundo donax Distribution and Impact Report

March 2011

Agreement No. 06-374-559-0
State Water Resources Control Board

Prepared by: **California Invasive Plant Council**

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This report and spatial data set (GIS geo-database) are available for download at:
http://www.cal-ipc.org/ip/research/arundo/index.php

or

http://www.cal-ipc.org/ip/mapping/arundo/index.php

The spatial data set is also viewable at the DFG BIOS web site:
http://bios.dfg.ca.gov/

BIOS project data sets are named:
Invasive Plants (Species) - Central_So. Cal Coastal Watersheds [ds645]
Invasive Plants (Prct Cover) - Central_So. Cal Coastal Watersheds [ds646]

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EXECUTIVE SUMMARY

Arundo donax (giant reed, giant cane) is a large non-native grass found in many coastal watersheds in central and southern California. It is an extremely problematic invasive plant characterized by extensive infestations and a range of severe impacts to both ecosystem and human infrastructure. Even with a significant increase in research and studies on *Arundo* over the past ten years, no large-scale mapping efforts have been completed and no comprehensive analysis of impacts has occurred. This report set out to accomplish these goals within the study area (Monterey to San Diego), as well as to examine watershed-based capacity to implement control programs. Over $70 million dollars have been spent to date controlling *Arundo* within the study area. It is important to document where this work has occurred and assess the resulting reduction in impacts.

Arundo was mapped at a fine scale using high-resolution aerial imagery and field verification across the study area. *Arundo* acreage prior to the initiation of control programs was 8,907 acres (gross). This is a significant area, but is much less than had been speculated by many in the field. Over 34% of this acreage (>3,000 acres) has been treated to date, with two highly invaded watersheds achieving over 90% control. Many other watersheds have more than 50% control. This indicates that watershed-based control is a realistic objective.

Mapping data show that *Arundo* is most abundant in large low-gradient river areas, where it averages 13% cover. Within specific reaches, there are sections greater than a half-mile in length that have over 40% *Arundo* cover.

This study carried out additional field work to characterize *Arundo* stands and infestations. This work verifies relationships explored by other studies, as well as generating new findings. *Arundo* within the study area was taller (average 6.5 m, maximum 9.9 m) than many previous studies reported. Biomass was confirmed as being extremely high per meter (15.5 kg/m^2). Leaf area was extremely high at 15.8 m^2/m^2 (LAI), which is consistent with other studies in California, but higher than reported in Texas where stands are shorter. Mature stands comprise most of the *Arundo* mapped in the study area. The leaf area of secondary branches is the majority of the leaf area in mature *Arundo* stands, based on leaf area and cane density of new and old canes.

This abundance of growth and cover generates many abiotic and biotic impacts. Mapping *Arundo* at high resolution allows examination and quantification of a number of these specific impacts, including water use, fluvial processes, fire, and listed species.

Spatial data, used in conjunction with stand leaf area measurements and published leaf transpiration rates, generated an *Arundo* stand-based water use value that was extremely high (40 mm/day) compared to most other plants. There are very few studies that have measured *Arundo* water use. Our results agree with one paper (from a study in California, 41.1 mm/day) and are higher than a study in Texas on the Rio Grande (9.1 mm/day). When translated into potential water savings per year from restoration, net savings of 20 ac-ft/yr was estimated. This estimate includes adjustments for replacement vegetation, as well as a reduction of *Arundo* water use to bring it into alignment with other forms of vegetation that consume large amounts of water. This is a large potential water use reduction that could have significant implications for both the ecosystem and human water use.

This study expended significant effort in broadening the understanding of how *Arundo* is impacting geomorphic and fluvial processes. These abiotic processes are particularly significant because they regulate the entire riparian ecosystem. Any changes to fluvial processes have the potential for system-wide ramifications. Large stands of *Arundo* were found to functionally increase bed elevations by five feet (based on field investigation and model re-calibrations following flood events in 1998). In addition to this *Arundo* stand-based modification of elevation, a high roughness coefficient for flows higher than

five feet was supported. This results in a significant reduction in flow capacity and represents an alteration of how *Arundo* stand function is characterized during flow events. New modeling was carried out for this study under four scenarios. Results indicated that *Arundo* stands constrain flows to the low-flow and bar-channel portions of the river profile. Over time this results in a deepening of the channel and a transformation of the system from a braided unstable channel form to a laterally stable single-thread channel form. Mapping of geomorphic forms on the larger systems documented that *Arundo* stands occur predominantly in the floodplain and terrace forms, and are nearly absent from the low-flow and active channel forms. Additional modeling using stream power indicated that over-vegetated floodplains and narrow, stable deep channels result in modifications of sediment transport during flow events. Sediment appears to be lost (removed) in channel areas and gained (aggregated) on floodplains/terraces with *Arundo* stands on them. These impacts to riverine fluvial processes change vegetation succession following flow events, sediment transport budgets, and the geomorphic structure of the habitat, all of which alter the ecosystem in a un-natural way. Such alterations are usually negative for native species that are adapted to pre-invaded ecosystem function. One system has had extensive *Arundo* control since the late 1990's, allowing examination of post-control system response. Active channel areas widened and portions of the floodplain with active flows increased. These are important post-control responses to flood events, indicating a 'normalization' of fluvial processing is occurring.

A historic review of large riparian systems using spatial mapping indicated that floodplain and low terrace forms have become much more vegetated on most systems over the last eighty years. This transformation has been observed in other systems, such as the Rio Grande, and is a result of water importation and a 'compression' of riverine systems. This dense vegetation is both native woody vegetation and *Arundo*. Mature *Arundo* stands, however, have much higher stem density and biomass per unit area, generating the observed flow reduction effects noted above. The historic analysis also showed a significant decline in acreage over time, on most systems, of the active channel area (low-flow and bar-channel areas with little vegetation). Most riverine systems have also become significantly compressed (narrower) over time as terrace and floodplain forms have been permanently separated from the river system by levees that protect both urbanization and agricultural land use. *Arundo* impacts to bridges, levees, and beaches were also described and documented. These impacts are from *Arundo* biomass and reduced flow capacity (*Arundo* stands and sediment trapping).

Impacts associated with fire were thoroughly explored with significant new findings. *Arundo*'s high biomass and stored energy were established based on field and published data. In addition to a high fuel load, *Arundo* stands have a tall, well ventilated fuel structure containing dry fuels throughout the year. This study specifically documented that transient encampments and highway overpasses are key ignition sources for fires that start in *Arundo*. This is a new class of fire events that are fully ascribed to *Arundo*. This study documented that fires are now starting in riparian areas, which did not occurred historically. Fire events were mapped over an eight year period on the San Luis Rey watershed. It was also demonstrated that *Arundo*-initiated fires are occurring on other watersheds. *Arundo*-initiated fires also burn un-invaded riparian habitat and fire suppression impacts were spatially quantified. Over a ten year period *Arundo*-initiated fires were estimated to impact 557 acres of *Arundo* and 732 acres of riparian habitat. Wildfires also burn *Arundo* stands. These fire events burned 544 acres of *Arundo* over a ten year period for the study area. *Arundo* stands that burn during wildfires burn hotter than native vegetation due to the high fuel load, and are very likely conveying fires through riparian corridors. The Simi fire in the Santa Clara watershed was one of the clearest examples of an upland wildfire spreading across a riparian zone dominated by *Arundo*, and then igniting fuels on a separate mountain range. *Arundo*-initiated fires and wildfires together burned 12% of *Arundo* acreage in a ten year period within the study area. The high acreage of burned *Arundo* and native vegetation, as well as suppression impacts, has significant impacts on the ecosystem and listed species.

Impacts to plants and animals were explored by examining 22 federally listed species from five taxonomic groups. Detailed biological assessments examining habitat, life history, distribution and abundance were carried out for these species. Listing documents and spatial occurrence data were used to evaluate *Arundo* impacts on each species. An *Arundo* impact score was calculated for each listed species. An additional metric examining the specific co-occurrence of *Arundo* and each species was derived for each watershed. The impact rank and the co-occurrence rank were then multiplied to generate an overall cumulative impact score. From this analysis, the taxonomic group, individual species, and watersheds were ranked based on scores. Avian and fish species were found to be the most impacted by *Arundo*, with amphibians also ranking high. Plants and mammals ranked very low in cumulative scoring. The two most severely impacted species were least Bell's vireo and the arroyo toad, followed by the southwestern willow flycatcher, southern steelhead, and tidewater goby. Several species that occur in estuary and beach habitat near river mouths also had impacts from *Arundo* identified. The watersheds with highest impacts to federally listed species were the Santa Margarita, Santa Ana, San Luis Rey, and Santa Clara watersheds. Three of the four watersheds have the oldest and most complete *Arundo* control programs in the study area.

A rudimentary cost-to-benefit analysis was also completed using *Arundo* spatial data. Cost of *Arundo* control was determined based on completed control work on numerous watersheds over the past 15 year. The $71 million expended to control 2,862 acres generates a per acre control cost of $25,000. Benefits derived from controlling *Arundo* are based on each impact (water use, sediment trapping, flood damage, fire, habitat, and beach debris). Valuations were conservative and a rationale was given for each impact class. Impacts that were difficult to quantify or value were not included. The benefit to cost ratio for *Arundo* at its pre-control distribution level was 1.94 to 1 ($380,767,747 to $196,481,844). Current *Arundo* distribution (reflecting 3,000 acres of control to date) generates a similar benefit to cost ratio of 1.91 to 1 ($239,461,270 to $124,934,194). A roughly 2:1 return ratio on funds invested is a significant benefit, particularly considering the additional impacts that were not assessed (due to complex valuation), as well as the conservative valuation of factors that were included.

The report concludes with a discussion of treatment priorities that include: continuing treatments of areas that have already been treated (protecting initial investment), controlling *Arundo* on watersheds where it is not abundant but could spread (early control is more cost effective), and prioritization of watersheds with large *Arundo* infestations. Programs are encouraged to use a top-down watershed implementation approach (starting in the upper reaches of the watershed), particularly if the watershed is heavily invaded. The watershed priority rankings are based on four impact classes (water use, geomorphology, fire, and listed species) and two classes of program capacity (experience and regulatory permits). Watershed-based control is most effective when there is a lead organization that can implement comprehensive control, acquire permits, obtain right of entry agreements, and secure funding.

1.0 INTRODUCTION

Arundo donax (giant reed, giant cane) is one of the largest grass species. A clonal plant that grows in dense stands, it is found in many subtropical and warm-temperate areas of the world. It is thought to be native to eastern Asia (Polunin & Huxley 1987), but the precise extent of its native distribution is unknown. *Arundo* has been introduced around the world as an ornamental/crop species, for erosion control, and for the production of reeds (musical instruments, construction, paper and pulp). It has become invasive in many places throughout the world, primarily in riparian habitat. Where *Arundo* invades, it often forms dense stands, resulting in a wide range of impacts to natural ecological systems (biotic and abiotic) as well as human created infrastructure. The Invasive Species Group of the World Conservation Union includes giant reed in its top 100 Worst Invaders of the World (Lowe et al. 2000).

Arundo was first introduced to California by Spanish colonists in the 1700s (Newhouser et al. 1999), and in the early 1800s for erosion control in drainage canals (Bell 1998). It is now a major threat to riparian areas in California, as well as other southwestern states. Two portions of the United States have particularly significant *Arundo* infestations (characterized as >40% of riverine habitat over areas longer than a river mile): coastal California (Monterey to San Diego) and the Rio Grande (Texas).

This study is the first research to take a broad range of impacts caused by the invasive non-native plant *Arundo*, and apply them to a significant portion of the plant's distribution in California. This was not previously possible because detailed *Arundo* spatial distribution data did not exist prior to this study. Mapping *Arundo* in high resolution from Salinas, California to the Mexican border in all coastal watersheds was the initial task. This captures *Arundo*'s primary distribution in coastal California.

There has been a significant increase over the past ten years in studies examining *Arundo*'s impacts and quantifying aspects of its productivity, structure, physiology, genetics and reproduction. We compiled information, and completed additional research and data collection to fill gaps in understanding or documentation. New research was primarily related to fluvial/geomorphic impacts, leaf area, biomass water use and fire impacts. Data collected also allowed verification that relationships described in the literature, such as biomass and structure data, applied to the study region. Many studies and reports have alluded to impacts related to fire, but this study explicitly quantifies fires that started in *Arundo*, as well as wildfires that burned *Arundo*, over the entire study area. Impacts to 22 federally-listed sensitive species were examined using spatial data for the species, spatial data for *Arundo*, and current understanding of the biology of the species. From this the magnitude of impact on listed species from *Arundo* is described and scored. Scores of cumulative impact are examined by species, taxa group, and watershed. To date, this is the largest suite of species over the broadest area to examine *Arundo* impacts.

This report presents the entire range of impacts over the entire study area, as well as each watershed. A coarse Cost Benefit Analysis is presented and made possible due to the explicit quantification based on acreage for each watershed, and the range of impacts that were quantified (with a cost assigned to them based on previous studies).

Finally this report provides a review of each watershed's *Arundo* control program, including: completed work to date, status of permits allowing work, and the identification of the lead entities carrying out the work. The spatial data set and impact quantification is used to highlight priority watersheds and actions. This is also examined in the context of current capacity to implement *Arundo* control projects. The need to implement sustainable watershed control programs with eradication as an obtainable goal is explored, as well as an evaluation of the challenges in completing programs, which is a process that can take over 20 years.

2.0 *ARUNDO* BIOLOGY

2.1 Physiology

Arundo is generally a hydrophyte, achieving its greatest growth near water. However, it adapts to many different habitat conditions and soil types, and once established is drought tolerant and able to grow in fairly dry conditions (Lewandowski et al. 2003). It can also tolerate saline conditions (Perdue 1958, Peck 1998), and in California it is found growing along the edges of beaches and estuaries (Else 1996). *Arundo* is a C_3 plant, but it shows the unsaturated photosynthetic potential of C4 plants, and is capable of very high photosynthetic rates (Papazoglou et al. 2005, Rossa et al. 1998).

Arundo's stems and leaves contain a variety of noxious chemicals, including triterpenes and sterols (Chandhuri & Ghosal 1970), cardiac glycosides, curare-mimicking indoles (Ghosal et al. 1972), and hydrozamic acid (Zuñiga et al. 1983), as well as silica (Jackson and Nunez 1964). These likely reduce herbivory by most native insects and grazers where *Arundo* has been introduced (Miles et al. 1993, Zuñiga et al. 1983).

Arundo responds strongly to excess nitrogen from anthropogenic and fire sources (Ambrose & Rundel 2007). Most studies on growth and transpiration indicate that water availability is the primary factor affecting metabolic rates and productivity (Abichandani 2007, Perdue 1958, Watts 2009). *Arundo* generally has a shorter stature and is less productive when there is limited water availability, such as on higher elevation riparian terraces or drier portions of the watershed. This observation is based on the distribution of these less productive stands on many watersheds within the study area.

2.2 Genetic variation

Isozyme and RAPD analyses of *Arundo* on the Santa Ana River in California indicated genetic diversity comparable with those in the literature for clonal species, supporting asexual reproduction as the primary means of *Arundo* spread (Khudamrongsawat et al. 2004). Samples were also taken from one out-group on a separate watershed (Aliso Creek, Orange County). Several phenotypes were dominant and were found spread along the Santa Ana River. These dominant phenotypes were also found in the out-group population, possibly due to spread by humans. The moderate levels of genetic diversity in *Arundo* are likely explained by multiple introductions over time, with early introductions as a building material, and more recent use for erosion control and as a landscape ornamental (Bell 1997; Frandsen 1997). The moderate level of genetic diversity and the asexual mode of reproduction increases the potential for application of biological agents for control of *Arundo* (Tracy and DeLoach 1999).

2.3 Physical Structure

For this study, data were collected from fourteen *Arundo* plots on five watersheds (Figure 2-1). A variety of measurements were taken, and canes were collected from these plots. These data are presented in this section, section 2.4, and Chapter 4.

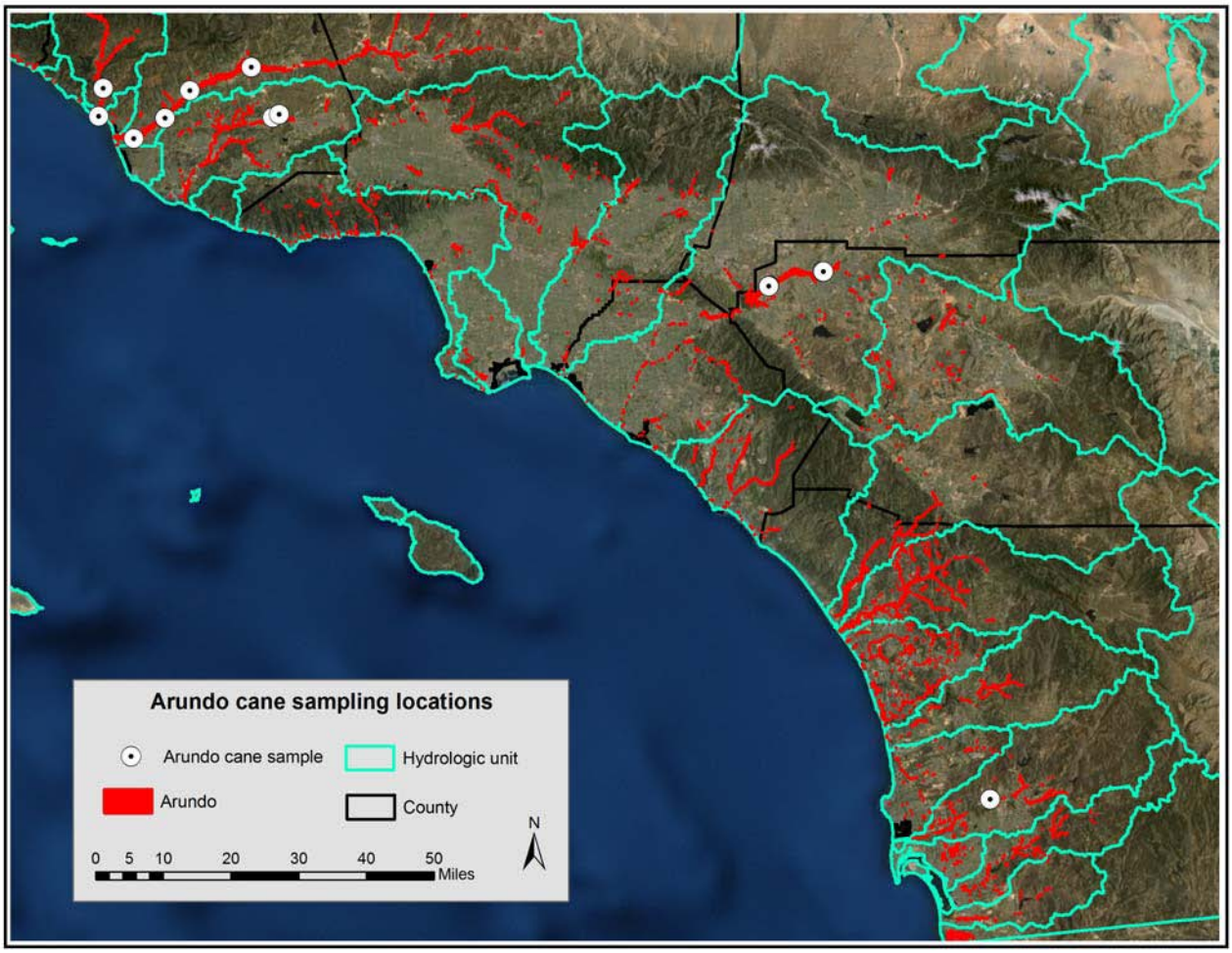


Figure 2-1. *Arundo* sampling locations in southern California.

Arundo is a clonal organism, so the plant will be examined at both the individual level (ramet) and at the stand scale (colony).

<u>The individual plant or ramet:</u>

Arundo is one of the largest herbaceous grasses, and is often mistaken for a bamboo (Figures 2-2 to 2-6). It is a tall, erect, perennial grass, 2 to 8 m high (Perdue 1958). Canes frequently attain lengths of 8 to 9 m in coastal California, as this study shows (Table 2-1). The main stems, or culms, are hollow with walls 2 to 7 mm thick and are divided by partitions at the nodes. In this study the culms were on average 23.8 mm wide (measured between nodes one and two). First year canes are un-branched, and in the second year single or multiple lateral secondary branches may form from the nodes (Figures 2-2 to 2-3) (Decruyenaere & Holt 2005). The secondary branches are a much smaller diameter than the main canes (typically <10mm versus >20 mm). In canes that are two years and older, the secondary branches bear a significant proportion of the leaves (this study). These secondary branches can themselves give rise to third degree and even fourth degree branches, but this is uncommon (Decruyenaere & Holt 2005, this study). Once a cane generates secondary branches these become the primary area of new growth, and continued growth of the main cane (leader) is slow to non-existent (Decruyenaere & Holt 2005).

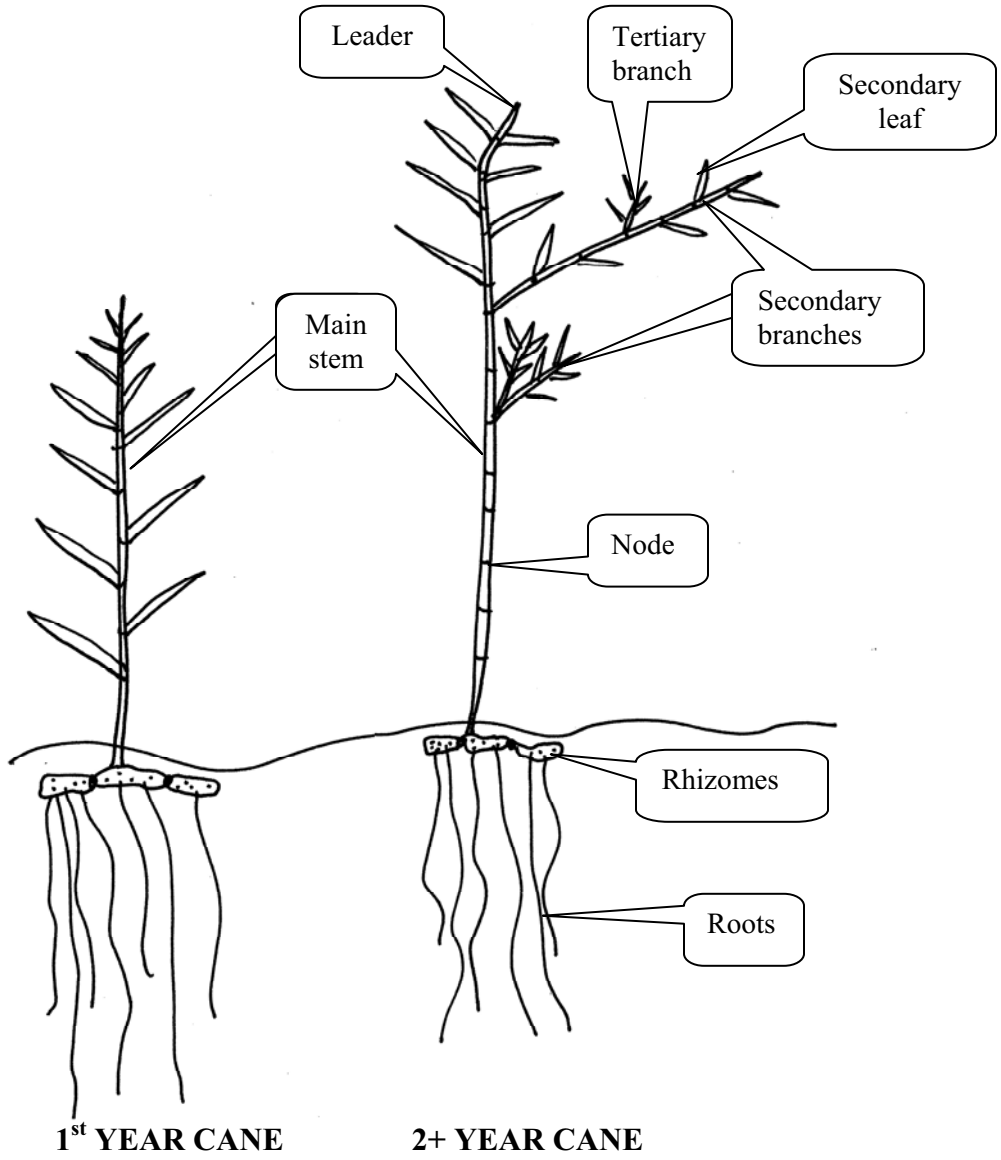


Figure 2-2. Illustration of *Arundo* structure for first year and 2+ year old stems. Older canes would have many secondary braches. Drawing by J. Giessow.

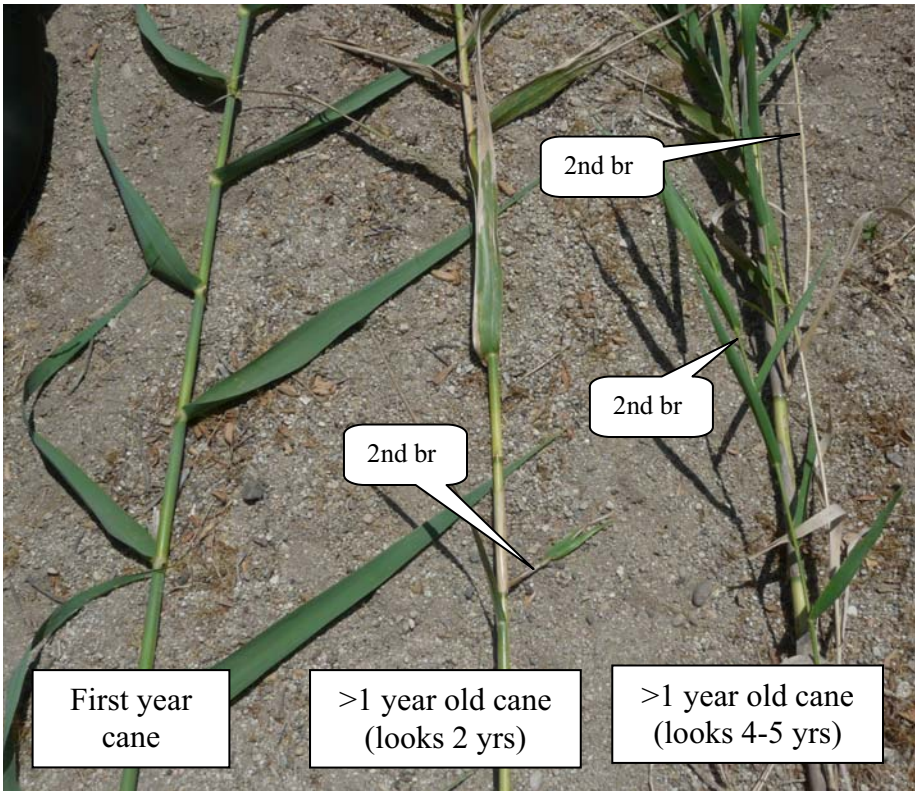


Figure 2-3. First year and >1yr year old *Arundo* canes, showing leaf and branching structure. First year canes have only cauline leaves. Older canes have an increasing number of secondary branches with leaves on them, and leaves on the old leader are often damaged and dying.

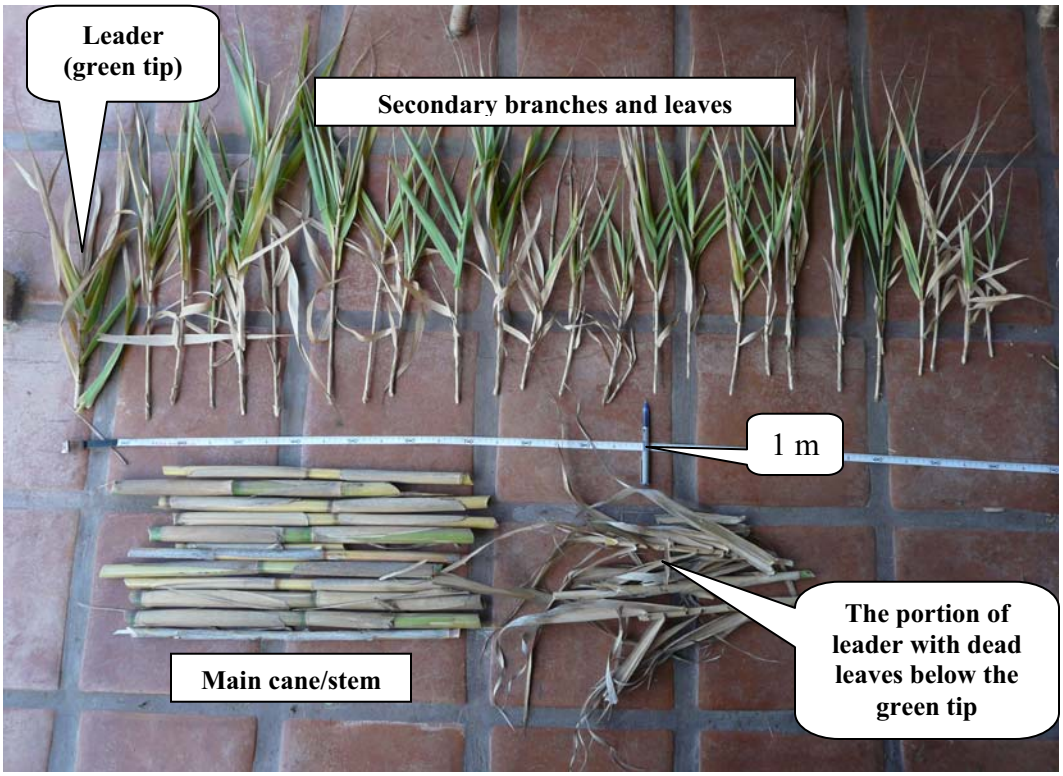


Figure 2-4. A single older cane with all secondary branches (25), leader, and main stem. This was cane SD#1b from the San Diego River with a height of 8.1m.

Figure 2-5. New first year canes often protrude from the *Arundo* canopy.
Older canes with extensive secondary branching cannot support the weight of the branches and leaves, and usually flop over and do not stand upright, especially in the upper portions of the stand's canopy.

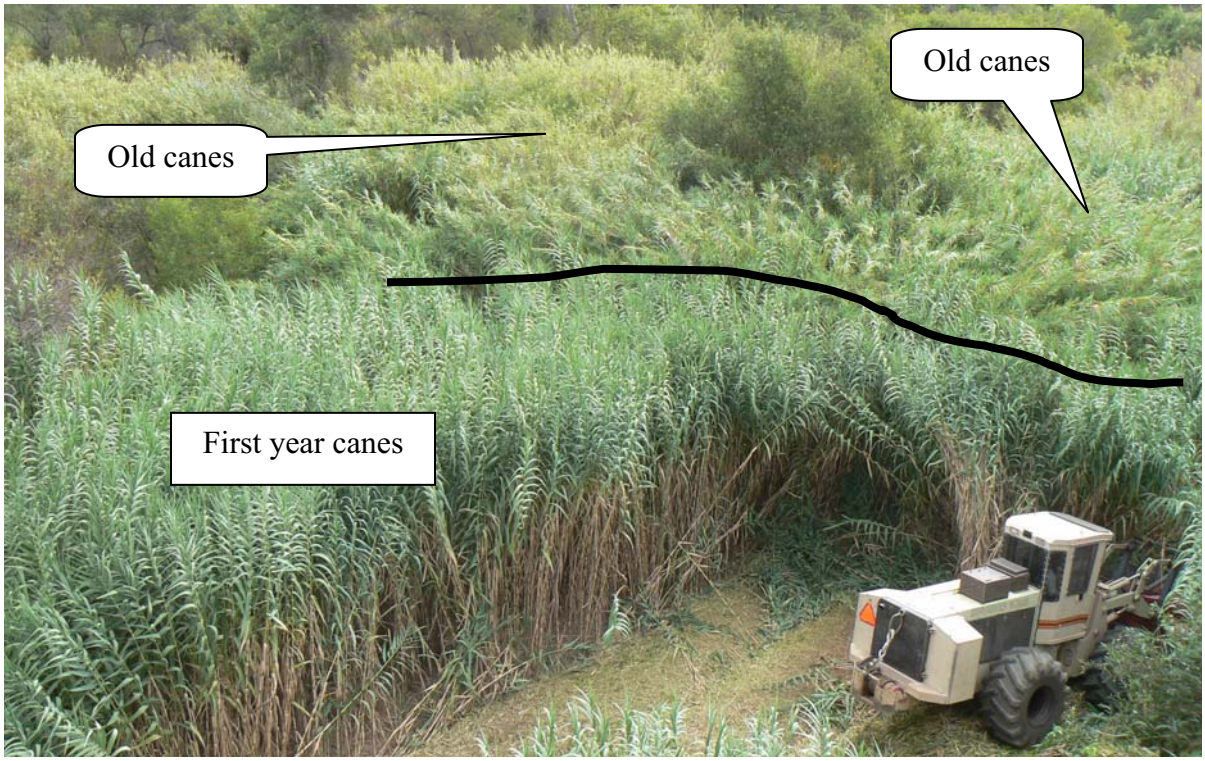


Figure 2-6. First year *Arundo* canes at full height (6+ m).
The tractor is 10' high. This area had been cut as a fuel break the year before and is being cut again. Energy stored in rhizomes underground allow this rapid regrowth after cutting or fire events. Note simple unbranched vertical structure, very high cane density, and deep green color of the new, resprouted canes. Older canes in the background are less vertical and are a more yellowish color.

Table 2-1. Summary of *Arundo* cane data from the fourteen locations sampled for this study. Locations of sampling plots are shown in Figure 2-1.

Plot	Cane height (m)	Cane diameter (mm)	Leader length (cm)	Leader # leaves	Mean leader single leaf area (cm^2)	# secondary branches	Mean branch length (cm)	Mean branch # leaves	Mean branch single leaf area (cm^2)	New cane # leaves	Mean new cane single leaf area (cm^2)
CC1	5.1	20	19	10	-	15	47.7	-	-	21	168.7
CC2 #1	9.7	28	90	23	83.7	57	11.7	4.5	10.5	-	-
CC2 #2	8.5	27	82	23	117.3	9	70.9	13.0	63.2	-	-
SA1	6.1	25	45	17	-	34	21.4	-	-	-	-
SA2	6.1	25	32	15	58.5	31	36.2	23.0	44.4	-	-
SA3	7.7	27	74	28	-	33	10.7	-	-	-	-
SA4	7.4	26	33	12	-	48	20.0	13.5	29.5	-	-
SC1	9.9	25	23	12	-	31	46.0	11.0	34.8	-	-
SC4	4.2	22	0	0	-	34	41.3	14.0	19.2	-	-
V1	8.4	26	0	0	-	28	43.4	-	-	21	216.2
V2	6.2	24	76	20	-	14	41.8	-	-	-	-
SD#1a	8.1	26	65	16	-	29	56.1	10.9	34.9	-	-
SD#1b	8.1	24	66	13	-	25	60.0	-	-	-	-
SC2	4.3	22	11	7	-	11	37.0	-	-	-	-
SC3	4.2	18	19	7	-	7	37.1	-	-	27	227.9
SC5 Lg	3.8	25	13	8	-	10	26.2	-	-	-	-
SC5 Sm	2.6	15	12	7	-	5	22.8	-	-	-	-
Mean	**6.5**	**23.8**	**38.8**	**12.8**	**86.5**	**24.8**	**37.1**	**12.8**	**33.8**	**23.0**	**204.3**
StdDev	**2.2**	**3.5**	**30.5**	**7.8**	**29.5**	**14.8**	**16.8**	**5.5**	**17.1**	**3.5**	**31.4**

CC = Calleguas Creek, SA = Santa Ana River, SC = Santa Clara River, V = Ventura River, SD = San Diego River.

Leaves are borne at nodes along the main stem and on the secondary branches. In this study, leaves found on the main stem were 5-6 cm (up to 8cm) broad toward the base, up to 61 cm long, and tapered to a fine point. Leaves on first year canes had an average width of 5.0 cm and length of 54.4 cm (n = 69) (Table 2-2). The main stem of older canes (>1 year) had much smaller leaves, average of 2.8 cm wide and 41.5 cm long (n = 60). As expected, secondary branch leaves were the smallest, average length of 27.9 cm and width of 1.7 cm (n = 200).

Table 2-2. Length and width of leaves of *Arundo* sampled in this study, by age and location.

Cane age and leaf location	# leaves sampled	Max (cm)	Min (cm)	Ave (cm)	SD
1st year cane: Leaves on stem					
Leaf length	69	74	15	54.4	14.5
Leaf width	69	6.8	2	5.0	1.2
>1yr cane: Leaves on main stem					
Leaf length	60	57	24	41.5	10.3
Leaf width	60	3.8	1.3	2.8	0.6
>1yr cane: Leaves on secondary branches					
Leaf length	200	52	4	27.9	10.8
Leaf width	200	2.8	0.1	1.7	0.5

This reduction in leaf size as canes mature is more than made up for by the much higher number of leaves found on secondary branches. Leaf density on the main cane decreased from an average of 23 for first year canes to 12.6 for older canes (Table 2-3), and leaf size also decreased. However, an entire new secondary branch class of leaves is present on canes >1 year. Leaf density on secondary branches was >270 on canes >1 year (Figure 2-4, Table 2-3). Canes older than one year had a leaf area that is greater than that of first year canes, and was predominantly made up of the secondary leaf area.

As canes mature, the leaves on the main cane become less important to photosynthetic production. The contribution of secondary branches to cane leaf area is an important observation that is not well documented in the literature. Decruyenaere and Holt (2005) note that the main canes have little growth once they generate secondary branches, and that the secondary branches become the primary areas of new growth. Leaf area is used to estimate water use and photosynthetic activity. This study will examine transpiration levels using leaf area data (Section 4.1). The field samples for this study were composed primarily of old canes. The large contribution of old canes with their secondary branches to stand leaf area can be seen in Figure 2-5, where the bulk of the leaves are secondary, and only a few new canes emerge out the top of the stand. First year and >1 year old canes can also be seen in Figure 2-6. The first year canes have a simpler structure with no branching, while the older canes in the background are more complex.

The underground structure of *Arundo* is composed of fleshy rhizomes from which arise roots that penetrate deeper into the soil (Figures 2-2 & 2-7 to 11). Rhizomes are generally shallowly buried, spreading out horizontally from the plant and forming a dense underground mat. Rhizomes are generally found 5-15 cm below the soil surface, with a maximum depth of 50 cm, while roots can be more than 100 cm deep (Sharma et al. 1998, this study).

Table 2-3. Density of leaves on *Arundo* stems sampled for this study, by class.

Cane Age and Leaf Location	# Sampled	Max	Min	Mean	StdDev
1st year cane: Leaves on					
Leaf density per cane (count)	3	27	21	23	3.5
Leaf area per leaf (cm^2)	69	352	29.6	206.3	
Leaf area per cane (cm^2)	3	6,153	3,542	4,740	
>1 year old cane: Leaves on culm					
Leaf density per cane (count)	3	23	15	12.6	8.3
Leaf area per leaf (cm^2)	60	141	30	86.5	
Leaf area per cane (cm^2)	3	2,580	877	1,000	
>1 year old cane: Leaves on secondary branches					
Leaf density per branch (count)	19	15	3	11.1	3.3
Leaf area per leaf (cm^2)	200	102	1.8	33.9	
Leaf area per branch (cm^2)	18	837	12	406	240
Leaf area per cane (cm^2) calculated	14	8,904	906	4,699	2,628

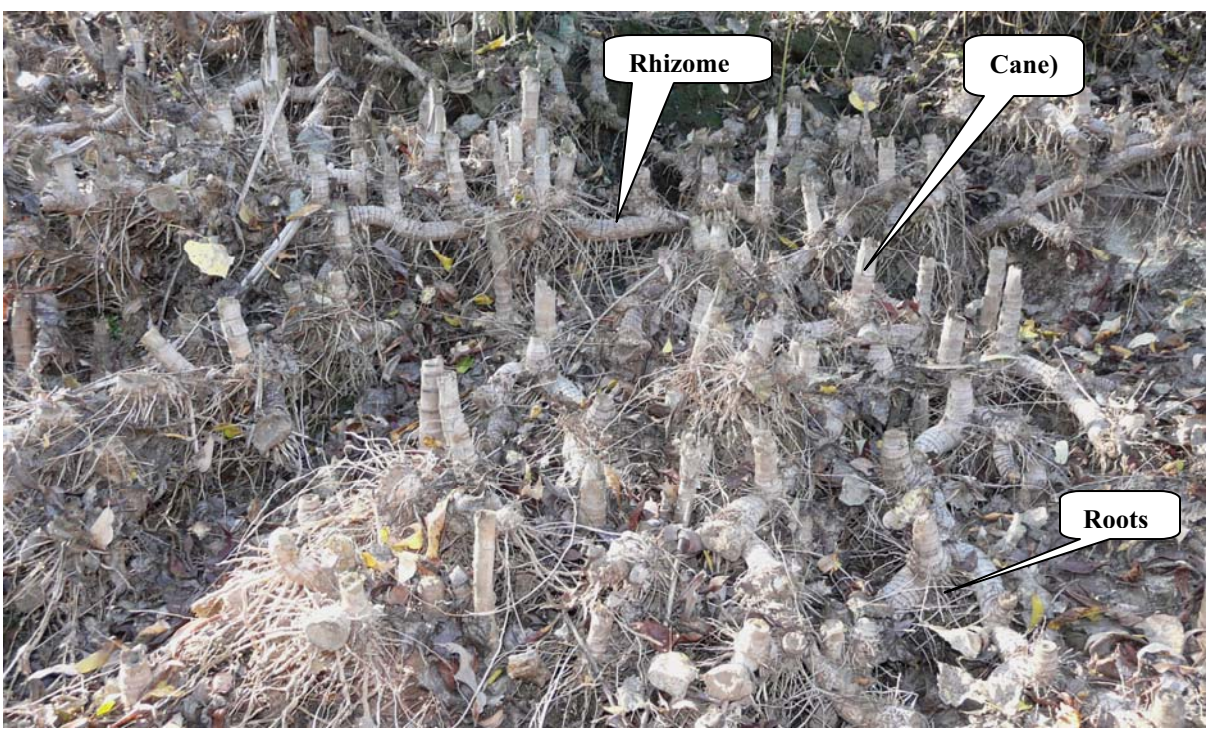


Figure 2-7. Dense rhizome and root network of an *Arundo* clump that was scoured during a flow event, removing the upper soil matrix and canes.

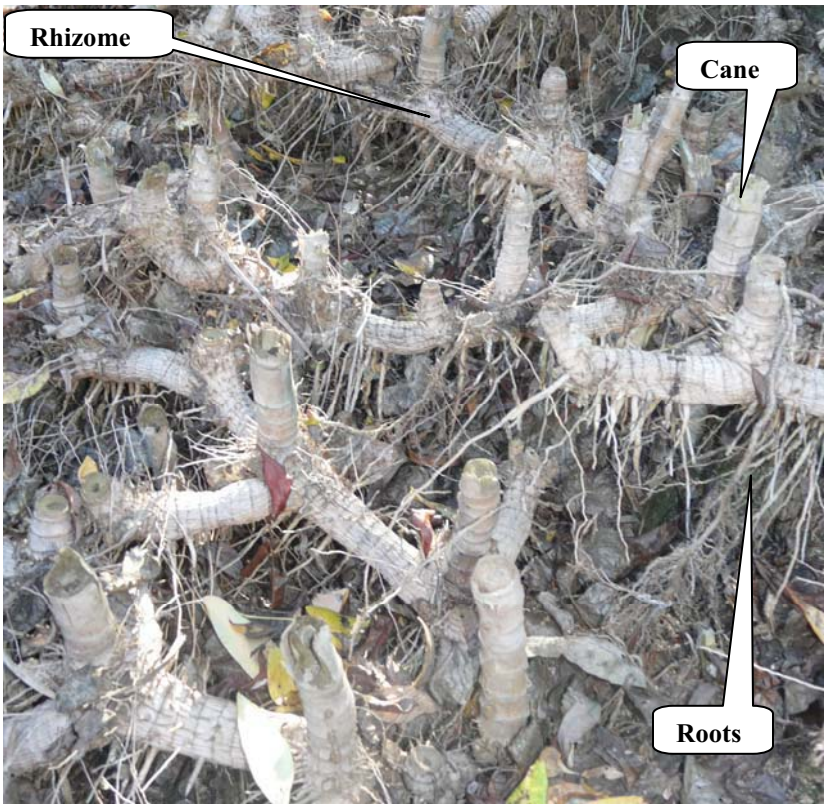


Figure 2-8. Close up of rhizomes showing emerging canes and roots.

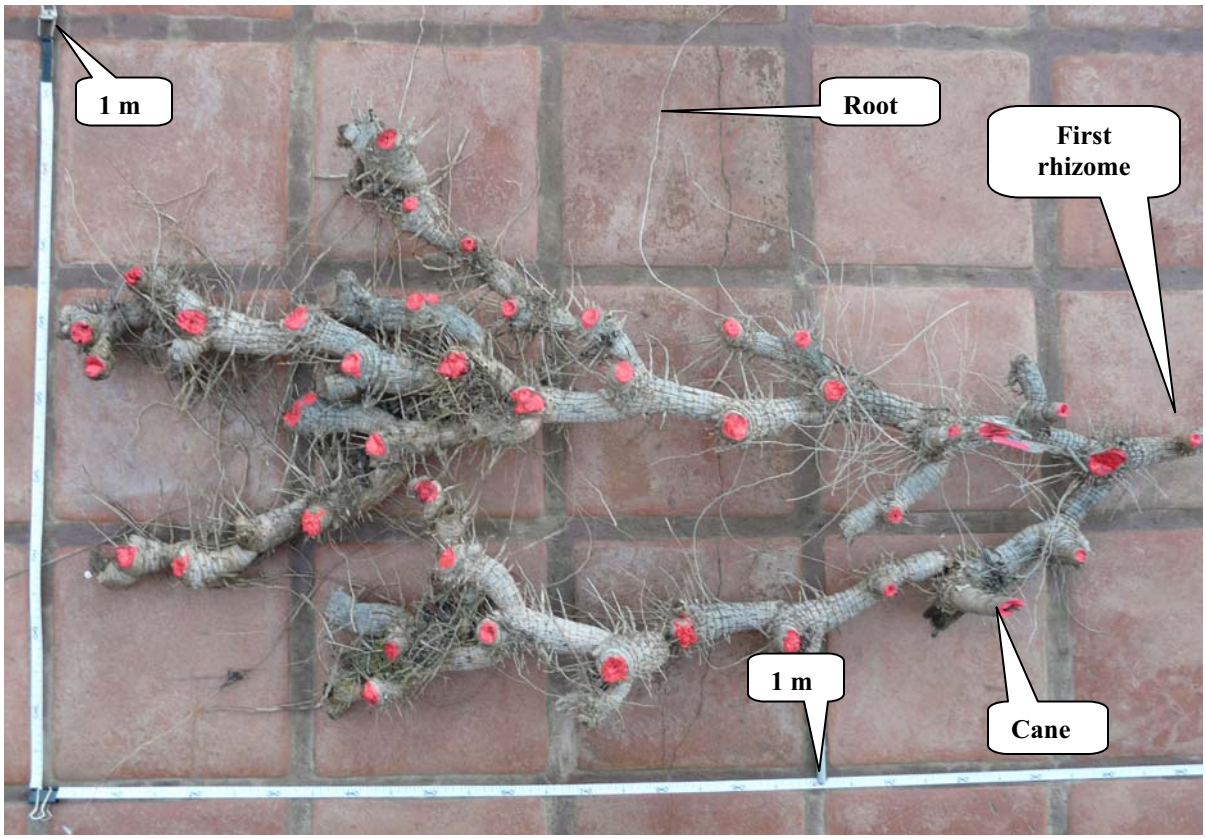


Figure 2-9. Rhizome network arising from a single growth point.
33 canes emerged from the marked 1 x 1m area (painted red).

Figure 2-10. Close-up of slightly desiccated *Arundo* rhizome.
The cane emergence points at the nodes are painted red, and long thin roots are visible.

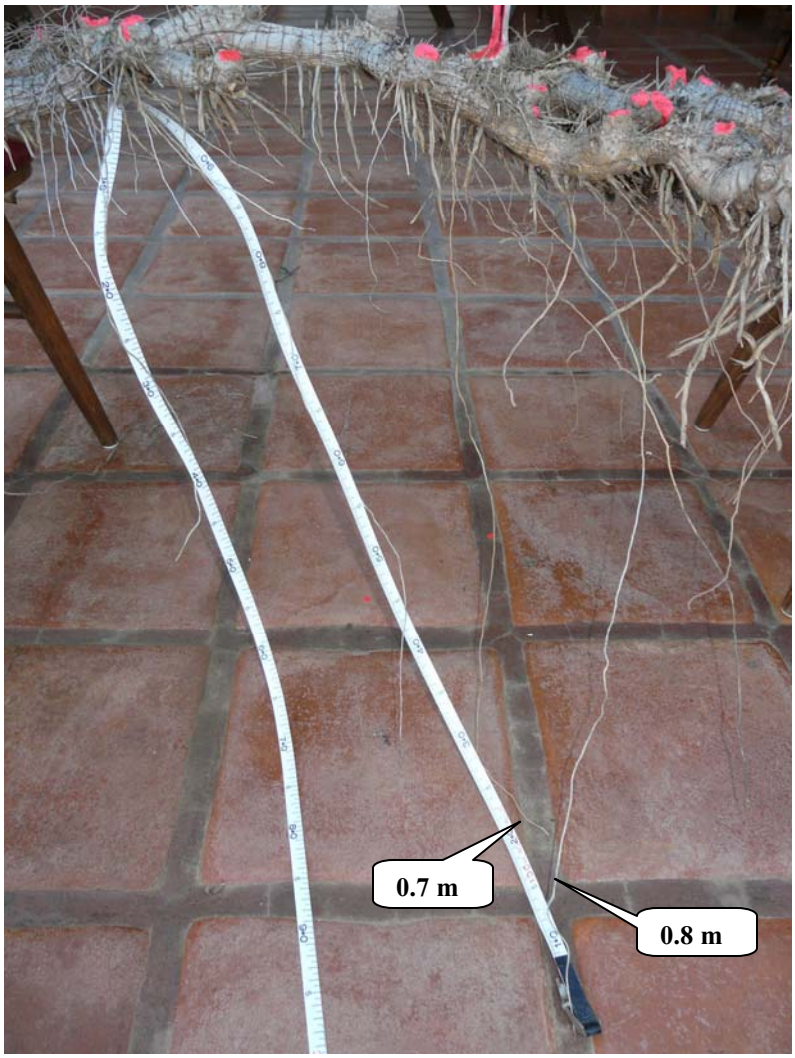


Figure 2-11. Rhizome network showing root length of up to 80 cm.
This was a dislodged rhizome network scoured out by flood action, so many of the roots have already been broken off, but it gives an idea of root density (near the rhizome) and length.

Arundo flowers are borne in large (3 to 6 dm long) plume-like terminal panicles, generally between March and September. However, many plants do not seem to ever flower, or at least not every year (Else 1996). The spikelets are several-flowered, approximately 12 mm long with florets becoming successively smaller.

Plants generally become dormant during the colder months, signified by the leaves turning brown/yellow, and the stems fading from their green color. These leaves and stems then turn green again in spring as temperatures rise and daylight lengthens. In areas with hard freezes during winter months, *Arundo* generally dies back to the ground and then re-sprouts in the spring. Deep freezes can kill the plant, probably by destroying the rhizome network.

The stand or clonal mass:

Few studies have specifically examined stand structure. Quantification of stand structure is critical in the scaling up of information derived from specific canes, leaves, or rhizomes to the stand scale. Specific information on biomass, leaf area, transpiration, and other data derived on a per cane basis cannot be converted into per unit land area without an understanding of stand structure. Some recent studies have specifically accounted for stand structure in scaling up cane-specific data (Abichandani 2007, Watts 2009, Spencer et al. 2006) although it was not always clear how they defined the stand area.

Scaling up from cane to stand (land area) based data is very sensitive to the measured cane density per land area. Determining cane density for a stand is not as straightforward as one might expect. Overestimations of cane density may be generated if one only samples in areas where canes emerge. Extrapolating specific data on a given parameter to spatial data, such as the GIS data set produced in this study, requires that the same definition of "stand area" be used when measuring cane density, or that adjustments be made to account for the sampling of canes from only the portion of the stand that has cane emerging.

In this study the *Arundo* stand is defined as its aerial extent as viewed from above, and all areas that have *Arundo* cover are classified as part of the stand footprint (Figure 2-12). This is the spatial extent of the stand as recorded in the GIS spatial data that was mapped for this project (more details can be found in Chaper 4). However, data on *Arundo* is typically collected on a per cane basis. To use cane data to represent an entire stand, we must understand cane distribution within the spatial area of the stand and if there is variation by stand size and/or age.

Arundo canes are not uniformly distributed within the aerial extent of the stand. There are two portions of the stand footprint that have no or very few canes. The first area we will examine is the edge of the stand. This area, when viewed from above, has *Arundo* canopy cover, but the canes are not rooted within the edge area, rather they are draping over into this space (Figures 2-12 & 13).

When individual ramet (cane) based data is scaled up to represent stand or clonal mass, adjustments need to be made to account for the areas that have no canes within the stand (if these areas were not sampled). This adjustment can occur as a reduction in cane density for the stand, or as an adjustment applied to account for the percentage of the stand that has no cane emergence. Most studies do not specify what was done with edge areas and gaps within the *Arundo* canopy. If these areas were sampled they would have cane density accounts of zero. Most studies seem to sample within the cane emergence zone only. The importance of the edge areas depends on stand size, which is usually a function of age. A small stand has significant edge (areas with aerial vegetation cover but no canes emerging from the zone, Figure 2-14). Over 70% of the stand area may have no canes emerging from it. Large stands, as long as they are not linear, have much less edge area as a proportion of the total stand area. Only 5% of the stand area might not have canes emerging from it.

The second area that has no canes in the aerial canopy of a stand occurs as alleys or gaps and is less predictable to specific locations of the stand (Figures 2-12 & 14). These areas are important in mid to large-sized stands that often form as multiple clumps grow into each other. As the stands grow older, these 'alleys' or gaps fill in. *Arundo* stands older than 10 to 15 years have fewer and fewer areas within the stand that have no canes. *Arundo* stands older than 20 years are difficult to sample internally, as these areas are not accessible from the ground. Old *Arundo* stands are more easily traversed across the top of the canopy than on the ground, where cane density precludes movement (Figures 2-15 & 16). Vegetation sampling crews on the Santa Margarita River could walk across the *Arundo* canopy for hundreds of meters in 1996 (Cummins pers. comm. 1998).

Gaps within *Arundo* stands also occur where there are low-flow channels (primary and sometimes secondary. These would technically be defined as separate stands as they have different rhizome systems, but they may appear as one stand when mapping. The 10 meter wide low flow channel of the San Diego River was crossed within *Arundo* canopy, attesting to the strength and density of the aerial cane network (Giessow pers. comm. 2009).

Cane density also varies within the portion of the stand where canes emerge. This makes sense since a stand starts as an individual (single fragment) or group of individuals (larger rhizome fragment with many nodes), and continually expands outward. Lateral growth creates a pattern of greater density within the older portions of the stand and lower density toward the edges (Figure 2-17). However, this variation is fairly minimal compared to the variation in cane density between different stands (field observation J. Giessow, this study). Data from this study recorded an average cane density of 6.5 m (maximum 9.9 m, minimum 2.6 m, Table 2-1). *Arundo* cane density is significantly higher than that of native vegetation (Ambrose 2006, NHC 1997a,b & 2001), and this has multiple effects such as restricting wildlife movement and blocking water flow. Sampling bias may also be occurring in many studies where cane density is not sampled from the interior of older stands which are hard to access. This study was able to sample deep interior portions of stands that were accessible during biomass reduction with heavy equipment. However, cane density does not increase indefinitely; eventually new canes that emerge do not reach light and they senesce each year (Decruyenaere1 & Holt 2005). Cane data collected in this study indicates that each square meter within the rhizome/cane emergence zone generates 3.4 (n=14, ± 2.7) canes per year. Dead canes were not common, with a density <1/m^2 on the study plots (Table 2-4). This study will adjust stand based calculations by multiplying the cane per me^2 by 70% to account for areas with no canes emerging from them (adjusting for edge drape and areas with no cane emergence within the aerial footprint of the stand).

Some areas are near a typical mature density (center), while edges and runners are expanding outward, creating lower density. Also see Figure 2-9 to look at rhizome growth pattern. This is a small 3 x 3 m clump, but similar patterns occur in larger stands. The canes drape and extend well outside of the central cane emergence footprint indicated in red.

This study will make scaling up adjustments of 70% to account for cane density measurements from sampling only carried out within the cane emergence zone. This will occur for stand-based biomass and water use calculations.

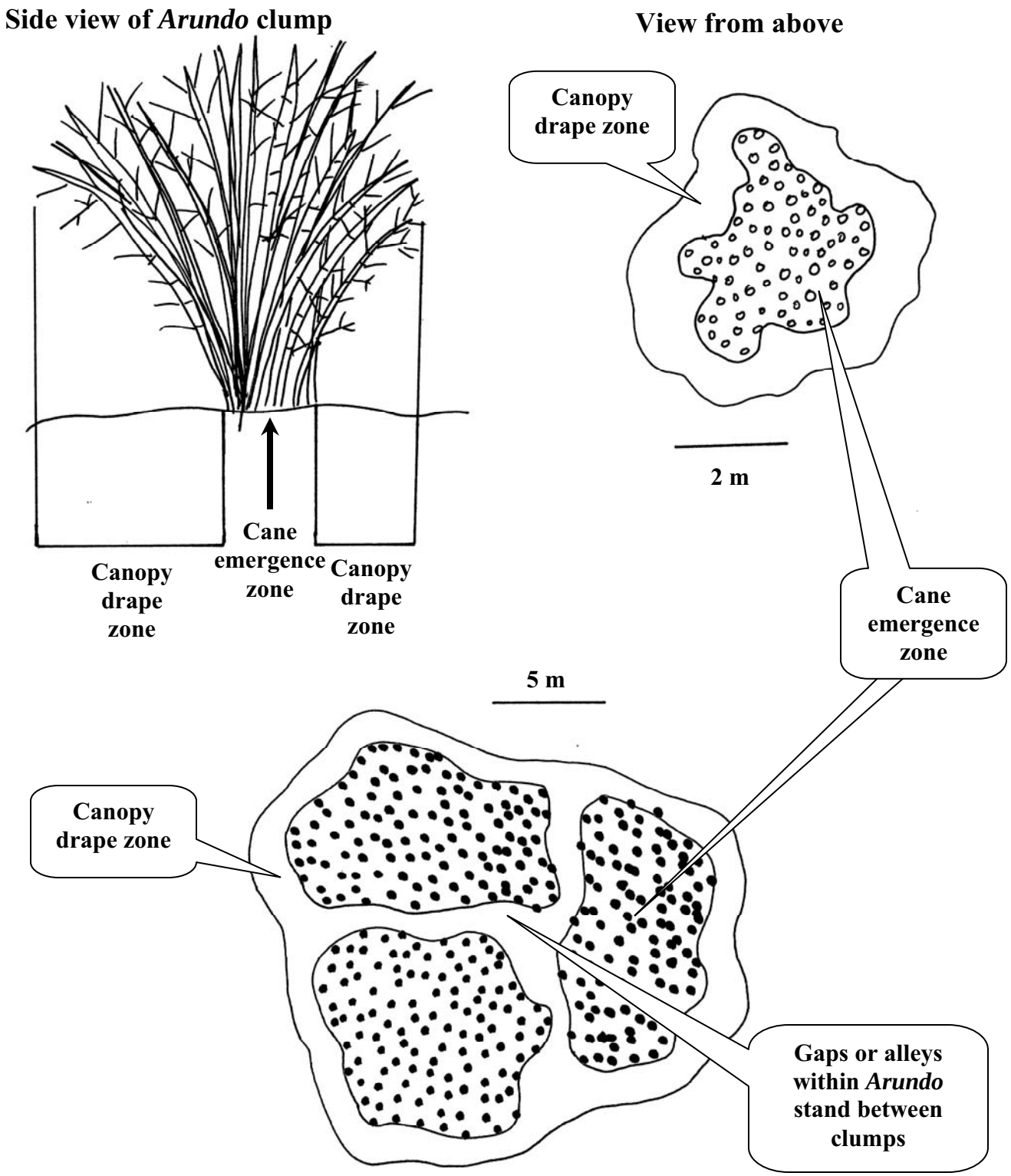


Figure 2-12. Draping effect of *Arundo* on the edge of the stand and gaps between clumps within a stand.
Drawing by J. Giessow.

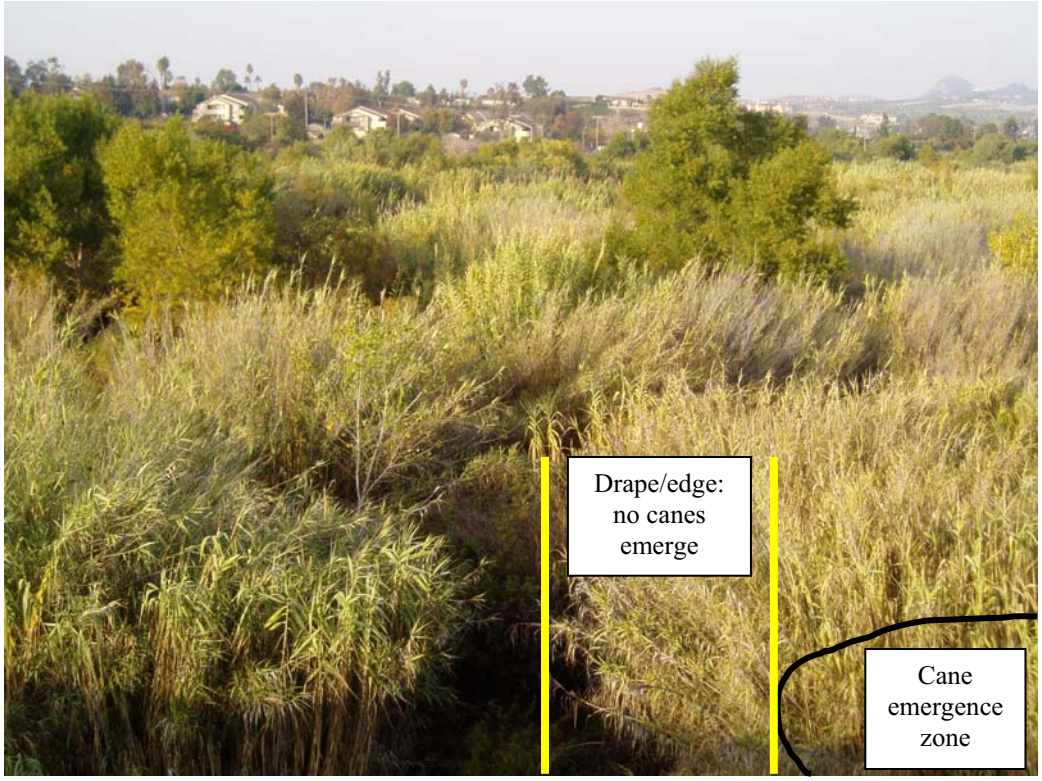


Figure 2-13. A mature *Arundo* stand showing draping of *Arundo* canes along an edge.

Figure 2-14. Oblique aerial photo showing patchiness of *Arundo* stands, particularly farther from the low-flow channel.
Greater patchiness means greater edge area composed of *Arundo* cover without actual canes emerging. The left side of image is unmowed/reduced *Arundo* and the right is immediately after reduction/mowing (San Luis Rey River 2007, J. Giessow).

Figure 2-15. View from bridge over San Luis Rey River showing the top of a mature *Arundo* stand. This stand is >10 years old, > 9 m height, and 100% cover. Note the high amount of leaf surface area and non-vertical (nearly horizontal) position of the upper portion of the canes with secondary branches.

Figure 2-16. *Arundo* stand being prepared for foliar herbicide treatment.
The crew is pushing the stand away from the native trees. *Arundo* canes are supporting the worker on the left. Canes are 8-9 m long and density is typical of a mature stand (about 40 canes/m^2). San Diego River, Giessow 2010.

Figure 2-17. A cut *Arundo* clump showing uneven cane density.

Table 2-4. Summary of *Arundo* cane density measurements from this study and others. This study and others typically sample cane density from the cane emergence zone.

Source	Location	New	Old	Dead	Total
Giessow et al.(2010)	S. California, coastal	3.4	38.1	<1	41.5
Spencer eta al. (2006)	Across U.S.				74.5
Ambrose & Rundel (2007)	S. California: Santa Clara River (post fire)				31.6
Abichandani (2007)	S. California: Santa Clara River				34.9

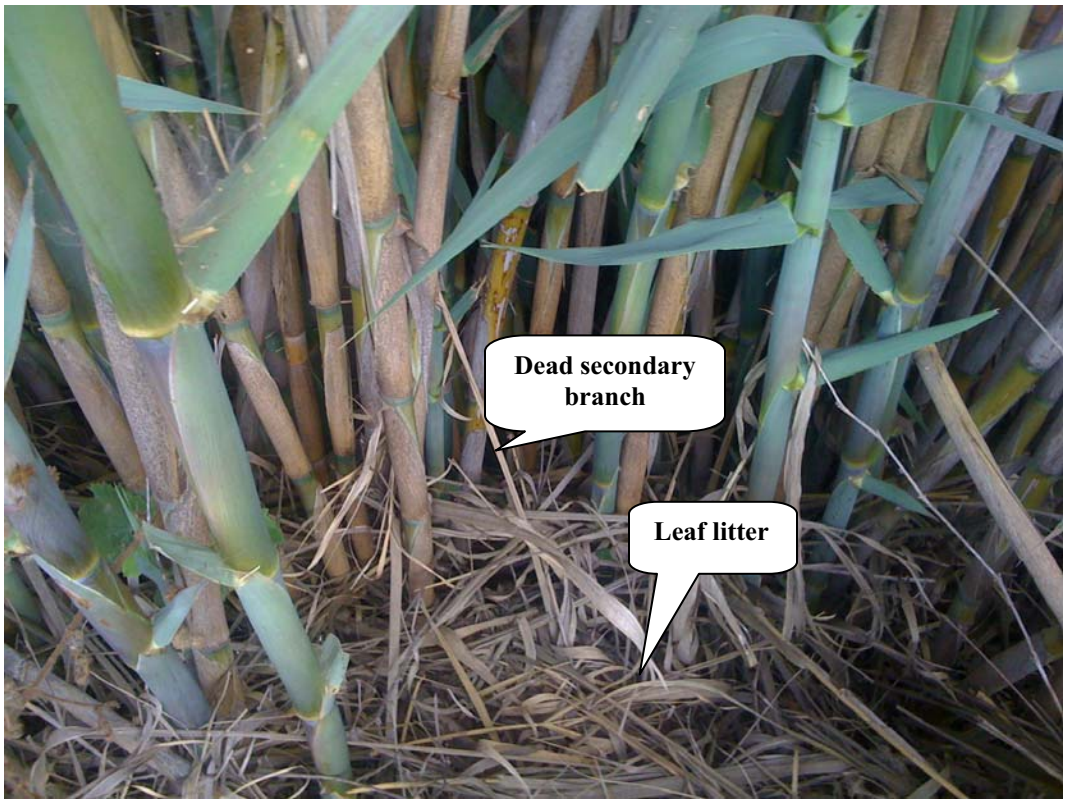


Figure 2-18. Cane density and dead leaf litter within a dense *Arundo* stand.

2.4 Biomass and Cane Density

Biomass (above and below ground) generated from *Arundo* is important as it sheds light on several factors related to impacts caused by the plant. It provides information on productivity, resource consumption (nutrients, light, and water), physical presence in the system (with impacts to flows, sediment, wildlife, light, wind, and other physical parameters), as well as indicating issues with the fate of the biomass material itself (both in aquatic and terrestrial portions of the watershed system).

Arundo has very high amounts of biomass per unit of land area as documented in many studies looking at standing biomass of wild infestations and annual productivity of cultivated stands (Table 2-5). This study found an adjusted *Arundo* stand biomass of 15.5 kg/m2, which is corroborated by the most comprehensive study evaluating *Arundo* biomass (Spencer 2006). The large amount of biomass is related to high productivity of the plant, high density of individuals (high cane density), and tall growth form of the plant (average 6.5 m in southern California). In addition to the high amount of biomass per unit of land area, *Arundo* has a large amount of energy per unit of dry weight (17 MJ/kg to 19.8 MJ/kg, see chapter 6). These values compare favorably with other fuel crops (*Arundo* is one of the highest) and are higher than most native tree, scrub, and herbaceous assemblages in the riparian zone. This is why fuel crop producers consider *Arundo* one of the top potential biofuel crops.

Belowground biomass estimates have been less studied, but appear to be in the range of 22.5% of the total plant/stand biomass (Sharma et al. 1998). Applying this proportion of above and below ground biomass generates overall estimates of 20.0 kg/m^2 or 89 t/acre (Table 2-6). These biomass levels are at the upper end of any vegetation class (Table 2-7), and are well above typical riparian vegetation values.

Table 2-5. *Arundo* aboveground biomass from various studies (wild and cultivated).

Location	Description	Above ground dry mass	Source
U.S. - 13 sites across US	Biomass of stands in field: wild	17.1 kg/m^2 171 t/ha 76 US t/ac	Spencer 2006
U.S. - 14 sites, 6 coastal watersheds in southern California	Biomass of stands in field: wild	15.5 kg/m^2 155 t/ha 69 US t/ac	This study
India	Biomass of stands in field: wild	3.6 to 16.7 kg/m^2 36 to 167 t/ha 16 to 74.3 US t/ac	Sharma et al. 1998
Southern CA (Santa Clara)	Annual yield (post fire): wild	49 t/ha 21.8 US t/ac	Ambrose & Rundel 2007
India – wild stands	Annual yield: wild	72 t/ha 32 US t/ac	Raitt 1913
Australia	Annual yield: crop	101 t/ha 45 US t/ac	Williams et al. 2008
Europe	Annual speculated max yield: crop	100 t/ha 45 US t/ac	Shatalov & Pereira 2000
Italy	Annual yield: crop	30 t/ha 13.4 US t/ac	Angelini et al. 2005
Italy – cultivated stands	Annual yield: crop	39.3 t/ha 17.5 US t/ac	Marinotti 1941
Greece	Annual yield: crop	120-230 t/ha 53.4-102.4 US t/ac	Mavrogiapolus et al. 2001
Greece	Annual yield (Yr 1, new crop): crop	15 t/ha 6.7 US t/ac	Hidalgo & Fernandez 2000
Greece	Annual yield (Yr 2): crop	20 t/ha 8.9 US t/ac	Hidalgo & Fernandez 2000
Greece	Annual yield (Yr 3): crop	30 t/ha 13.4 US t/ac	Hidalgo & Fernandez 2000
Greece	Annual yield (Yr 4, mature): crop	39 t/ha 17.4 US t/ac	Hidalgo & Fernandez 2000
Spain	Annual yield: crop	45.9 t/ha (ave) 29.6-63.1 t/ha (range) 13.2-28.1 US t/ac	Hidalgo & Fernandez 2000

Table 2-6. Above and below ground biomass values for *Arundo*, using relationship from Sharma 1998 (22.5% of biomass is below ground).

Study	Above ground biomass	Below ground biomass	Total biomass
This study	15.5 kg/m^2 155 t/ha 69 US t/ac	4.5 kg/m^2 45 t/ha 20 US t/ac	20.0 kg/m^2 200 t/ha 89 US t/ac
Spencer 2006	17.1 kg/m^2 171 t/ha 76 US t/ac	5 kg/m^2 50 t/ha 22 US t/ac	22.1 kg/m^2 221 t/ha 98 US t/ac

Table 2-7. Typical biomass values for different vegetation types.

Study	Above ground biomass	Study
Willow forest (as crop)	4-8 t/ac (annual) 15 t/ac (4 year growth)	Turhollow 1999
Switch grass	5 t/ac	Turhollow 1999

2.5 Growth Rate

Individual Ramet or Cane Growth:

When conditions are favorable, *Arundo* canes can grow 0.3-0.7 m per week over a period of several months (Perdue 1958). Young stems rapidly achieve the diameter of mature canes, with subsequent growth involving thickening of the walls (Perdue 1958). Annual yield studies demonstrate the productivity of *Arundo* stands (Table 2-5). Old canes typically have little new growth on the main leader (Decruyenaere & Holt 2005), but have extensive growth on secondary branches, as well as growing new secondary branches. In colder regions of the world *Arundo* dies back and then resprouts, although frost can damage the plant if it occurs after initiation of new growth (Sharma et al. 1998, Perdue 1958). In southern California dormancy is limited to total to partial browning of the canes and leaves during the winter.

Rhizome Growth:

In mature stands, most new shoots develop from large apical buds at rhizome termini, resulting in relatively evenly spaced, vertically oriented shoots 2 cm or more in diameter (Decruyenaere & Holt 2005). Rhizome growth extends laterally along an axis, but will branch (Figure 2-8). Rhizomes appear to 'self-discriminate', growing into areas with no rhizomes present (Decruyenaere & Holt 2005). Stands expand 7-26 cm/year (Decruyenaere & Holt 2005), as well as generating higher density. Comparisons of imagery over a 10 year period for sites in San Diego showed minor (none visible) to moderate

(0.5m/yr) expansion of established stands. Generally expansion was surprisingly slow, but highly variable. A few studies have examined expansion and lateral spread of rhizomes and canes, but these data are presented as increasing cane density within quadrats. Future studies should more explicitly describe length (m) or area (m^2) of spread.

Stand Growth:

Three general factors seem to affect growth rates of both canes and rhizomes: 1) availability of water, 2) availability of nutrients and 3) temperature regimes (affected by shade). Water availability seems to be the primary factor restricting the growth of *Arundo* stands in coastal California. This is based on field observations across the study area and our review of transpiration and nutrient studies. Generally watersheds in coastal California have favorable temperature ranges and are not nutrient limited. Areas with water available throughout the year develop into dense, tall *Arundo* stands. Areas with low water availability, such as upper terraces that are far from the water table, frequently have *Arundo* stands with lower cane density, shorter stature, and large amounts of dead material in the canopy (an indicator of stress).

Riparian systems are typically not nutrient limited in coastal California (Peterson et al. 2001, Suffet & Sheehan 2000). Artificially high nutrient levels increase growth rates of all riparian vegetation, but *Arundo* with its higher productivity potential (compared to native vegetation) is able to capitalize on this, turning it into a competitive advantage (Ambrose and Rundel 2007).

Nutrient use/nutrient loaded systems:

In the last century, nutrient inputs to river systems have increased dramatically due mainly to agriculture and municipal sewage. These same nutrient inputs are present in high quantities in the rivers of Southern California's watersheds (Pederson 2001, Suffet and Sheehan 2000). Nationwide, the use of fertilizer in agricultural areas has increased from 20 to 40 million tons annually. The average percent of nitrogen, the main constituent in commercial fertilizers, has risen from 6.1 to 20.4 % (Texas Water Resources Institute 1986). This increase in use and composition of fertilizer alone has led to a loading of river systems with nutrients, mainly nitrogen and phosphorus. Nitrogen, found in the form of nitrate in fertilizer, poses unique risks to river systems; it is soluble and moves quickly through soils in the shallow groundwater between agricultural practices and rivers. Phosphorus, on the other hand, is not very soluble and typically adheres to soil particles. Other anthropogenic and natural sources are thought to have also contributed to nutrient loading in river systems, including: nitrogen enriched rainfall and air; manure from animal feedlots and corrals; fertilizer applied to lawns; leaky septic tanks; oxidation of organic materials; and the symbiotic nitrogen fixation by plants.

2.6 Reproduction and Spread

This discussion is separated into spread within a site, spread within a watershed, and spread between watersheds.

2.6.1 Within Stand Spread

Once *Arundo* is present at a given location it grows and spreads laterally. Lateral spread occurs mainly through lateral rhizome growth and budding (forming new ramets or individuals in the asexual colonial

Arundo stand) (Decruyenaere & Holt 2005). In addition, *Arundo* canes can drape/bend over and touch the soil surface, and if conditions are favorable (wet and/or sediment covering a node) a new bud may form (developing into a new ramet or individual) (Boland 2006).

2.6.2 Spread Within A Watershed

Arundo is dependent on asexual reproduction. *Arundo* plants in North America do not appear to produce viable seed. Multiple studies in California have determined that seedlings are not present in the wild (Else 1996, Witje et al. 2005) and that plants that flower do not produce viable seed (Khudamrongsawat et al. 2004). Studies in India indicate that the apparent sterility of *Arundo* seed is caused by the failure of the megaspore mother cell to divide (Bhanwra et al. 1982).

New individuals within a watershed and the colonies they grow into are created through vegetative propagation. This occurs when plant fragments, usually rhizomes, become rooted at new locations and form into separate plants. Dispersal generally occurs during flood events, when floodwaters break off pieces of *Arundo* plants and transport them downstream (Else 1996, Decruyenaere & Holt 2005). Establishment of new *Arundo* stands within a watershed is, therefore, generally limited by the extent of river flow and floodplain inundation. However, *Arundo* fragments can also be moved to new locations within a watershed via human disturbance.

Several studies have shown that almost any segment of stem or rhizome can sprout if it possesses an axillary bud (Boose and Holt 1999, Wijte et al. 2005, Else 1996). Buds occur at the stem nodes and approximately 5-10 cm apart on the rhizomes (Wijte et al. 2005). Both rhizomes and stems can withstand a certain amount of drying out and still sprout. Drying rhizomes to 58.8% moisture loss and stems to 36.5% moisture loss did not affect their ability to sprout (Else 1996). Rhizomes were able to sprout when buried up to one meter deep (Else 1996), but stems have shown reduced sprouting at depths as low as 10 cm due to limited energy reserves in the stem (Boose and Holt 1999).

Else (1996) reported that of *Arundo* vegetative reproduction observed following dispersal by flooding on the Santa Margarita River in San Diego County, 57% was from rhizomes, 33% was from stem fragments, and for the remaining 7% the plant part that gave rise to the new plant could not be identified. Rhizomes are frequently broken off at bank edges when they are undercut (Brinke 2010) or scoured out (Figure 2-7). Any disturbance (natural or human caused) that mobilizes live rhizome material during conditions that are favorable for establishment will likely result in spread of *Arundo*. Flow events will break off rhizome fragments along stand edges and disperse them within flow areas (Brinke 2010). For this reason significant spread of *Arundo* within a watershed is episodic. Flows reach higher geomorphic forms (floodplain and terraces) only during large events. These large hydrologic events mobilize *Arundo* material for potential asexual propagation. Low flow events are confined to channel areas. New *Arundo* establishment in this area is often removed during later flood events. Little propagule material is typically mobilized during these low flow events in comparison to larger events, but undercutting of *Arundo* stand edges does generate a steady amount of propagules downstream.

The combination of within watershed dispersal events and stand growth rates generates a pattern of expansion that increases episodically to the system's maximum carrying capacity for *Arundo*. Larger watersheds with favorably wide floodplains have about 13% *Arundo* cover, but portions of these systems can have cover >44%.

2.6.3 Historic Air photo Analysis: Stand Growth Rates and Spread Within Watershed

Review of historic aerial photography on watersheds in the study area indicated some interesting patterns of spread and growth. The basic pattern that repeated on most watersheds was that there was little *Arundo* present on most systems from the 1930's to the 1960's. It looks as though *Arundo* was present as scattered clumps and small stands. Aerial photography during this time was of low resolution and black and white, limiting our ability to detect and map *Arundo*. Large stands of *Arundo* would have been detectable, but they were not present. The overall historic extent of *Arundo* on most systems was scattered with low total acreage. As will be seen later in this report (Chapter 5), this makes sense, since historically riparian systems were broad and dry.

In the 1960's riverine systems became much narrower (levees and land use change) and water was imported. This resulted in perennial flows on many systems or at minimum, significantly raised water tables. *Arundo* responded to these changes by aggressively spreading and growing into dense stands. This transformation occurred during the 1970's and 1980's on most systems. By the 1990's *Arundo* had achieved an extensive distribution that appears to be at or near the current distribution of the plant.

Lateral expansion of established stands appeared to be fairly slow, on the order of 1 to 2 feet a year. Disturbance events (fire, grading, clearing, flood action) and the subsequent growth seem to be more important to rapid expansion of *Arundo* than the slow lateral growth of established stands. The concurrent use of both growth strategies allows *Arundo* to become abundant on southern California watersheds that are characterized by episodic flow events. Review of historic aerial photos indicated that significant spread of *Arundo* within a watershed appears to be very episodic. Large magnitude flow events (25 to 100 year) are necessary for the plant to actively invade significant new areas in a riparian system, particularly higher floodplains and terraces.

2.6.4 Spread Between Watersheds

The spread of *Arundo* between watersheds is primarily due to humans moving *Arundo* plants (planting or dumping biomass) or soil/fill material contaminated with *Arundo* fragments. *Arundo* fragments can wash up into estuaries, but generally cannot get very far up into the riparian system as river flows push material out of the system.

2.7 Ecological Function: Abiotic and Biotic

2.7.1 Abiotic

Invasive species that modify abiotic ecosystem processes have significantly greater impacts than those that affect only biota (flora and fauna) because abiotic processes shape and control the entire ecosystem. *Arundo* strongly affects riparian abiotic processes, including: hydrology/geomorphology (including flooding - Chapter 5, water use/transpiration - Chapter 4) and fire (Chapter 6). *Arundo*'s strong influence on these ecosystem properties has two main consequences: 1) it modifies the habitat in ways that impact native flora and fauna, and 2) it modifies habitat in ways that benefit its own growth and continued spread. The modification of flows, geomorphology and sediment transport strongly affects successional patterns of vegetation. *Arundo*'s proliferation indicates that it benefits from this alteration of river processes. The significant increase in fire events (area and frequency, as documented in Chapter 6) and intensity also favors *Arundo*, as it is more productive than native vegetation after fire events (Ambrose & Rundel 2007).

2.7.2 Biotic

2.7.2.1 Vegetation

Arundo tends to form dense, monotypic stands that replace native riparian vegetation and naturally occurring open areas between vegetation groups. The displacement of native vegetation results in changes to vegetation composition, vegetation structure, and food resources. These changes have impacts on the native flora and fauna.

When *Arundo* forms dense stands, there is generally less plant diversity in comparison to un-invaded areas. A study in the Russian River in northern California showed that *Arundo* invasion was associated with significantly lower richness of native perennial plant species on stream banks, but not on gravel bars (Cushman and Gaffney 2010). Plots invaded by *Arundo* exhibited significantly lower native and exotic species richness and abundance of both established plants and seedlings than un-invaded plots. In coastal southern California watersheds, *Arundo* often displaces nearly all vegetation, leaving only mature gallery trees, which have a canopy layer higher than the *Arundo* stand (Figures 2-15 & 16). Native vegetation displacement is particularly pronounced in the shrub, perennial herb and annual herb growth form classes. Within dense *Arundo* stands there is generally little or no understory vegetation (Figure 2-19). In addition to displacing native vegetation, *Arundo* also alters the habitat by filling in areas that would naturally be open and unvegetated. Open portions of riparian habitat can be critical for fauna that use these areas for movement (both within and through the habitat). Unvegetated soil substrate can also be a place of refuge (both sand and litter covered).

A system that has dense stands of *Arundo* affects abiotic processes, tending to have a higher fire frequency and intensity, as well as altered flooding patterns. Removal of riparian vegetation by *Arundo* exacerbated flood and fire events alters the natural riparian successional patterns, and generally leads to more dominance of *Arundo*. This is an important positive feedback loop that leads to type conversion (Ambrose & Rundel 2007).

Arundo's impacts on vegetation and federally listed plants will be discussed further in Chapter 7.

2.7.2.2 Arthropods

Several studies have examined the impacts of *Arundo* on arthropods. All have indicated reduced diversity, density and/or productivity of arthropods within *Arundo* stands compared to native riparian vegetation. Native riparian vegetation in Sonoma County in spring contained twice the abundance, biomass, and species richness of aerial insects compared to *Arundo* (Herrera & Dudley 2003). Furthermore, insects recorded in *Arundo* were rarely observed feeding there, indicating that *Arundo* is used for its structure more than as a food source. Ground dwelling insects showed the same responses to *Arundo*, but to a lesser degree than aerial insects. Habitat that contained a mixture of *Arundo* and native riparian habitat showed an intermediate response. The *Arundo* infestation within the study area was at a much lower level than some southern California systems. High cover stands would likely show even less use.

Studies on arthropod use of *Arundo* leaf material indicate it is of low quality for native arthropods. Aquatic caddisfly larva survival was much lower for individuals fed *Arundo* (20%) compared to Alnus, Salicaceae, or Tamarix litter (85%) (Going & Dudley 2008). The high concentration of secondary compounds (tannins, alkaloids) and silica in *Arundo*, and the low nitrogen levels are likely to be poor food resources (Khuzhaev & Aripova 1994, Wynd et al. 1948).

Invertebrate species assemblages within soil and leaf litter in *Arundo* stands tend to be opportunistic forms that generally do not utilize the plant tissue directly and tend to be non-native. Invertebrates associated with *Arundo* rhizomes in southern California followed this pattern (43% non-native), and non-native detritivorous isopods were the most abundant in the Sonoma County study (Lovich et al. 2009, Herrera & Dudley 2003).

The preference of arthropods for native riparian vegetation over *Arundo* stands is likely due to the greater habitat structure, the more complex and massive litter layer, and the higher quality food resources. Despite its large biomass per square meter, *Arundo* appears not to provide much to the food web. This has significant impacts on wildlife. A large reduction in aerial insects, in particular, could have serious negative impacts for insectivorous birds such as the endangered least Bell's vireo (*Vireo bellii pusillus*) and southwestern willow flycatcher (*Empidonax traillii extimus*).

2.7.2.3 Wildlife

Dense *Arundo* stands can negatively impact fauna through a reduction in food resources, alteration in structure for nesting/denning, and creation of a physical barrier to movement within and through riparian habitat to upland areas (wildlife corridor). While there have not been many studies that document all of these impacts, they do seem probable based on the limited research that does exist, coupled with personal field observations and wildlife specialists' assessments as reported in management plans and regulatory documents. *Arundo* biomass has the potential to contaminate pools and areas used by native fish and amphibians for breeding and feeding, and can impact wildlife on beaches and estuaries where it collects after flood events. *Arundo* biomass piles and live plants may also create structure in areas where none naturally occurs, which may impact predation.

Studies on the use of *Arundo*-invaded habitat by wildlife are often compromised by native riparian habitat adjacent to and/or dispersed within the *Arundo* stands. Large continuous stands of *Arundo* do exist, but they are difficult to monitor as the density of canes restricts access to interior portions of the stand. Species frequently have territories/ranges that include *Arundo*-invaded and un-invaded habitat. Even with this caveat, patterns are still apparent.

Many reports and surveys have identified *Arundo* as a factor in reduced habitat fitness for reptiles and amphibians, although there are no specific research studies. Since reptiles and amphibians are highly dependent on specific hydrological/geomorphological processes occurring, they may be severely impacted due to *Arundo*'s complicated, long-term impacts on hydrology, geomorphology, and water use. This report explores these impacts in depth, and the impacts appear to be significant. *Arundo* stands can impact reptiles and amphibians by creating physical barriers to their movement within the riparian habitat, and to adjacent upland areas. Arroyo toads appear to avoid *Arundo* stands on MCB Camp Pendleton (Camp Pendleton Land Management Branch Reports and pers. comm. with land managers), but are dependent on migrating from breeding pools to upland habitat. Specific impacts will be explored for four endangered reptiles and amphibians in Chapter 7.

Arundo impacts on geomorphology/hydrology, especially channel and pool formation, are likely to be significant factors affecting fish species. There may also be impacts associated with contamination by large amounts of *Arundo* biomass within pools and other areas used for breeding and juveniles. It is generally thought that *Arundo* does not shade the waterway in the same way as native vegetation, resulting in increased water temperatures that would negatively affect fish and amphibian species. However, there is no published data on temperature in *Arundo* dominated streams as compared to native vegetation. Of greater consequence would be *Arundo*'s impact on channel depth, width, and number of channels/braiding (Chapter 5). Deeper, narrower channels may be cooler, but they also have reduced feeding opportunities and appropriate substrate may be lacking. Wrong depth and aspect, and higher

water velocity may also impede movement and/or cause reproduction to fail. Four endangered fish are examined in Chapter 7, with a more detailed discussion of *Arundo* impacts on habitat, movement/migration and reproduction.

Arundo impacts bird species due to its physical structure and its apparent reduction in abundance and diversity of insects (available data primarily relate to insectivorous species). In three drainages in southern California, *Arundo* stands contained reduced abundance and species richness of birds compared to native stands (Kisner 2004). The number of non-listed avian species declined by 32-41% as *Arundo* cover increased from 0 to 50%. Species richness of both ground and foliage gleaning birds declined in areas with increased *Arundo* cover. Preliminary results of a study on the lower Santa Clara River in southern California show diminished avian species diversity and fewer total individuals in *Arundo* stands relative to native stands, with intermediate diversity in mixed patches (Orr 2010). *Arundo* may also affect bird abundance as avian species rarely use it for nesting. The branching structure of *Arundo* is very different from native shrubs and trees, and it is presumed that it does not provide the architecture or support required for nesting. In the Prado Basin on the Santa River in southern California, from 1987 to 2006, only 0.8% percent of least Bell's vireo nests were in *Arundo*, compared to 76% in willow and mulefat (Pike et al. 2007). *Arundo* biomass washes downstream during flood events and can collect within estuaries and beaches. On the Santa Margarita River watershed, large piles of dead and sprouting *Arundo* eliminate nesting sites for Western snowy plovers and increase the presence of predators, which use it as perches and prey on rodents in the piles of vegetation (USFWS 2001). Eight endangered bird species will be reviewed in Chapter 7.

Arundo has complicated effects on mammal species. *Arundo* stands may provide areas for dens, but food resources are lower in comparison to native plants due to lack of seed and low quality forage. The dense cover and growth reduces mobility of mammals, which could reduce the use of riparian habitat as corridors for movements. This would be a significant impact and it remains undocumented. One endangered mammal, the San Joaquin kit fox, will be examined in Chapter 7.

2.8 *Arundo* Biology: Conclusions

Several observations were made in field studies, including:

- Mature stands are taller than has been typically reported in the literature: 6.5 m mean and a range of 2.6 – 9.9 m. (Section 2.3)
- Adjustments need to be made when scaling up from cane specific data to stand data due to canes not actually emerging within all areas of the *Arundo* canopy. Areas along edges and gaps within stands few to no canes. (Section 2.3)
- Biomass per unit area measured in this study is very high for mature *Arundo* stands: 15.5 kg/m^2. This is in general agreement with the literature. (Section 2.4)
- Reviewed literature demonstrates that *Arundo* spreads through asexual propagation (fragments of rhizomes and, infrequently, canes). Seeds are not viable. This makes *Arundo* spread dependent on flood action or anthropogenic disturbance. (Section 2.5)
- Review of historic aerial photography indicates that spread of *Arundo* within a watershed is very episodic. Large magnitude (50 to 100 year) events are necessary for the plant to actively invade significant new areas in a riparian system, particularly floodplains and terraces. (Section 2.6.4)

3.0 SPATIAL DATA SET: The Distribution and Abundance of *Arundo* from Monterey to Mexico

3.1 Methodology

Arundo was mapped for all coastal watersheds from the Salinas River in Monterey County in the north to the Tijuana River in the south (Figure 3-1). Four additional large-form riparian invasive plant species (*Washingtonia robusta, Phoenix canariensis, Cortaderia selloana, and Cortaderia jubata*) were also extensively mapped due to their presence and high abundance within a majority of the riparian corridors that were surveyed. Due to limited high-resolution aerial photo coverage, only partial mapping of all five species occurred in the Bolsa Nueva, Pajaro River, and Big Basin watersheds just north of the Salinas River Watershed. In addition, mapping of both *Cortaderia* species was limited to the immediate coastline above Santa Barbara County. For *Cortaderia* species, central coast populations north of Santa Barbara were mapped as jubata grass (*C. jubata*), and populations south of Santa Barbara were listed as pampas grass (*C. selloana*). The photo resolution that was available for most of this region (Central Coast) was too coarse to differentiate *Cortaderia* populations to species.

The mapping methodology utilized for this project borrows techniques from previous large-scale, watershed-based weed mapping efforts that have taken place in San Diego and Los Angeles Counties. Each plant population was captured using one of the following digital mapping approaches: (a) in-house surveys compiled by heads-up digitizing on high resolution aerial photography within a GIS; (b) field surveys using high resolution aerial photography on an integrated Tablet PC/GPS or; (c) a combination of option a. and b. (in-house surveys followed up by field checking).

3.1.1. Step-by-Step Process

1) In-office Surveys

Initial mapping efforts took place in the office. The database was generated within ESRI's desktop GIS application (ArcGIS 9.3) using a geodatabase (GDB) as the chosen file format. Domains (i.e. a data dictionary) were setup before mapping commenced to help ensure data integrity by limiting the choice of values within each field. Target species were then digitized within the GIS implementing a dual-monitor workstation setup. A primary tablet monitor (Figure 3-2) hosts the GIS application where plant populations are delineated as defined areas (i.e. polygons). High-resolution (1 ft or better) vertical aerial photos[1] were the primary base layer used for delineating plant population boundaries in the GIS. After a population was digitized, key attributes were noted (Table 3-1). Relevant supporting data was also captured during this phase that included "area mapped" to discern presence/absence and homeless encampment locations within the riparian zone. A secondary reference monitor was used as an additional aid to help distinguish smaller clumps as well as those populations partially covered by thicker tree canopy cover. High-resolution oblique imagery from four directions served as the reference. These images were freely available for all urban and wildland-urban interface (WUI) areas across the project extent courtesy of Microsoft's Bing maps "bird's eye view" function (*www.bing.com/maps*). The California Coastal Records oblique imagery database *(www.californiacoastline.org)* also served as a reference source for the immediate coastline (particularly for the central coastline *Cortaderia* species mapping).

[1] Two to four time periods (2004, 2005, 2006, and/or 2008) were available depending on the given area.

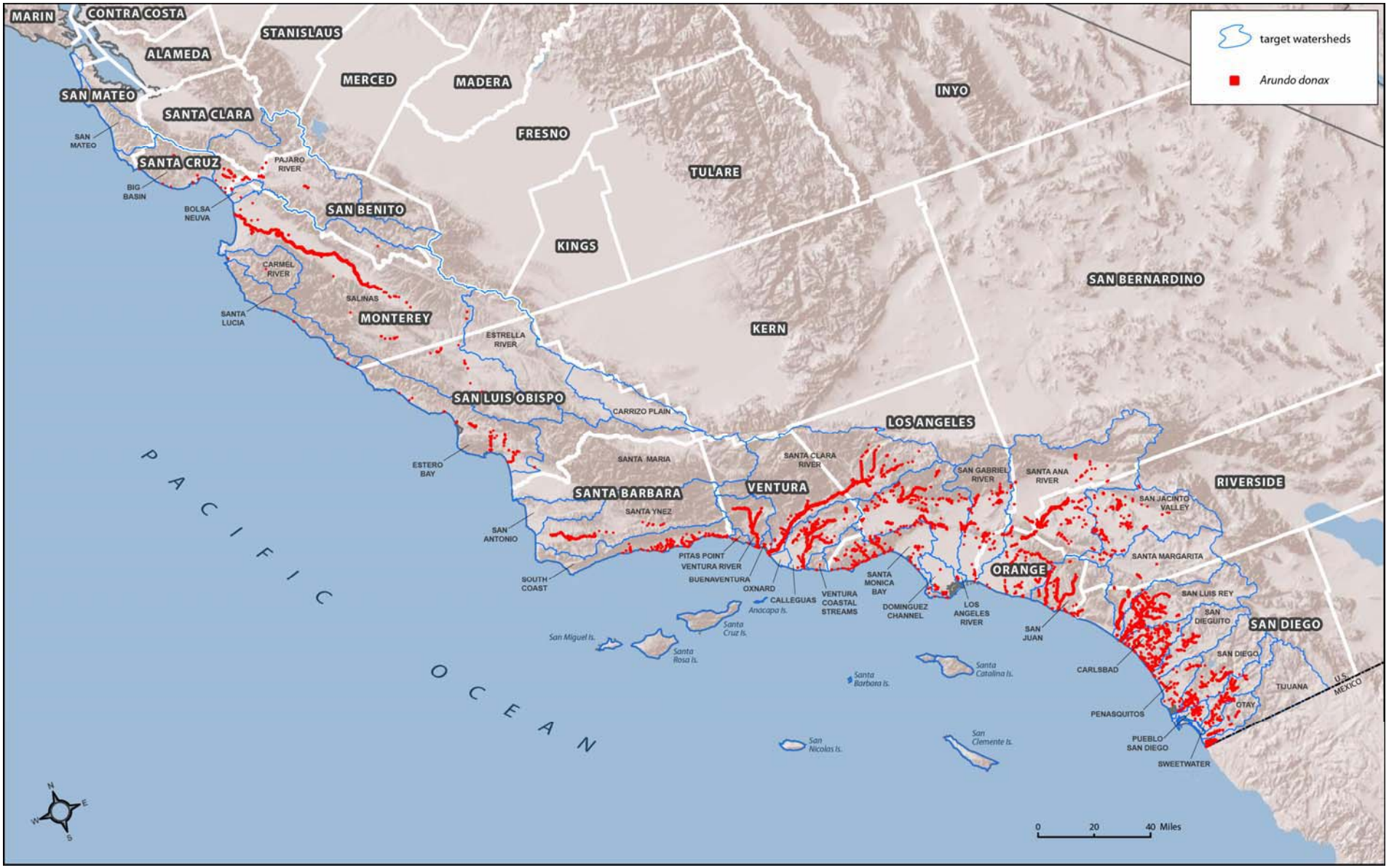


Figure 3-1. Distribution of *Arundo* mapped within the study area from Monterey to San Diego, CA.

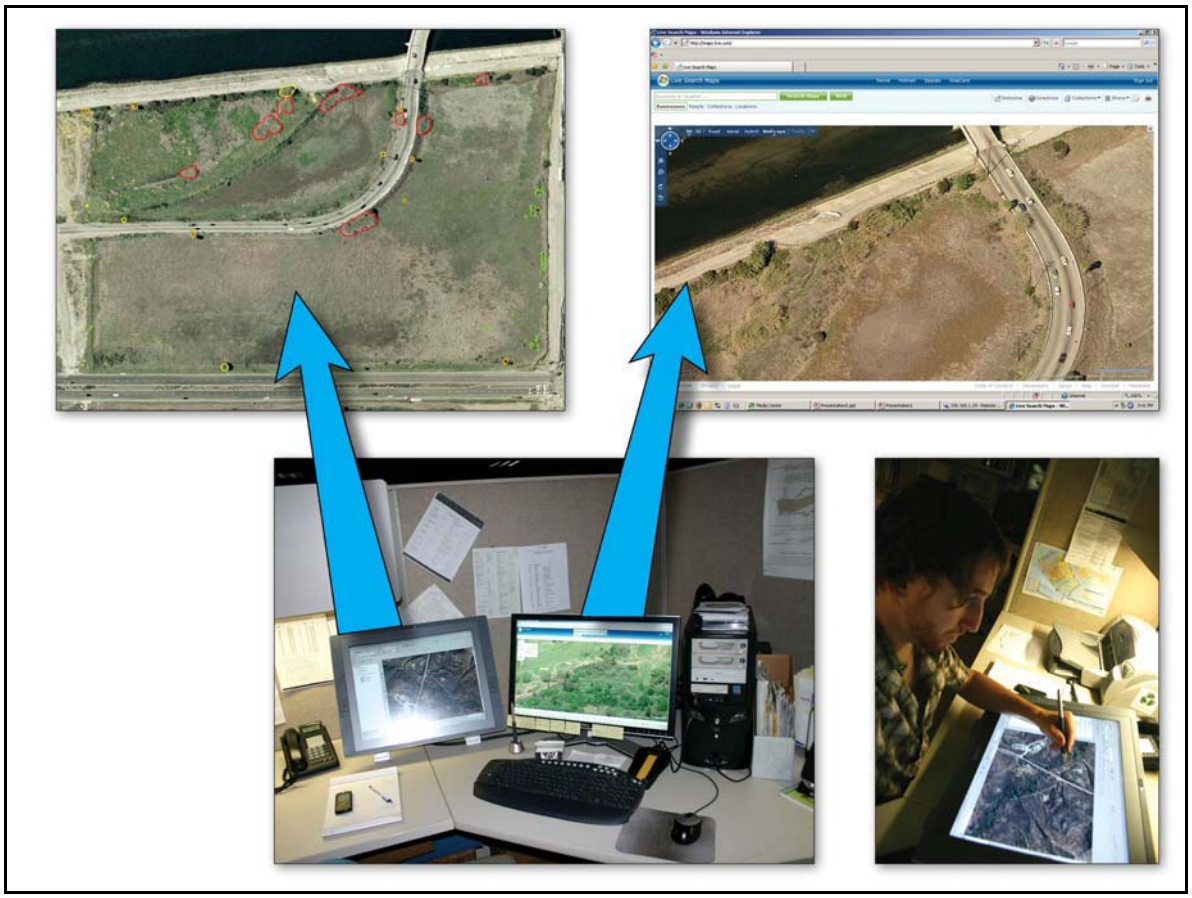


Figure 3-2. In-office surveys using a dual-monitor workstation.

Table 3-1. Data dictionary used for plant mapping.

Attribute	Notes
Plant Species	Common and scientific names are noted.
Percent Cover	70-100%= 100%; 50-69%= 50%; 15-49%=20%; 2-14%=5%
Plant Count	Estimated number of trees within a polygon
Average Height	Estimated tree height
Treatment Status	Status was marked as: treated, untreated, funded for treatment, or status unknown
Comments	Supplementary information
Observer	Person responsible for the last edit of a particular record
Mapping Methodology	Method was noted as: in-office survey, field survey, or combination
Date Mapped	Records that were only collected in-office took the date of the base photography as the map date; all other records used their observed field date
Data Source	Organization that collected the record
Watershed Name	HUC unit name
Gross Area (Acreage)	Total overall area in acres
Net Area (Acreage)	Total net area (factoring in percent cover) in acres

2) Data Transfer to Tablet

After the initial survey of a watershed was completed, the data was "checked out" of the GIS database and transferred to a ruggedized tablet PC. The field tablets used for this project (Xplore's iX104c3) were outfitted with GPS receivers (mounted or bluetooth) with an accuracy of 2-5 m (with real-time corrections) (Figure 3-3). The most current vertical aerial photography from the GIS database was also transferred onto the tablet as a base layer for the field mapping software. ESRI's ArcPad 8.0 was chosen as the mapping application because of its seamless integration between the field computers and central database back in the office. Toolbars in ArcPad were customized to optimize the time spent collecting data in the field.

Figure 3-3. Field surveys with ruggedized tablet PCs and integrated GPS.

3) Field Verification

After data was transferred to the field tablets, crews were sent out to verify the accuracy of the in-office surveys if locations were accessible and a line-of-sight could be established. Records were checked for spatial accuracy, percent cover estimation, and current treatment status. New populations and edits to existing populations were also collected by sketching directly on the tablet with a digital pen (Figure 3-4). The GPS functionality was only used only as a reference to orient the mapper's position on the basemap (i.e. high-resolution aerial photograph). Tracklogs in ArcPad (digital "breadcrumbs") were used to document surveyed areas and track progress/time spent mapping in the field.

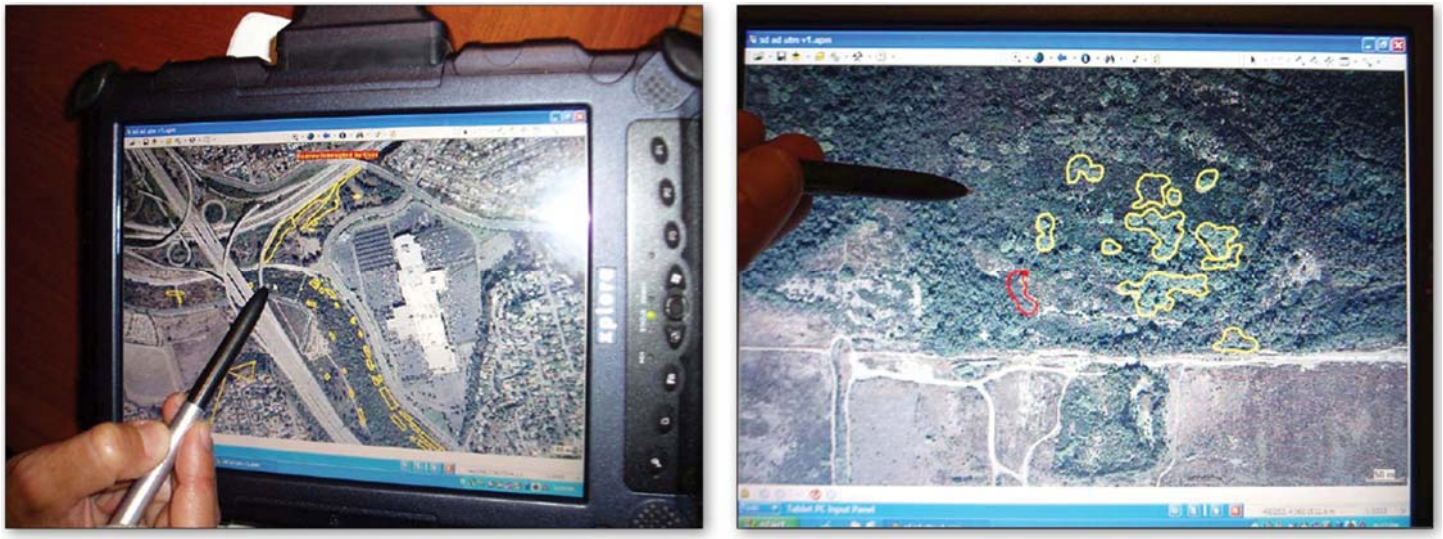


Figure 3-4. Digital sketch mapping.

4) Data Transfer To GIS

After field verification was completed for a given watershed, data is "checked" back into the GIS database at the office. Additional data attributes (watershed name, mapping status, acreage) were added through an automated process and existing attributes were re-checked for consistency.

3.1.2. Data Quality

The combination of methodologies mentioned above is the obvious choice for capturing the highest possible accuracy, but there were instances where either the in-house or field surveys were not feasible. In-house surveys were not completed when high-resolution imagery (6 in-1 ft vertical or 1 m plus oblique photography) was not readily available for a particular region. As field checking commenced, it became apparent that smaller clumps were often misidentified or omitted when high-resolution imagery was unavailable.

There were instances when field surveys were not achievable due to access (i.e. private property, difficult terrain, etc.) and/or general project time constraints. For instance, the Salinas River has thousands of smaller disconnected clumps of *Arundo* that were widely dispersed across several miles. Field checking all of these populations was not practical, nor was it achievable within the given timeline and budget. Preselected locations along the Salinas River were visited and field checked where it was inherently difficult to distinguish *Arundo* populations in-office. *Cortaderia* populations along the Central Coast also were not field verified. There are hundreds of miles of coastline covered by steep bluffs in this region that have a significant amount of *Cortaderia* present throughout the landscape. Given the time constraints, the area that needed to be covered, and the fact that this was species was a lower priority in terms of project goals, ground-truthing this extent was not achievable for the project.

It should also be noted that all species mapped were defined by their full footprint extent as interpreted from a vertical perspective. For *Arundo* in particular, this means capturing both the cane emergence zone and cane drape zone (as shown in Fig 2-13). Mapping populations in this manner can have an effect on acreage estimates, depending on the photo resolution used to delineate the footprint extent. Because individual canes are much more identifiable on the 6in. and 1ft. aerial imagery, the delineated

footprint of a population can be wider than a delineation of that same population using 1m imagery. Higher resolution, in turn, will boost acreage estimates, especially in areas where individual clumps are widely dispersed and cane drape zones are more extensive.

Attribute Accuracy

"Percent cover" was determined based on a rough visual interpretation from the ground. In some cases, values may be moderately under or overestimated because of issues with access to property and/or line-of-sight due to other vegetation cover, structures, etc. This holds true for *Arundo* and *Cortaderia* in particular. Based on local field comparisons of previous surveys that used a similar methodology, overall acreage totals tend to be underestimated by approximately 15-20% (Giessow pers. comm. 2010). Because the resolution of the base photography has significantly improved over time (1 m in 2001 compared to the present standard of 1 ft/6 in), it is expected that the acreage calculations now have a higher degree of accuracy.

"Treatment status" may not represent current ground conditions due to ongoing treatment programs that are currently unknown or not being tracked by the project team. Because this is intended to be a living database, the plan is to update treatment information periodically as the data becomes available.

There may be misclassifications of species because of the inability to ground truth a particular population, or because the field mapper misidentified the species. This holds true for the *Washingtonia robusta* and two *Cortaderia* species in particular. It is currently not possible to accurately distinguish between *W. robusta* and *Washingtonia filifera* when conducting in-office surveys alone.

Positional Accuracy

Positional accuracy may vary across the project extent due to fluctuating base imagery resolutions that were available when the in-house mapping took place. Data collected during the project is no better than that of the base photography's accuracy used to delineate a population's extent.

Cartographic offsets may be present in the data due to several conditions including (a) GPS accuracy affected by quality of unit, and/or poor signal due to canopy cover, terrain, cloud cover, time of day, etc; (b) scale and legibility constraints due to the basemap aerial photography's resolution and quality, and/or; (c) field mapper interpretational errors due to line-of-sight issues caused by dense vegetation, terrain, structures, etc.

Completeness

In order to accurately quantify impacts within each system, one goal for the project was to map the full baseline extent of all *Arundo* populations present within any given system over time. While the mapping team used 2006 imagery as the starting point for developing this baseline extent, some watersheds previously had large watershed-scale eradication programs in place. These include the Santa Ana, Santa Margarita, San Luis Rey, and Carlsbad watersheds. Subsequently, earlier datasets provided by local program managers as well as historic aerial photographs were used to fill in gaps for areas that were treated and re-vegetated prior to 2006. Therefore, it should be noted that the final data output is not a single snapshot for one specific year. There may be several time periods represented for a given area, particularly in San Diego County. Santa Ana Watershed *Arundo* acreage was also adjusted higher to reflect *Arundo* control (in the mid 1990's) that could not be documented in aerial photography. The acreage adjustment estimation was based on existing program management documentation and annual reports available through the Santa Ana Watershed Authority (SAWA).

It should be noted that *Arundo* stands were certainly missed within the study area, particularly small clumps and stands that were obscured by native tree canopy or scattered stands in areas with little *Arundo*. The mapping data set captures a majority of the population that occurs in the project area, but it does not capture all *Arundo*. For instance, a majority of neighborhoods outside of the immediate urban-wildland interface were not extensively surveyed for *Arundo*. Because these areas may be connected to streams and rivers, projects should re-evaluate this data set prior to utilizing it for a specific project or use.

Data set availability at BIOS and Cal-IPC

The GIS database (ESRI geodatabase) is currently hosted on the Department of Fish and Game BIOS (Biogeographic Information & Observation System) web-based mapping application. (http://bios.dfg.ca.gov/). The data sets are named:

Invasive Plants (Prct Cover) - Central_So. Cal Coastal Watersheds [ds646]

Invasive Plants (Species) - Central_So. Cal Coastal Watersheds [ds645]

It can be viewed and printed from this platform along with a multitude of other spatial data. The geodatabase is also available for download at Cal-IPC (http://www.cal-ipc.org/ip/mapping/arundo/index.php). This website also hosts a PDF version of this report and associated map books tied to the distribution and listed species co-occurrence with *Arundo*). There is currently no funding to maintain or update the invasives GIS data set. If future revisions do occur, updates will be indicated on the Cal-IPC website.

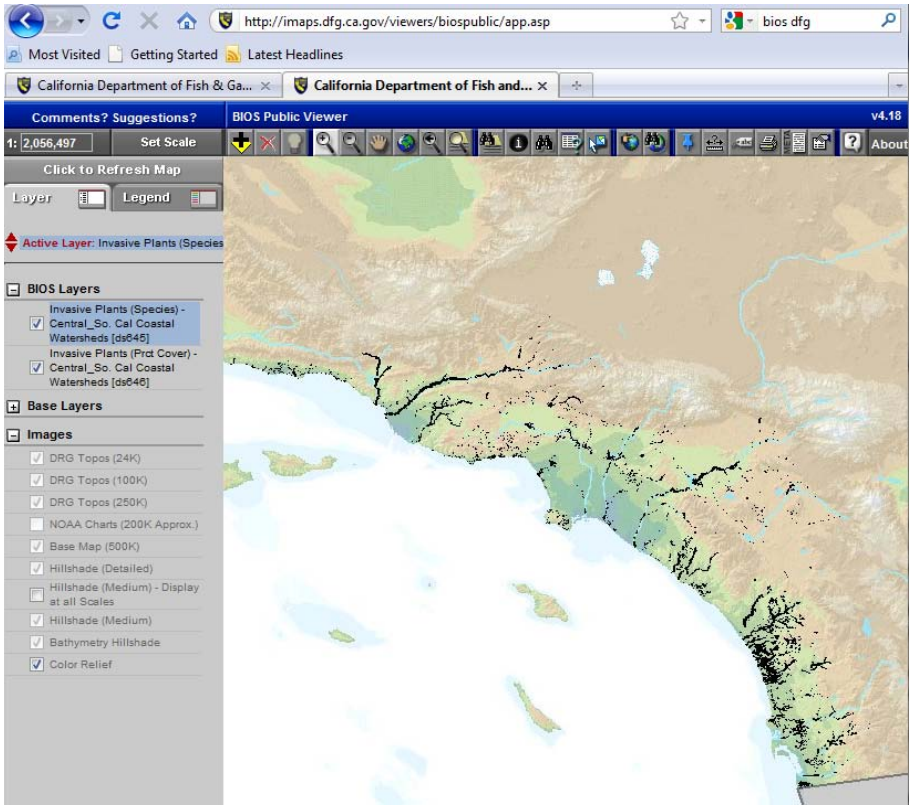


Figure 3-5. DFG BIOS data viewer with invasive plant data set active.

Figure 3-6. Cal-IPC web site project page for *Arundo* mapping downloads.

3.2 Results: Acreage by Watershed and Region

Arundo acreage for coastal watersheds from Monterey to San Diego was estimated to be 8,907 acres at its peak distribution (Table 3-2). This captures the 'full maximum extent' of *Arundo* on all watersheds within the study area prior to the initiation of control programs (Figure 3-1). This data will be used to examine and quantify impacts in the chapters that follow. In most areas mapped, dense stands (>80% cover) were the 'typical' stand structure. This is not surprising given the clonal nature of the plant. The largest exception to this observation was the Salinas River, which had many expansive areas with low *Arundo* cover. This is unusual for *Arundo* and may reflect water management practices on the river that have made flows seasonal over the last 20 years. For this reason, 'net' acreage is also given (gross acreage multiplied by the noted stand-specific *Arundo* cover). Examination of Table 3-2 shows that most *Arundo* stands on watersheds were mapped as having high cover, such that gross and net acreage values are similar. Later sections of the report use acreage values that are most relevant to the particular effect being looked at. The fire chapter uses gross acreage, while biomass and water use (which are sensitive to cane density) use net figures.

This study's mapped value of 8,907 acres, although high, is far lower than some estimates of *Arundo* acreage, even for individual watersheds. Santa Ana River has been reported as having over 10,000 acres of *Arundo* (Iverson 1993). This highlights the need for a more standardized and consistent approach to mapping *Arundo*. Many programs continue to map *Arundo* in mixed vegetation classes. This can lead to drastic overestimation of *Arundo* biomass and distribution. Vegetation mapping is very different then species-specific mapping and they should not be used interchangeably. Newer programs, such as on the Ventura and Salinas Rivers and in the San Diego region, use *Arundo*-specific mapping. This data set will aid all programs in using a standardized approach to gauging *Arundo* distribution and abundance.

The *Arundo* mapping also tracked treatment status. Impressively 36% of *Arundo* distribution is already under management/control (Table 3-2). This reflects a substantial investment of federal, state, and local

resources. It is encouraging to see significant acreage has been controlled. Several watersheds have achieved particularly high rates of initiated control including: Santa Margarita (99%), San Luis Rey (90%), Carlsbad HU (67%), San Dieguito (51%), Ventura (47%), and Santa Ana (40%). Several watersheds that are heavily invaded have had little or no work occur in them, such as Salinas, Santa Clara, and Calleguas. A later section of this report will examine watershed-based programs and their status.

The *Arundo* mapping acreage is an important tool for not only quantifying impacts but also planning and implementing control efforts. These accurate estimates of *Arundo* acreage allow for better project descriptions, budgets and rationalization of project needs. High quality spatial mapping also assists with environmental planning and permitting. Agencies can more precisely see where *Arundo* occurs, and sensitive species and other concerns can be addressed more specifically. State level funding and project prioritization decisions may also be made in a broader context. Multiple factors still need to be weighed, but this high-resolution mapping gives land managers a stronger quantification of both benefit and cost, much more than was possible prior to the project.

As noted under the discussion of accuracy, this data set under-represents the acreage of *Arundo*. The *Arundo* mapped only accounts for stands that were visible in imagery and field reconnaissance. While there are very few instances of misclassification, there are *Arundo* clumps and portions of stands that are missed due to obstructed views and/or it was too small to see. Previous work by the authors has indicated that detailed re-mapping of areas during control has typically indicated a 15-20% underestimation of *Arundo*. This data set may be slightly more accurate (10-15% underestimate) in many areas as aerial imagery has improved in quality and resolution within the last several years. It is highly unlikely that *Arundo* acreage has been over estimated by this study.

3.3 Conclusions: Distribution and Abundance

- *Arundo* mapping documented a total (gross) of 8,907 acres of *Arundo* within the study area. Net acreage, adjusted for *Arundo* cover, was 7,864 acres. This represents the peak distribution of *Arundo* in the study area prior to control activities. (Section 3.2)
- Over 3,000 gross acres of *Arundo* have been treated to date within the study area. This is 34% of the peak *Arundo* acreage occurring within the study area. (Section 3.2)
- Three large, contiguous watershed units have the highest levels of *Arundo* control observed in the study area: Santa Margarita at 99%, San Luis Rey at 90% and Carlsbad HU at 70 %. (Section 3.2)
- Most other invaded watersheds in the study area with more than 100 acres of *Arundo* have had at least 30% of their *Arundo* treated. Noted exceptions to this are Calleguas, Salinas and Santa Clara watersheds, which have less than 10% of their *Arundo* acreage under treatment. (Section 3.2)

Distribution and abundance data is extremely valuable because it quantifies past and current levels of invasion on watersheds, allows detailed examination and quantification of impacts, and facilitates watershed based control. Programs can use the spatial data to implement watershed based control, develop proposals and budgets, and manage control programs.

Table 3-2. *Arundo* acreage in central and southern California by hydrologic unit.

Hydrological Unit	Total Area (Acres)	Treated *Arundo*		Untreated *Arundo*		Total *Arundo*		Percent treated
		Gross Acres	Net Acres	Gross Acres	Net Acres	Gross Acres	Net Acres	
Big Basin[3]	235,181			0.3	0.3	0.3	0.3	0%
Bolsa Nueva	32,649			0.2	0.2	0.2	0.2	0%
Buena Ventura	13,226			0.5	0.5	0.5	0.5	0%
Calleguas	220,527	1.4	1.4	230.0	227.7	231.5	229.1	1%
Carlsbad[3]	135,753	103.7	103.7	44.0	44.0	147.7	147.7	70%
Carmel River	163,643			0.0	0.0	0.0	0.0	0%
Carrizo Plain	278,848							
Domigz Channel	81,760			2.6	2.6	2.6	2.6	0%
Estero Bay[3]	480,544	1.2	1.2	15.0	8.6	16.1	9.8	12%
Estrella River	610,278							
Los Angeles	533,834	16.3	16.3	116.5	115.1	132.8	131.4	12%
Otay	98,380			18.6	18.6	18.6	18.6	0%
Oxnard	18,721							
Pajaro River	838,942			8.1	8.1	8.1	8.1	0%
Penasquitos	103,790	2.2	2.2	21.4	21.4	23.6	23.5	9%
Pita's Point	14,051			0.5	0.5	0.5	0.5	0%
Pueblo S. Diego	37,546	0.0	0.0	15.4	15.0	15.4	15.0	0%
Salinas	2,272,492	137.4	106.4	1,868.7	1,225.3	2,006.1	1,331.7	8%
San Antonio	135,624							
San Diego	278,977	56.2	56.2	94.0	93.3	150.2	149.5	38%
San Diego Bay	10,931							
San Dieguito	221,555	89.8	89.8	85.2	85.2	175.0	175.0	51%
San Gabriel	456,886	3.5	3.5	41.0	40.8	44.6	44.3	8%
San Juan[3]	317,261	13.2	13.1	161.9	160.3	175.2	173.4	8%
San Luis Rey	358,662	612.4	612.4	71.4	71.4	683.9	83.9	90%
San Mateo[3]	164,484							
Santa Maria	1,188,373			0.1	0.1	0.1	0.1	0%
Santa Ana[1]	1,752,490	1,083.1	1,006.9	1,640.7	1,526.8	2,723.9	2,533.8	40%
Santa Clara	1,037,141	0.3	0.3	1,081.0	1,018.5	1,081.3	1,018.8	0%
Santa Lucia[3]	193,641			0.1	0.1	0.1	0.1	0%
Santa Margarita	475,449	684.7	684.7	4.2	4.2	688.9	688.9	99%
Santa Monica[3]	267,152	0.4	0.3	18.3	18.2	18.6	18.5	2%
Santa Ynez	576,066			21.4	6.0	21.4	6.0	0%
South Coast[3]	240,092	7.8	7.8	22.0	22.0	29.8	29.8	26%
Sweetwater	146,781	5.7	5.7	36.7	36.1	42.3	41.8	14%
Tijuana[2]	299,181	41.1	41.1	94.5	89.5	135.6	130.6	31%
Ventura[3]	22,475			0.1	0.1	0.1	0.1	0%
Ventura River	144,669	143.6	117.4	188.4	132.5	332.0	249.9	47%
Totals:	**14,458,055**	**2,995.5**	**2,861.9**	**5,911.7**	**5,001.8**	**8,907.2**	**7,863.7**	

[1]Adjusted- added 400 ac treated for older treatments that were not detectable; [2]Adjusted- added 40 ac treated for older treatments that were not detectable; [3]Hydrologic Unit composed of many smaller coastal streams/watersheds.

4.0 IMPACTS OF *ARUNDO*: *Arundo* Water Use and Stand Transpiration

4.1 Determining *Arundo* Water Use (Stand transpiration)

Water loss from watershed systems resulting from *Arundo donax* invasion is a topic of serious concern, but realistic or direct estimates of such losses are scarce. This chapter attempts to estimate water loss (in mm per day per m^2 of ground area) from *Arundo* stands in southern California as a function of *Arundo* leaf transpiration. Study estimates utilize reported transpiration rates for *Arundo* from a variety of areas coupled with leaf area indices and cane densities measured in the study area. Comparisons are also made between this study's estimates of stand-level water loss to those reported by others.

4.1.1 Background:

Vegetation in a system contributes to water loss primarily as function of *transpiration* through the leaves (E), but *evaporation* of water from exposed soil (i.e., not covered by plant canopy or litter) is also a contributing factor. Combined water loss via plant transpiration and surface evaporation is termed *evapotranspiration* (ET). Measuring ET is often a complicated process (Allen et al. 1998), but plant physiology studies often directly measure E using individual plant leaves and gas analyzers. The leaf-based measurements (E_l) can then be scaled up, based on leaf area per unit area of ground ("leaf area index" or LAI), to yield estimates of water loss at the stand scale via plant transpiration (E_{stand}, or water lost per unit area of ground). In a mature vegetation stand, where much of the ground is shaded, E_{stand} will account for the majority of total water loss via ET (Allen et al. 1998).

4.1.2 Methods

In an effort to estimate water loss from *Arundo* stands in the study area, published scientific and unpublished gray literature was searched for direct estimates of *Arundo* transpiration (E) or evapotranspiration (ET) from *Arundo* stands. The search yielded three Master's thesis studies that measured *Arundo* E_l (Abichandani 2007, Watts 2009, Zimmerman *unpublished data*), two of which then scaled up to E_{stand}. One direct measurement of ET was also found from a Mediterranean region study reported in a conference proceedings (Christou et al. 2003) and one additional internet report in which stand-scale *Arundo* water loss was estimated using data from Zimmerman's thesis work (Hendrickson & McGaugh 2005). LAI values are a very important factor in calculating stand transpiration rates. Additional data on *Arundo* stand LAI is also reported for papers that examined stand structure (Sharma et al. 1998, Spencer 2006).

The *Arundo* leaf-scale transpiration rates (E_l) reported in the three Master's theses were fairly similar. To be conservative, the lower measured value from the Abichandani study was used to estimate stand-scale water loss via transpiration (E_{stand}) for this study. In order to scale up from the average reported E_l to E_{stand} for the study area LAI for the study area was calculated based on filed sampling of *Arundo* stand structure. *Arundo* cane density and a number of structural traits on canes taken from 14 sites in the southern California study area were measured (Figure 2-1). Sites were selected in the field to represent mature *Arundo* stands, not areas that had been previously controlled, burned or otherwise disturbed. Mature *Arundo* stands are the majority of the acreage in the study area. The goal of this study is to measure water use of mature *Arundo* stands. Mature *Arundo* stands do vary significantly in cane density and robustness of growth- predominantly as a function of water availability. For this reason samples were taken from 11 'wet' sites (73%) and 3 'dry' sites (27%). This is approximately the proportion of wet and dry stands observed in field mapping within the study area.

One or two representative "old" (>1yr) *Arundo* canes were collected from each of the 14 sites (17 canes total) and one "new" (1st year) cane from three of the sites (Table 4-1). Leaf area was calculated as length*width*0.74 based on an examination and measurement of leaf shape. Structural traits measured on old canes included (a) length of and number of leaves on the leader portion (i.e. the portion of the central branch with green leaves) and (b) number and length of secondary branches. Individual leaf area for all leaves was then measured on a subset of leader canes (3 canes, 60 leaves) and secondary branches (18 branches, 200 leaves). Only the green photosynthetic area was measured on leaves. Cane (stem) surface and leaf sheaths were not included in calculations of photosynthetic area. The sum of measured leaf areas for each leader or branch was used to determine the average total leaf area per unit length of leader cane or secondary branch (26.8cm^2 leaf area/cm leader and 5.7cm^2 leaf area/cm secondary branch). Total expected leaf area was then calculated for all 17 old canes collected as a function of their leader and total secondary branch lengths multiplied by the appropriate leaf area/cm branch value.

Structural traits measured on new canes included the length of the cane, number of leaves and total leaf area, calculated as the sum of areas measured for each individual leaf (3 canes measured, 69 leaves). An average leaf area for a new cane was then calculated. To determine site-specific LAI, the total expected leaf area of each collected old cane was multiplied by the number of old canes counted in a representative square meter within the site and added to the average total leaf area of a new cane multiplied by the density of new canes in that same square meter (Table 4-2). Stand adjusted LAI is also given, representing for true stand-based leaf area (adjusts for area with no canes emerging, see Section 2.3). As there are significantly more old canes per unit area in a mature *Arundo* stand, greater effort was expended in calculating old cane leaf area.

Secondary branch leaf area relationships were explored using three different formulas: a linear regression, a quadratic regression and the branch length to leaf area relationship that was used. All three relationships were fairly consistent, generating final secondary branch LAI values ranging from 15.0 (linear), 19.0 (quadratic), and 17.0 (average leaf area per cm) (Figure 4-1, Table 4-2).

While leaf-based transpiration (E_l) is often reported in mmol $m^{-2}_{\text{leaf area}}$ s^{-1}, different studies utilize discrete (and sometimes unspecified) methods for scaling up to the level of the stand. Consequently, there appears to be no clear convention in units used to report such water loss (e.g., kg m^{-2} hr^{-1} or mm/day, etc.). For ET water loss is often reported in mm/time (Allen et al. 1998), which is roughly equivalent to a water loss of 1 liter/m^2/unit time. Following the assumption that the bulk of evapotranspirative loss in a mature stand is accounted for by transpiration, mm/day was used to report this study's calculated E_{stand} for *Arundo*. To scale from E_l to E_{stand} in mm/day: (1) average E_l was multiplied by the molar mass of water, giving grams H_2O $m^{-2}_{\text{leaf area}}$ s^{-1}; (2) divided by the density of water at 25C, giving m^3 H_2O $m^{-2}_{\text{leaf area}}$ s^{-1}; (3) multiplied by the LAI (in m^2 leaf area per m^2 ground area), giving m^3 H_2O $m^2_{\text{ground area}}$ s^{-1}; (4) divided m^3 H_2O by 0.001 to yield mm H_2O $m^{-2}_{\text{ground area}}$ s^{-1}; and (5) multiplied by 34,679 s/day of daylight (9.6 hrs or 3,516 hrs/yr - this value is based on average sunlight per day for the study area with 932 hours subtracted for winter dormancy. To compare this study's E_{stand} estimate with those reported in the other papers, reported E_{stand} values were sometimes converted from other units. Thus, some conversion error should be expected. However, when possible and for the greatest consistency in comparisons, E_{stand} was recalculated using average E_l and LAI values from the paper and following the general method above. These recalculated values are reported along with those given directly in the paper (Table 4-3). This re-calculation of values for other studies validates the process being used in this study to scale up from leaf-based transpiration to stand-based transpiration.

Table 4-1. Structural characteristics measured on *Arundo* canes collected from 14 sites in southern California study area.

Plot	Cane height (m)	Cane diam (mm)	Leader Length (cm)	Leader # leaves	Ave leader single leaf area (cm^2)	# secondary branches	Ave branch length (cm)	Ave branch # leaves	Ave branch leaf area	New cane # leaves	Ave new cane single leaf area
CC1	5.1	20	19	10	-	15	47.7	-	-	21	168.7
CC2 #1	9.71	28	90	23	83.7	57	11.7	4.5	10.5	-	-
CC2 #2	8.45	27	82	23	117.3	9	70.9	13.0	63.2	-	-
SA1	6.11	25	45	17	-	34	21.4	-	-	-	-
SA2	6.06	25	32	15	58.5	31	36.2	23.0	44.4	-	-
SA3	7.74	27	74	28	-	33	10.7	-	-	-	-
SA4	7.42	26	33	12	-	48	20.0	13.5	29.5	-	-
SC1	9.9	25	23	12	-	31	46.0	11.0	34.8	-	-
SC4	4.16	22	0	0	-	34	41.3	14.0	19.2	-	-
V1	8.41	26	0	0	-	28	43.4	-	-	21	216.2
V2	6.21	24	76	20	-	14	41.8	-	-	-	-
SD#1a	8.08	26	65	16	-	29	56.1	10.9	34.9	-	-
SD#1b	8.1	24	66	13	-	25	60.0	-	-	-	-
SC2	4.33	22	11	7	-	11	37.0	-	-	-	-
SC3	4.22	18	19	7	-	7	37.1	-	-	27	227.9
SC5 Lg	3.77	25	13	8	-	10	26.2	-	-	-	-
SC5 Sm	2.61	15	12	7	-	5	22.8	-	-	-	-

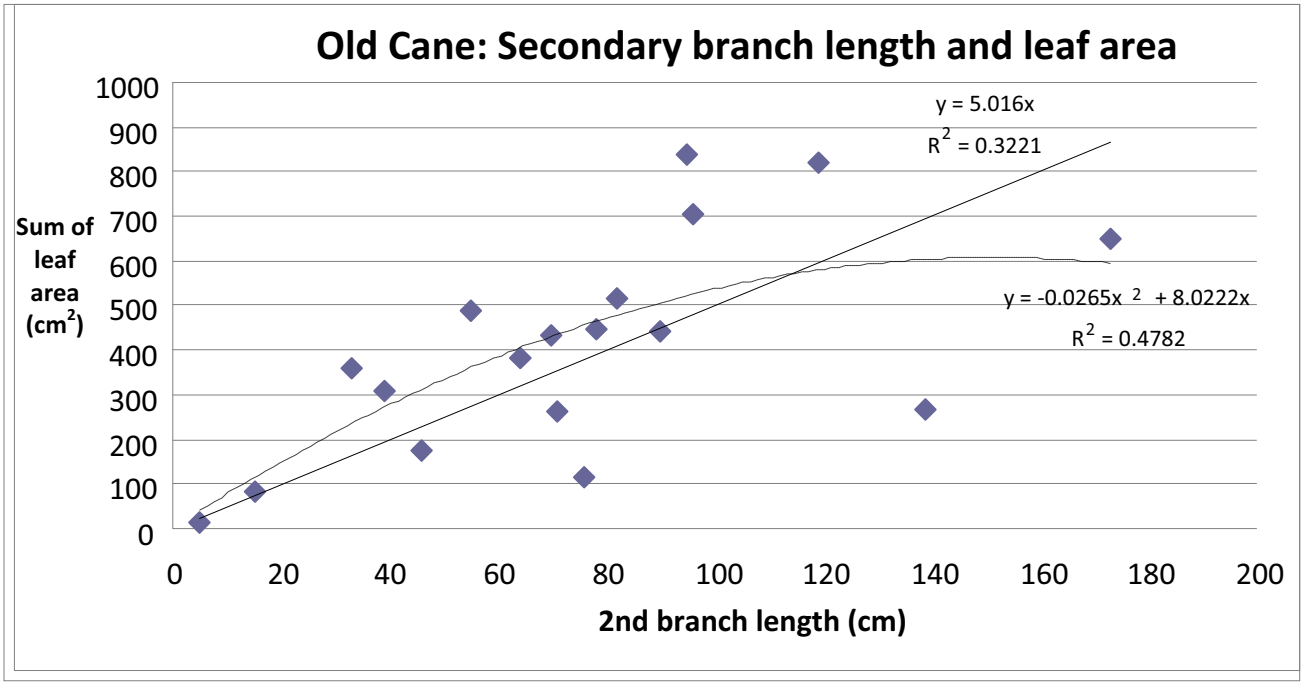


Figure 4-1. Secondary branch leaf area to length relationship.

Table 4-2. *Arundo* cane densities and leaf area indices (LAI) for 13 of the 14 study sites.
The contribution of leader canes, secondary branches, and new canes toward the total LAI for the site is shown. Cane densities were not measured on the San Diego site, thus LAI could not be computed.

Plot	Hydrology	Leaf area (m^2) per cane				Cane density/m^2		Leaf area/m^2 ground (LAI)				
		Leader: old cane	2ndry branch	Total old cane	New cane (<1yr)	Old cane	New cane (<1yr)	Leader old cane	2ndry branch	New cane	Total: old+new	Stand adjusted (70%)
CC-1	Wet	0.05	0.41	0.46	0.47	53	4	2.7	21.6	1.9	26.2	18.3
CC-2	Wet	0.23	0.37	0.6	0.47	29	4	6.7	10.8	1.9	19.4	13.6
SA-1	Wet	0.12	0.41	0.53	0.47	66	2	7.9	27.4	0.9	36.2	25.4
SA-2	Wet	0.09	0.64	0.73	0.47	30	2	2.6	19.2	0.9	22.7	15.9
SA-3	Wet	0.20	0.20	0.4	0.47	84	11	16.6	16.9	5.2	38.8	27.1
SA-4	Wet	0.09	0.55	0.64	0.47	19	4	1.7	10.4	1.9	14.0	9.8
SC-1	Wet	0.06	0.81	0.87	0.47	25	2	1.5	20.3	0.9	22.8	15.9
SC-4	Wet	0.00	0.80	0.8	0.47	36	4	0.0	28.8	1.9	30.7	21.5
V-1	Wet	0.00	0.69	0.69	0.47	28	5	0.0	19.4	2.4	21.8	15.2
V-2	Wet	0.20	0.33	0.53	0.47	30	5	6.1	10.0	2.4	18.5	12.9
SD1	Wet	0.18	0.89	1.07	0	44	0	7.7	39.2	0.0	46.9	32.8
SC-2	Dry	0.03	0.23	0.26	0.47	24	2	0.7	5.6	0.9	7.2	5.1
SC-3	Dry	0.05	0.15	0.2	0	40	0	2.0	5.9	0.0	8.0	5.6
SC-5	Dry	0.03	0.09	0.12	0.47	26	2	0.7	2.4	0.9	4.0	2.8
	Mean:	**0.09**	**0.47**	**0.56**	**0.41**	**38.1**	**3.4**	**4.1**	**17.0**	**1.6**	**22.6**	**15.8**
	StdDev:	**0.08**	**0.26**	**0.27**	**0.17**	**18.3**	**2.7**	**4.6**	**10.3**	**1.3**	**12.4**	**8.7**

Table 4-3. Summary of *Arundo* transpiration (E) and evapotranspiration (ET) reported in literature or calculated as described in the text.

Study	Location	Stand biomass (t/ha)	Average single leaf area (cm^2)	Average # leaves per cane	Leaf area per cane (m2)	Average # canes per m^2	LAI (m^2 leaf/m^2 ground)	Peak (mid-day) E_l ($mmol/m^2/s$)	E_{stand} (mm/day)
Direct Measurements of transpiration (E)									
Abichandani 2007	Santa Clara River, CA		163.3 (132.5-215.9)[1]	25.0 (21.5-28.4-27.9)	Newer (1 to 3 yr): 0.4082	Ave 34.9 (riverbed 29.2, n= 43; terrace 40.6, n=26)	14.25	4.03 (1.89-5.80)[a]	41.1 (36.4)[a]
Watts 2009	Rio Grande River, TX						4.1 (3.4-6.1) and 4.5	4.3 (1.6-8.4)[b]	9.1 (11.0)[b]
Zimmerman (unpublished)	Napa River, CA							6.3 (2.5-11) Summer only	
Indirect calculation of stand-level transpiration									
Cal-IPC (this study)	Southern California	155	1st yr: 206.3 > 1 yr: leader 86.5, 2ndry branch 33.9	1st yr: 23 (SD3.5) >1 yr old: leader 12.6 (SD8.3) + 2ndry branch lvs 271.6 (SD 174.9) = 284.2	1st yr: 0.474 >1yr: 0.556 (leader 0.100, 2ndry branch: 0.457)	41.5 (SD 19.7)	15.8	Used 4.03 in calcs	40.0
Iverson 1998	Based on rice								4.7[d]
Hendrickson & McGaugh 2005	Cuatro Cienegas, Mexico								17.3[d]
Other structural data									
Spencer 2006	16 sites across US (leaf area is north CA)	171	1st year: 520.7	1st yr:10.3(SD 6.1) >1 yr old: 100.6	1st yr: 0.5362 > 1yr old: 0.1162	74.5	11.22	Used 4.03	28.3[c]
Sharma et al. 1998	India	36-167				53 to 82	12.6 to 28.7		
Direct Measurements of Evapotranspiration									
FAIR 2000-EU study	Europe								3.22
Christou et al. 2003	Greece & Italy	21.1							1.6 (ET)

[a] Average across season, and wet and dry sites; [b] E_{stand} as calculated using formulas applied to this study; [c] E_{stand} calculated using formulas from this study using LAI from the that paper; [d] E_{stand} reported in paper, but insufficient additional data to use formulas in this study.

4.1.3 Results and Discussion

Examination of calculated water loss values for *Arundo* (both reported and results from this study) reveals a substantial amount of variation in E_{stand} (Table 4-3). While some of this variation may be an artifact of differences in scaling procedures and conversion factors, variation should be expected. Both *Arundo* transpiration (E) and evapotranspiration (ET) are affected by prevailing ambient conditions (temperature, humidity, wind, and available soil water) as well as characteristics of the vegetation. For example, both Abichandani (2007) and Watts (2009) found higher leaf-based transpiration (E_l) rates for *Arundo* in areas with higher available soil moisture. Zimmerman's unpublished *Arundo* transpiration data showed E_l also increases with temperature, while Abichandani and Watts found higher E_l rates in summer and spring when temperatures are higher. Thus, variation should be expected among regions where such conditions are likely to vary both within a season and on average across a year. Nonetheless, the average E_l rates (accounting for seasonal and hydrological variation) reported by Abichandani and Watts are quite similar despite the different study regions (Table 4-3). Zimmerman's average E_l is higher, but those measurements were only taken during the summer while the others studies included cooler seasons.

Given the similarities in E_l, variation in E_{stand} across studies must be primarily driven by factors other than leaf-scale transpiration rates. Watts (2009) showed much lower E_{stand} than either Abichandani (2007) or this study, and it should be noted that Watts' estimate includes refinements that would lead to a lower average. Specifically, prior to scaling-up transpiration rates, Watts divided the *Arundo* canopy into vertical layers and adjusted E_l rates downward for shaded leaves. In addition, Watts accounted for diurnal fluctuations in E_l in his scaling operations. It is unclear whether Abichandani's tabled E_{stand} values include such refinements, but this study's calculations are based on average peak E_l rates for sunlit leaves without any adjustment downward for shading or diurnal drops in leaf transpiration. As a result, the E_{stand} estimate for this study is probably more representative of an average maximum water loss, rather than an overall average. Yet, these adjustments are still unlikely to be the primary cause of the large differences seen in E_{stand} among studies. It is reported LAI that appears to be driving different stand based transpiration estimates. The average LAI reported by Watts (4.1) is much lower than that reported by Abichandani (14.25), which is slightly lower than results found on this study's sites (15.8) (Table 4-3). Consequently, differences in *Arundo* stand structure are likely the primary factor driving variations in E_{stand} across all studies reviewed.

Structural differences probably explain the lower estimate of E_{stand} reported by Hendrickson & McGaugh (2005) despite their likely use of a higher E_l rate than used in this study (i.e., Zimmerman's summer measures). However, it is not clear exactly what E_l rate they used or exactly how their scaling-up from leaf to stand was performed, though some adjustments for lower daily and seasonal E_l rates were incorporated. Variation in *Arundo* stand structure could also partly explain the lower daily ET rate derived by Christou et al. (2003) in the Mediterranean (Table 4-3). For example, the studies by both Abichandani (2007) and Christou et al. were performed on relatively young, artificially created *Arundo* stands, which may have shorter canes or less leaf area overall than naturally-occurring, mature stands. In Abichandani, the stand was 3-4 years old. Average cane densities were similar to those found in this study (Table 4-3), but the average area of a single leaf was larger and more comparable to leaves on new canes from this study (Table 4-1, average = 206.3cm^2). In addition, the average number of leaves per cane reported by Abichandani (Table 4-3) is comparable to the average number of leaves counted on just the leader portion of a cane plus only one secondary branch in this study (Table 4-1). Thus, it seems likely Abichandani's planted stand had bigger but far fewer leaves overall, as reflected in the lower LAI compared to this study. This may also be true of the Mediterranean stands reported in Christou et al., which were 1-3 years old during the study. Christou et al. did not report any leaf area data, but their reported average *Arundo* biomass (21.1 tons/ha) is roughly 7 times lower than the average biomass

estimate generated for this study's stands (156.8 tons/ha). Given such large differences in stand structure among the study regions, it is likely that even a more refined measurement for this region would still be much higher than those in the other regions reviewed.

However, the large disparity between the daily ET rate derived from Christou et al. and the E_{stand} rates reviewed here becomes more pronounced when one considers that water lost via transpiration and evaporation combined should be higher, even if only slightly, than transpiration alone. It is unlikely that structural differences, differences in regional climate, and errors in converting data from one unit convention to another can fully explain the large differences seen here in E_{stand} versus ET. Instead, the comparison demonstrates the difficulty of generating realistic estimates of water loss from *Arundo* stands. Utilizing locally measured rates of leaf transpiration and stand structure is a good start, but complex scaling procedures will likely yield better estimates of stand-scale transpiration losses. Ultimately, though, actual locally measured ET may be more reliable, though perhaps more costly. Future studies need to focus on determining ET of mature *Arundo* stands that are comparable to *Arundo* stands in the field that have high leaf area and high biomass per unit area.

4.2 *Arundo* Water Use Across Study Area

This study found an average leaf area (LAI) for *Arundo* stands of 15.8 m^2/m^2. This value was within the range of LAI values reported by other studies (4.1 - 28.7; Table 4-3). The study area LAI value was then used with published leaf transpiration values to generate a stand-based transpiration value of 40 mm/day (Table 4-3). There are only two published studies for *Arundo* stand based transpiration. One study found a similar stand transpiration value of 41.1mm/day (Abichandani 2007). It was conducted on the Santa Clara Watershed which is one of the watersheds within this studies project area. Stand structure, density and leaf area were all comparable to data collected for this study. The other published paper found a much lower stand based transpiration value of 9.1 mm/day (Watts 2009). This study was on the Rio Grande River in Texas. Stands there were shorter and had significantly lower leaf area (Table 4-3).

The current study and the two other published studies would be classified as 'leaf area transpiration measurements scaled up using LAI'. Additional studies looking into stand based water use are definitely needed and would preferably utilize a range of methods used to measure stand based transpiration/water use. Other methods include: lysimeters (tank with soil and plants with controlled water supply), base flow separation studies (stream inflow and outflow studies), analysis of diel groundwater fluctuations, semiemperiacal models, micrometeorological approaches (Brown Ration Energy Balance) and eddy covariance (as outlined in Shafroth 2005).

Using the stand-based transpiration values from this study to calculate water use per acre generates water use estimates that are very high (Table 4-4). Water consumption per acre of *Arundo* is 48 ac ft/yr, and this is far above published values for most vegetation (Johns 1989). Even with the high LAI values measured in this and other studies, an average annual stand-based transpiration is likely to be closer to 20 mm/day, which equals 24 ac ft/yr/ac of water use. The value of 20 mm/day is still at the high end of values published for other 'water hungry' vegetation types such as *Phragmites* (Moro et al. 2004), which is similar in structure and habit to *Arundo*, albeit smaller (less biomass and lower LAI values reported).

Water loss via ET in an *Arundo* stand would not equal the water gained or 'saved' through *Arundo* control. Removal of *Arundo* from riparian systems would likely increase water lost to evaporation, runoff, and any water use of re-colonizing vegetation (see Watts 2009 and/or Shafroth 2005 for additional discussion and references).

A replacement vegetation water use value of 3.3 mm/day or 4 ac-ft/yr/ac was used in our analysis (Table 4-4). This was based on a 'typical' vegetation mix that replaces *Arundo*, which is composed of: 25% trees, 25% shrubs, 25% herbs, and 25% open/un-vegetated. Water use was estimated based on data collected in a major water use review paper that compiled data from hundreds of studies using a wide range of water use measuring methods (Johns 1989). This data, along with a review by Shafroth et al. (2005), were used to approximate replacement vegetation water use. Compared to the estimates shown here for *Arundo,* the lower and more restricted range of replacement vegetation water use estimates suggests that most types of replacement vegetation will potentially use significantly less water.

As within *Arundo* stands, water loss under alternative states is probably best determined through direct measurement or complex models, and very few reports of such exist for riparian vegetation within the study area. Reported estimates of ET or E_{stand} for native riparian vegetation in other areas may be a good starting point for comparison, but many of these studies were conducted in the more arid southwestern portion of the U.S. where water availability may be significantly less than the coastal watersheds of southern California (especially considering the artificial water augmentation from urban and agricultural runoff that has transformed most systems into perennially flowing rivers and streams).

Willow water use from eight studies ranged from 0.9 to 3.3 mm/day (Johns 1989). Mixed riparian vegetation water use from three studies ranged from 0.9 to 1.6 mm/day (Johns 1989). Cottonwood water use from three studies ranged from 2.8 to 6.5 mm/day (Johns 1989). *Typha* (cattail) water use from six studies ranged from 2.4 to 13.8 mm/day (Johns 1989). Mulefat water use from two studies ranged from 2.2 to 3.9 mm/day (Johns 1989). Other riparian/wetland studies looking at other non-native plants found widely ranging water use. E_{stand} based on eddy-covariance from a site dominated by *Tamarix ramosissima* (salt cedar) reached up to 7 mm/day (Cleverly et al. 2002). In a similar study, E_{stand} from sites dominated by mixtures of native and invasive woody species reached peak values of approximately 9 mm/day (Dahm et al. 2002). E_{stand} in a pond lined by *Phragmites australis* in Nebraska was estimated at 4 mm/day in a stand that had a maximum LAI of 2.6 (Burba et al. 1999). E_{stand} in *P. australis* in Germany was estimated at 10 to 16 mm/day in stands with summertime LAI of about 5 (Herbst and Kappen 1999). *P. australis* in semi-arid Spain has been shown to have average midsummer E_{stand} values of about 23 mm/day in a stand with LAI values of 8.9 (Moro et al. 2004).

The final estimated net water savings from removing an acre of *Arundo* was 16.7 mm/day or 20 ac ft/yr/ac (Table 4-4). This represents a very large potential water savings, even if it represents a peak or maximum savings yield. If future studies are able to corroborate water savings of similar magnitude, *Arundo* control could represent an important water conservation action that will benefit multiple uses including habitat, urban and agricultural water use.

Arundo Impacts: Transpiration and Water use

- Due to high leaf area of mature stands, stand-based transpiration is very high (E_{stand} 40 mm/day). There are two other studies evaluating stand-based *Arundo* transpiration. One study on the Santa Clara watershed (within this project's study area) is in agreement (41.1 mm/day). The other study on the Rio Grande River is lower (9.1 mm/day). (Section 4.1).
- Stand-based transpiration rates of *Arundo*, when used to calculate total water over larger areas, indicate very high levels of water use: 48 ac-ft/ac per year. (Section 4.2)
- Net water savings for areas after *Arundo* removal are high (16.7 ac-ft/yr), even when *Arundo* water use is lowered to 20 mm or 24 ac-ft/ac per year to reflect levels that may be closer to physiological water transpiration limits. (Section 4.2)
- New studies using different approaches to measure stand-based water use of *Arundo* are needed to corroborate and refine stand-based water use found in this and other studies. New studies

need to be on mature stands of *Arundo*. Stands under treatment or in post-fire or flood recovery should be excluded, as these are not representative of the majority of *Arundo* stands within the study area. (Section 4.2)

Water use by *Arundo* appears to be a significant impact on invaded systems. Water use by vegetation is difficult to measure. Additional baseline and comparative studies are needed.

Table 4-4. Estimated water use by *Arundo*, replacement vegetation and net water savings from *Arundo* control.

Hydrologic Unit	Net *Arundo* Acreage	ESTIMATED WATER USE (Ac-ft/yr/ac)			
		***Arundo*: This study** (using 40mm)	***Arundo*: likely maximum** (using 20mm)	**Native vegetation** (using 3.3mm)	**Net gain from *Arundo* control** (using 16.7mm)
One acre of Arundo	*1*	*48*	*24*	*4*	*20*
Calleguas	229	10,983	5,487	905	4,582
Carlsbad	148	7,088	3,542	584	2,957
Los Angeles River	131	6,297	3,146	519	2,627
Otay	19	891	445	73	372
Penasquitos	24	1,129	564	93	471
Pueblo San Diego	15	719	359	59	300
Salinas	1,332	63,828	31,890	5,262	26,628
San Diego	149	7,164	3,579	591	2,989
San Dieguito	175	8,387	4,190	691	3,499
San Gabriel	44	2,124	1,061	175	886
San Juan	173	8,312	4,153	685	3,468
San Luis Rey	684	32,778	16,377	2,702	13,674
Santa Ana	2,534	121,442	60,675	10,011	50,664
Santa Clara	1,019	48,829	24,396	4,025	20,371
Santa Margarita	689	33,018	16,497	2,722	13,775
Santa Monica Bay	18	886	443	73	370
Southcoast	30	1,429	714	118	596
Sweetwater	42	2,002	1,000	165	835
Tijuana	131	6,261	3,128	516	2,612
Ventura	250	11,977	5,984	987	4,997
Other watersheds	28	1,359	679	112	567
TOTAL:	**7,864**	**376,948**	**188,333**	**31,075**	**157,258**

5.0 IMPACTS OF *ARUNDO*: Hydrology, Geomorphology and Flooding

5.1 Hydraulics, Sediment Transport, Geomorphology

5.1.1. Introduction

Arundo is a highly aggressive, non-native plant species that has invaded riparian areas and floodplains, displacing native plants, degrading habitats, and altering channel characteristics. The biology and ecology of *Arundo* have been fairly well studied and reported, but comparatively few studies have examined the effects of *Arundo* on river form and process. The changes in river geomorphology, flood risk, and sediment erosion, storage, and delivery that follow *Arundo* invasion are not well understood.

The overall goal of this study is to describe the potential effects of *Arundo* invasion on river processes in selected of Southern California watersheds. The specific objectives are to:

- Develop an understanding of the typical response of river forms and processes to invasion by *Arundo*, or other non-native plants (tamarisk), from review of published literature and reports
- Summarize the geomorphic environments and extent of *Arundo* infestation for three of the Southern California study streams – the Santa Margarita, San Luis Rey, and Santa Ana Rivers – from GIS
- Prepare a case study of the effects of the *Arundo* invasion on the hydraulic characteristics, geomorphology, sediment budgets and sediment transport capacity of the Santa Margarita River
- Based on the GIS analyses and the case study results, develop a simplified scoring system to evaluate the potential response of the San Luis Rey and Santa Ana Rivers to their *Arundo* infestations.

This section relies on existing information from previous reports and studies, as well as information collected for this study. This information included review of the existing literature on the effects of *Arundo* on geomorphology. Data generated for this study included: GIS databases and maps of river environments and *Arundo* distributions (mapped for this project: Section 3), a HEC-RAS model of the Santa Margarita River initially developed by NHC (1997a), and other reports on the Santa Margarita River. The documents reviewed for this study are listed in the References Section.

Work completed specifically for this project included: additional HEC-RAS runs for different vegetation scenarios and analysis of RAS model output to assess hydraulic and sediment transport capacity characteristics. The Santa Margarita River was inspected on October 1st, 2010. Study methods and their limitations are described further in the text.

To the extent practical, the analyses and results for this study were prepared in a GIS environment. We relied on GIS support from other team members for the analysis and mapping of *Arundo* and fluvial landforms on the three Southern California Rivers included in this study. Further details on their methods and procedures are described in Sections 3 and 5.2.

Section 5.1.2 summarizes the effects of *Arundo* infestation on river form and process from a review of published and unpublished literature and develops a general understanding of riverine response to infestation. Section 5.1.3 summarizes the riverine and riparian or floodplain vegetation characteristics of three of the Southern California study streams. Section 5.1.4 provides a case study of the Santa Margarita River, briefly describing its watershed and historical geomorphology before analyzing the

potential effects of *Arundo* infestation on hydraulic conditions, sediment transport capacity and long-term sediment budgets. The relationship between changes in hydraulics and sediment transport and river form and process are summarized at the end of this chapter.

Section 5.1.5 then combines the geomorphic analyses of the three rivers studied herein with the trends and observations on hydraulics and sediment transport along the Santa Margarita River to predict likely impacts of *Arundo* on the San Luis Rey and Santa Ana Rivers. Section 5.1.6 provides conclusions and recommendations.

Elevations are reported in feet and refer to the North American Vertical Datum of 1988 (NAVD 88). Elevations originally reported in the National Geodetic Vertical Datum of 1929 (NGVD 29) were approximately converted to NAVD 88 by adding 2.74 feet, a value obtained for the Santa Margarita study area using the datum and coordinate system conversion software program Corpscon (USACE 2004). All GIS data for this project are in the UTM Zone 11N NAD 83 (m) coordinate system.

The Marine Corps Base, Camp Pendleton and U.S. Naval Facilities Engineering Command are gratefully acknowledged for their support of this study which included the use of hydraulic and sediment transport models previously developed by NHC. In addition, Base Command and the Navy granted access to Camp Pendleton and permitted discussions with base personnel involved with *Arundo* control and management on the Santa Margarita River.

5.1.2 Arundo and River Morphology

This chapter briefly summarizes the establishment, spread, and distribution of *Arundo* in the river environment and the observed effects of the spread of *Arundo* on the morphology and characteristics of rivers and streams from existing literature. The riverine response to *Arundo* infestation focuses on large, low-gradient, braided rivers in the American Southwest that are similar to selected coastal rivers being studied in Southern California.

The general purpose of this chapter is to develop a qualitative understanding of river morphology evolution under *Arundo* infestation and identify gaps in our understanding. This conceptual model will be used to help extend and interpret specific hydraulic and sediment studies on the Santa Margarita River, which are discussed in Section 5.1.4.

5.1.2.1 *Arundo* in the River Environment

General Characteristics

Arundo donax (Giant Reed) is a member of the grass family (Poaceae) and is native to tropical and subtropical areas of Asia and Europe. *Arundo* was introduced to America in the 1800s for use as construction material and for erosion control along streams and ditches. Tamarisk (*Tamarix* spp.), or salt cedar, is another invasive, non-native species with a similar distribution to *Arundo*. The two species are often found together and studies of *Arundo* in the river environment often also include this species. Tamarisk includes several shrub and tree species native to drier areas of Eurasia and Africa that were introduced to North America in the 1800s as an ornamental shrub, windbreak, and for shade.

Arundo tends to be found on bare, moist substrate where water is plentiful, including the bed, banks, unvegetated bars and islands, and the floodplain of rivers (Else 1996; Stillwater Sciences 2007). *Arundo* requires significantly more water than native plants to support its very fast growth rate (Iverson 1994, Watts 2009, Abichandani 2007). Once established, *Arundo* plants grow very quickly, as much as 10 cm per day in its early growth stages (Quinn and Holt 2004), and mature stands reach heights of 6 m to 10

m (Rieger and Kreager 1998, Lawson et al. 2005, this study-Chapter 2). *Arundo* stands spread laterally via rhizomes (Rieger and Kreager 1998), often resulting in extremely dense, monotypic stands. Growth rates are so high that it often out-competes other species, particularly when colonizing sites that have been disturbed by erosion or wildfire.

Tamarisk grows in similar environments to *Arundo* and appears as shrubby trees growing as high as 35 ft tall along rivers in the American Southwest (Graf 1978). Tamarisk spreads by both adventitious roots and by seeds that are dispersed by wind or flowing water. Tamarisk is salt tolerant and survives in dry conditions by growing roots that extend up to 100 feet deep, as they follow a slowly receding ground water table (Graf 1982).

Dispersal & Establishment

Arundo relies on downstream dispersal of stem or rhizome fragments for vegetative propagation, which primarily occurs during seasonal floods. *Arundo* seeds are thought to be infertile (Khudamrongsawat and Holt 2004, Bhanwra et al. 1982). Thus, new *Arundo* stands are limited to the lateral extent of river flows and floodplain inundation. *Arundo* can be widely dispersed into disturbed soils when large floods occur, such as those in Southern California in 1969 (Ambrose and Rundel 2007).

The dynamics of *Arundo* establishment in the river environment have been examined on the Santa Margarita and Santa Clara Rivers in Southern California. Else (1996) examined *Arundo* establishment after a large flood on the Santa Margarita River. She found the density of establishment was greatest on depositional bars, followed by channel banks, and floodplain areas nearest to the river. Establishment was least common on the channel bed. *Arundo* dispersal was directly correlated with flood magnitude and it was most widely distributed in broad, unconfined reaches of the Santa Margarita River with low stream gradients. Steeper confined reaches showed less *Arundo* establishment, presumably as a result of greater flow velocities that provided fewer areas for *Arundo* propagules to deposit and grow.

Rates of Spread

Over a period of decades, *Arundo* stands can laterally propagate throughout the floodplain from points where it was deposited during flood events. Large floods can cause much more extensive lateral spreading of *Arundo* in a single season but these events are infrequent. Based on mapping of *Arundo* extents on the Santa Margarita, Santa Ana, and San Luis Rey Rivers by Cal-IPC (2010b), the maximum coverage of the floodplain by mature *Arundo* along a river reach may be from 40% to 55% of the total area occupied by the floodplain and active channel.

Erosion of *Arundo* Stands by Floods

During floods, large rafts of *Arundo* are observed to float downriver and deposit on the inundated floodplain. It is also common for tidal currents and wave action to cover beaches with *Arundo* that was transported downstream during a large flood (Else 1996; Cal-IPC 2010a). While *Arundo* stands are eroded during large, infrequent floods, it is not known what velocities or shear stresses can be resisted by the *Arundo* stands. It appears floods remove the plants and roots, and in some situations only the above-ground vegetation is mobilized.

5.1.2.2 Observed Effects on Rivers

Introduction and Context

Arundo (and to some extent, Tamarisk) is typically found in rivers and streams in Southern California to elevations of 1,000 feet. This elevation range, and geographic area, includes a broad range of river types and environments. However, the focus of this study is on large, low-gradient coastal rivers where *Arundo* was found to be most abundant (Chapter 3). As described in the next section, the riparian systems of the Southern California coastal study streams are dominated by *Arundo*, which often occupies most of the surrounding low floodplain (Jackson et al 1994). Effects may be very different in other river types and environments where the dispersal and establishment of *Arundo* is limited by channel or flood characteristics.

Most of our understanding of the effects of *Arundo* on river morphology is based on historical case studies, generally from analysis of maps or air photographs. These studies have two weaknesses. One is that the study period is relatively short, generally less than 70 years, so the role of large floods in eroding existing stands or distributing propagules is not well understood.

The second complicating factor is that the study period also includes human impacts on watersheds and flows that may reinforce the observed riverine response to *Arundo*. The effect of *Arundo* on river morphology in these human-modified streams would be correctly interpreted as the difference between the channel evolution that would have occurred without *Arundo* and that which occurred with *Arundo* present. We found no studies that had adequate control or had completed sufficient analyses to resolve this issue.

Long-term Historical Studies

The effects of *Arundo* and Tamarisk infestation on long-term geomorphic change have been studied on several large rivers in the American southwest, including the Rio Grande in Texas (Dean and Schmidt 2010), the Green River in Utah (Graf 1978; Allred and Schmidt 1999; Birken and Cooper 2006) and the Rio Puerco in Arizona (Friedman et al. 2005). These studies relied on interpretation of historical aerial and ground photographs to assess and measure changes in the river planform. Information on channel profiles, invert elevations and cross-section areas was often not available.

General Observations

Historically, rivers in the arid southwest were often dry during the summer and fall and they typically exhibited a wide, shallow, laterally unstable channel, with multiple flow paths around large, unvegetated sand and gravel bars. Studies on these rivers reported similar trends following *Arundo* and Tamarisk infestation, with the planform showing long-term channel narrowing coupled with a simplified channel form and increased lateral channel stability.

The braided channels transformed into a narrower, more laterally stable single thread channel with root-stabilized, steep banks supporting both native and non-native vegetation. Few unvegetated bars remained and secondary channels were eventually filled in with sediment, covered by vegetation, and attached to the adjacent floodplain. In some cases, bed scour and channel deepening occurred due to confinement of flows.

Channel narrowing primarily occurred through the development of floodplains from vertical accretion of bar surfaces along the river bank. Plant colonization, by *Arundo* and Tamarisk, stabilized the bar

surface and increased floodplain and bar roughness and sediment trapping efficiency, creating a mechanism for further sediment capture, deposition and vertical accretion.

Trends in Width and Planform

Allred and Schmidt (1999) noted a long-term trend to narrowing and bed aggradation on the Green River, based on comparing re-surveys of cross-sections. Similarly, Friedman et al (2005) found long-term channel narrowing and bed aggradation along the Rio Puerco, which led to a 27% decline in cross-section area at their study site. In contrast, Pollen-Bankhead et al. (2009) reported channel narrowing and incision following non-native plant infestation in Canyon de Chelly, Arizona. At this site, channel incision may have resulted from flow confinement and erosion-resistant banks, the latter resulting from root reinforcement and vertical accretion of fine-grained, cohesive bank sediments.

The relationship of the channel width and area following *Arundo* infestation has not been related to the local flood regime and to typical dominant discharges and it is not clearly understood how the rivers have adjusted to narrowing, increased bank strength, and dense vegetation on the floodplain. It has been noted on the Green River, Rio Grande and Rio Puerco, that channel narrowing and floodplain accretion after infestation have resulted in a more frequent overbank flooding than occurred historically, suggesting that channel dimensions have not adjusted to the local flood regime. Further adjustments, likely to channel depth, might be expected.

On the Rio Grande, Dean and Schmidt (2010) reported that large floods acted as a negative feedback mechanism or 'reset' event, restoring the channel condition to a previous wider and more laterally unstable state but that channel narrowing resumed immediately thereafter. Since the last large flood in 1991, they found as much as 90% of unvegetated sand and gravel bars in the active channel bed had become part of the vegetated floodplain (which is dominated by *Arundo*). No such effect was observed following large floods in Tamarisk infested sections of the Green River (Birken and Cooper 2006). Whether this is a result of the differing resistance to erosion of the two species or to the differing hydraulic forces exerted on the floodplain vegetation is not known. It is also not known if floodplain and bed elevations are "re-set" by these large floods.

The above indicates that large floods do not always 'reset' channel and floodplain characteristics in river reaches altered by non-native plant infestation. Little is known of the hydraulic forces that can be resisted by these invasive plants so it is not possible to predict a particular flood frequency or magnitude that will lead to their erosion and partial removal. However, the Dean and Schmidt (2010) study suggests that the time to return to the channel form observed under *Arundo* infestation is much less than the typical period between large floods that disturb the channel and floodplain.

Vertical Adjustments of the Bed and Floodplain

Dean and Schmidt (2010) measured sediment accretion on the floodplain of the Rio Grande that occurred during a rapid invasion of *Arundo* and Tamarisk. Average rates of vertical floodplain accretion of 0.6 ft/yr to 0.77 ft/yr were estimated using anatomical changes to tree rings caused by burial. The accretion occurred over a 15 year period following a large flood 'reset' event. Friedman et al. (2005) measured rates of channel filling in response to hydrologic changes and Tamarisk infestation on the Rio Puerco, New Mexico. Channel filling occurred in two phases, a period of channel narrowing with little change in thalweg elevation followed by vertical accretion of the floodplain and channel bed at an average rate of 0.26 ft/yr from 1962 to 2000.

Lateral Migration and Bank Erosion

Gran and Paola (2001) conducted flume experiments that documented how vegetation affects channel form and process in braided stream environments. In general, they observed channel responses that were similar to those following *Arundo* and Tamarisk infestations discussed above. They found that vegetation reduced the number of channel braids because smaller channels were choked with sediment and could not reestablish themselves. Gran and Paola (2001) noted a direct relationship between channel stability and the density and extent of vegetation. Vegetation also created less variability in flow velocity through the channel cross-section and resulted in increased bank strength (associated with dense root mats that are characteristic of these species) and decreased bank shear stress due to added roughness effects. Consequently, lateral migration rates declined. Increased bank strength also increased channel relief through the formation of higher and steeper banks and promoted channel scour, increasing maximum channel depths.

Additional studies examining the effects of invasive plant colonization on bank stability were conducted by Pollen-Bankhead et al (2009) and Brinke (2010). Pollen-Bankhead et al (2009) documented the effects of invasive plants on bank stability and bank retreat rates in Canyon de Chelly National Monument, Arizona. They found that tamarisk and Russian Olive, another invasive plant species, significantly increased bank stability through root reinforcement of the sand banks in the study area. Bank retreat rates doubled from an approximate rate of 2.5 ft/yr to 5 ft/yr following vegetation removal.

Brinke (2010) measured the root density and tensile strength of *Arundo* on stream banks of the Santa Clara River, California. When compared with Red Willow, a common native species, *Arundo* had a denser root mass and provided 40% greater tensile strength in the upper 10 cm of the bank. The converse was true below 10 cm depth, where Red Willow showed higher root density and greater tensile strength. Brinke (2010) concluded that *Arundo* contributed to less bank cohesion on stream banks exceeding one vertical foot and speculated that undercutting and cantilever failure were a primary bank erosion mechanism for *Arundo*-topped stream banks.

5.1.2.3 Observed Effects on Hydraulics and Sediment Transport

We found very few studies that compared hydraulic and sediment transport characteristics of large, low-gradient rivers; either prior to or following *Arundo* infestation. NHC (1997a,b; 2001) did complete geomorphic, hydraulic, and sediment transport studies of the lower Santa Margarita River in support of bridge and levee improvement projects at the Marine Corps Base Camp Pendleton (MCBCP). Section 5.1.4 discusses these studies in detail.

Although they do not specifically address the effects of *Arundo* on hydraulic capacity, numerous HEC-RAS models that include estimates for the hydraulic roughness effects of non-native vegetation have been used to support flood control and river management applications (USACE 2009). Few studies have reliable flow and water level data available to accurately calibrate hydraulic models for the effects of *Arundo*. However, where adequate calibration data are available, analysis of the specific effects of *Arundo* infestation scenarios may be possible with these existing HEC-RAS models.

Spencer (2010) investigated the hydraulic effects of *Arundo* on Manning's *n*, flow velocity and flow direction at study sites on Cache Creek and Stony Creek, California. Flow velocity measurements were collected around five *Arundo* plants growing in Cache Creek and a set of artificial *Arundo* stalks placed in the river bed on Stony Creek. Measured Manning's *n* roughness coefficients were found to vary between 0.019 and 0.121 with an average roughness of 0.066. Channel roughness was higher when *Arundo* was present, resulting in higher water surface elevations for the 2-year and 100-year flood

events when modeled using HEC-RAS, a software program that simulates one-dimensional, open channel flow (USACE 2010).

Response to *Arundo* Removal or Eradication

Despite a number of programs to eradicate *Arundo* on rivers throughout California, we did not find any reports in the literature that documented the geomorphic, hydraulic or sediment transport effects of widespread *Arundo* removal. In particular, the period between *Arundo* eradication and re-establishment of native vegetation presents significant opportunity for local and downstream channel adjustment and changes in sediment transport processes, particularly if large floods occur during this period.

5.1.2.4 Summary of Understanding

Since its introduction in the late 1800s, *Arundo* (and to some extent, Tamarisk) has flourished on rivers and streams in Southern California to elevations of about 1,000 feet. This elevation range, and geographic area, includes a broad range of river types; however, our focus has been on large, low-gradient, braided rivers similar to the Southern California study rivers. It is in this river type that *Arundo* is likely to best disperse and establish most rapidly.

These river types have also been altered by humans. For instance, water development projects that divert flows, reduce flood flows or capture coarse sediment from the upper watershed are expected to narrow channels and convert braided rivers to simpler forms, among other effects, even in the absence of *Arundo*. Channel confinement through levees and construction of bank protection or river training structures may also have similar effects on river morphology. Other factors, such as altered seasonal flow patterns, changes to groundwater elevations, or more frequent and greater low flows, may also affect riparian vegetation, *Arundo* establishment, and channel form. The effects of some these changes may be confounded with those that directly result from *Arundo* establishment and growth.

Based on the existing literature, the response of this river type to *Arundo* infestation consists of a simplification of channel form, increased lateral stability, floodplain accretion, and long-term channel narrowing. Bed aggradation and shallower channels have been observed in some studies; channel incision or deepening in others. The long-term expectation would be for a deeper channel following narrowing and confinement of flows. However, this may be obscured by changes in watershed hydrology, the time required to erode sufficient sediment to deepen the main channel, or by rapid floodplain accretion.

Historically, braided and laterally unstable channels prior to infestation transform to narrower, more laterally stable single thread channels with root-stabilized, steep banks following infestation. Plant colonization stabilizes bar and floodplain surfaces, increasing channel roughness and sediment trapping efficiency, thereby creating a mechanism for further sediment capture, deposition and vertical accretion. Observed long-term rates of vertical accretion vary widely in the reported literature and are as high as 0.8 ft/yr. Long term average annual accretion rates likely vary with the magnitude and frequency of flooding, volume of sediment in transport, as well as the specific river conditions.

The local depths of deposits following large floods can be much greater, NHC (1998, 2001) observed several feet of sediment deposition in many locations on the floodplain adjacent to the Santa Margarita River following the 1993 flood that flooded the Marine Corps Air Station (MCAS).

There may be an upper limit on vertical accretion, which would about correspond to the elevations of typical floods. This may be reached fairly soon if the channel bed incises or does not accrete as rapidly

as the floodplain. If the channel bed fills as the floodplain accretes, this limit may not be reached for a long time.

Most research on the effects of *Arundo* and Tamarisk on river systems is limited by the duration of study (about the last 70 years) and the simultaneous occurrence of human-caused changes affecting basin hydrology and sediment load. These changes often produce river responses that are similar to those from *Arundo* infestation and may obscure identification of geomorphic change specifically due to *Arundo*.

5.1.3 Southern California Study Streams

5.1.3.1 Introduction

This chapter summarizes geomorphic and vegetation characteristics of the three Southern California study streams: the Santa Margarita, Santa Ana and San Luis Rey Rivers. These study streams were selected because they contain some of the greatest observed concentrations of *Arundo* found in Southern California coastal rivers (Chapter 4, Cal-IPC 2010b). The geomorphic and vegetation characteristics presented in this chapter form the basis for comparing results from the Santa Margarita River case study (Chapter 4) to other study streams (Section 5.1.5).

5.1.3.2 Study Streams

The Santa Margarita, Santa Ana and San Luis Rey are large, sand bed, Southern California Rivers that cross coastal lowlands before discharging into the Pacific Ocean. Cal-IPC has identified specific sections of the lowland portions of these rivers as areas of interest (AOI). These management sections ranged from 17 to 37 miles in length and either ended at the Pacific Ocean or, in the case of the Santa Ana River, at a reservoir.

The AOIs were divided into broad reaches based on changes in channel planform, the degree of confinement by hillslopes or levees, and the extent of *Arundo* infestation. Geomorphic and riparian vegetation characteristics from the GIS analysis are summarized by reach in Tables 5-1.1, 5-1.2 and 5-1.3. The management sections and stream reaches are shown in Figures 5-1.1, 5-1.2 and 5-1.3; yellow areas in each figure represent the extent of the floodplain mapped in the GIS for each reach.

5.1.3.3 CAL-IPC GIS Analysis

Cal-IPC (2010b) mapped geomorphic and vegetation characteristics of the study streams in a GIS (see Methods in Section 5.2). They divided channel and floodplain into the categories described below from 2009 aerial photos and digital elevation models (DEM) from the U.S. Geological Survey (USGS 2010). No field verification was completed.

Fluvial Landforms

- *Low Flow Channel* – The part of the main channel where water was flowing at the time of the aerial photos.
- *Bar / Channel / Floodplain - unvegetated* – Main channel or floodplain areas with less than 50% vegetation cover, usually consisting of bar surfaces, dry channel beds or recent flood deposits or erosion
- *Floodplain - vegetated* – Areas on the river floodplain with more than 50% vegetation cover.

- *Floodplain / Low Terrace – vegetated* – Areas on either the river floodplain or an adjacent low terrace with more than 50% vegetation cover.
- *Upper Terrace - vegetated* – Areas on higher ground adjacent to the low terraces with more than 50% vegetation cover.

The above mapped landforms were used to calculate river characteristics by reach. Channel width was defined as the area of the low flow channel divided by the reach length. This width may not be representative of the active or main channel width commonly adopted for river studies. This is discussed further throughout the text.

Floodplain area was defined as the sum of the "low water channel", "bar/channel/ floodplain unvegetated", "floodplain – vegetated" and "Floodplain/ low terrace" areas. The average floodplain width was defined as the above area divided by the reach length. A width ratio (expressed as a percentage) was then constructed for each reach by dividing the average channel width by the average floodplain width.

Anthropogenic Features

- *Line Features* – Levee crests, bridge berms, in-stream grade control weirs, and dams
- *Point Features* – bridge crossings, water infiltration ponds, stormwater and treatment pond inflow points

Longitudinal Profile – Longitudinal stream profiles of each study reach were generated from USGS 10 m grid DEM data (USGS 2010).

Arundo Coverage – The spatial extent of *Arundo*, as mapped by Cal-IPC (2010b) from 1996 to 2009. The quoted coverage in Tables 5-1.1 to 5-1.3 represents the maximum observed extent of *Arundo* infestation. *Arundo* coverage has changed on the study streams in recent years because of eradication programs.

5.1.3.4 Study Stream Characteristics

General Morphology

In the late 1990s, the study streams had single thread channels at low flows that were bordered by well-vegetated floodplains; only a few reaches had less than 50% vegetation cover. Except where the rivers were confined by natural topography or levees, the low flow channel width (See definition above) was generally less than 10% of the floodplain width (see Width Ratio; Tables 5-1.1 to 5-1.3); alternatively, the floodplain was at least 10 times as wide as the low flow channel.

The San Luis Rey and Santa Ana Rivers study streams are about twice as steep as the Santa Margarita River, on average. However, the three study streams have a common pattern of steeper slopes in their upstream reaches and shallower slopes near the mouth. Along the study stream, slopes near the mouth are about one-fourth to one-eighth of those in the most upstream reaches.

Floodplain widths averaged 1,100 feet in the Santa Margarita River, 800 feet in the San Luis Rey River and 1,300 feet in the Santa Ana River (removing the very wide Reach 1) and they varied considerably from one study reach to another, as a result of both human and topographic confinement. Width ratios and the portion of the floodplain that was not vegetated were greatest in the Santa Ana study reaches; the portion of the floodplain that was vegetated was greatest in the San Luis Rey study reaches, where less than 15% of the floodplain and channel area has less than 50% vegetation coverage.

Arundo Characteristics

Arundo coverage varied from 15 to 23% of the total floodplain and channel area in the three management sections. The percentage *Arundo* cover was not a consistent portion of the total vegetation cover and it covered from less than 1% to more than 50% of the total floodplain area when averaged over the study stream reaches. *Arundo* was uncommon within the low flow channel width (Section 5.2).

All three study streams show a marked decline in *Arundo* coverage in the upstream study reaches compared to the downstream ones. Such an observation may result from slow upstream propagation, flood history, or the role of steeper stream slopes in limiting the establishment and development of *Arundo*. The relative importance of these two factors cannot be resolved with the existing information, but Tables 5-1.1 to 5-1.3 suggest that *Arundo* is an insignificant portion (in terms of geomorphic processes) of total cover in those study reaches where slopes exceed 0.004, including those steep reaches on the San Luis Rey River that have much of their floodplain covered with other vegetation.

There also appears to be a pattern along the study streams, and particularly on the Santa Margarita River, where the reaches with the highest *Arundo* concentrations occur where slope declines or the floodplain widens considerably when compared to the reach upstream. The best example is on Reach 7 of the Santa Margarita River which has the highest percent *Arundo* coverage of the study reaches (Table 5-1.1). The slope in Reach 7 is about half of that in Reach 6 and the floodplain is about twice as wide. This pattern is thought to occur because the less steep, wider reach has much lower average velocities which promote deposition of *Arundo* propagules and increase the likelihood of *Arundo* establishment and propagation. Section5.1.5 discusses this observation in more detail.

Table 5-1.1. Santa Margarita River summary of GIS analysis.

Reach No.	Reach Length (mi)	Average Slope	Average Floodplain Width (ft)	Ave Low Flow Channel Width (ft)	Width Ratio (%)[1]	Vegetated Area (%)[2]	*Arundo* Area (%)[3]
1	1.52	0.0008	1270	163	12.8%	59.7%	1.5%
2	1.47	0.0017	773	66	8.5%	91.0%	14.7%
3	1.70	0.0015	1444	58	4.0%	87.4%	21.5%
4	0.42	0.0015	2493	52	2.1%	91.5%	18.9%
5	0.90	0.0014	1929	72	3.8%	87.5%	44.3%
6	1.30	0.0024	2505	61	2.4%	92.2%	28.2%
7	0.42	0.0015	2213	87	3.9%	93.1%	54.8%
8	1.60	0.0023	1045	73	7.0%	71.7%	44.6%
9	0.77	0.0024	630	52	8.2%	66.9%	18.2%
10	1.21	0.0031	823	58	7.0%	73.9%	10.2%
11	1.89	0.0026	664	105	15.7%	68.7%	24.9%
12	4.11	0.0033	424	48	11.3%	69.7%	21.0%
Weighted Ave		**0.0023**	**1,078**	**73**	**8.7%**	**76.3%**	**23.1%**
Total	**17.32**						

[1] – Width Ratio = Average Floodplain Width / Average Low Flow Channel Width
[2] – Vegetated Area = Percent area of the floodplain and channel surface with more than 50% vegetation cover
[3] – *Arundo* Area = Percent area of the floodplain and channel surface occupied by *Arundo* (Cal-IPC 2010b)

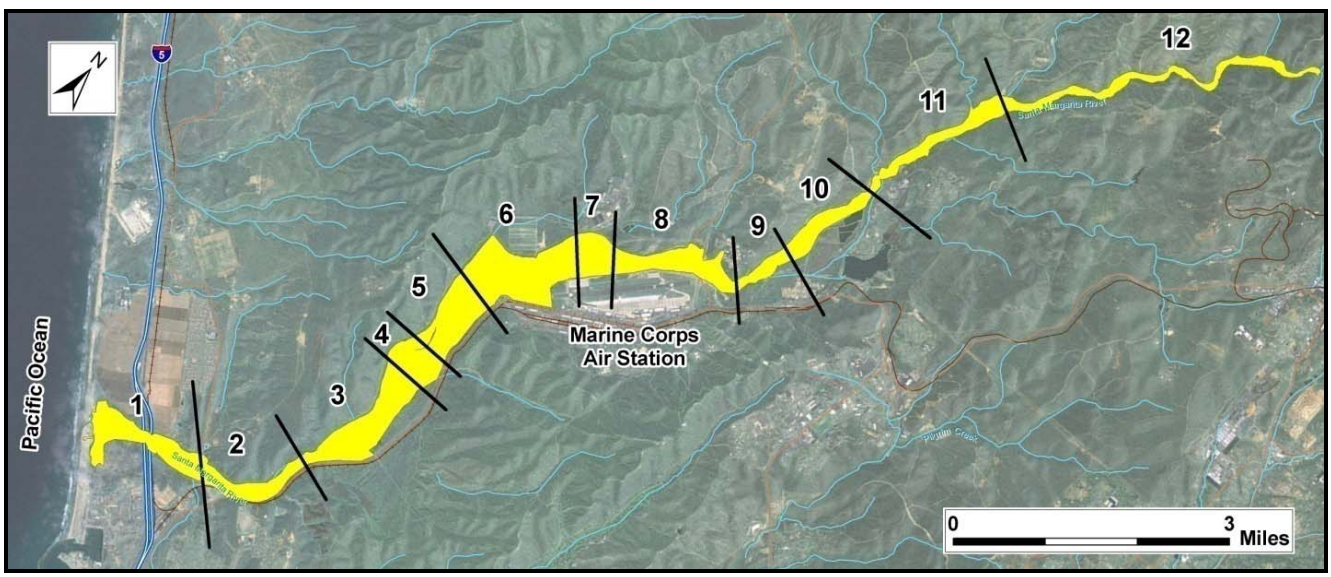


Figure 5-1.1. Santa Margarita River study reaches, with yellow denoting extent of mapped floodplain.

Table 5-1.2 Santa Ana River summary of GIS analysis.

Reach No.	Reach Length (mi)	Average Slope	Average Floodplain Width (ft)	Ave Low Flow Channel Width (ft)	Width Ratio (%)[1]	Vegetated Area (%)[2]	*Arundo* Area (%)[3]
1	3.16	0.0012	9146	90	1.0%	98%	12.5%
2	12.17	0.0025	1758	136	7.7%	82%	41.2%
3	2.08	0.0030	733	207	28.3%	56%	10.5%
4	2.35	0.0047	2312	219	9.5%	76%	19.4%
5	9.67	0.0038	749	197	26.3%	30%	0.2%
6	3.98	0.0058	529	151	28.5%	36%	0.4%
7	3.44	0.0097	1441	133	9.3%	49%	0.0%
Weighted Average		**0.0039**	**1942**	**159**	**15.7%**	**59.8%**	**16.6%**
Total	**36.86**						

[1] – Width Ratio = Average Floodplain Width / Average Low Flow Channel Width
[2] – Vegetated Area = Percent area of the floodplain and channel surface with more than 50% vegetation cover
[3] – *Arundo* Area = Percent area of the floodplain and channel surface occupied by *Arundo* (Cal-IPC 2010b)

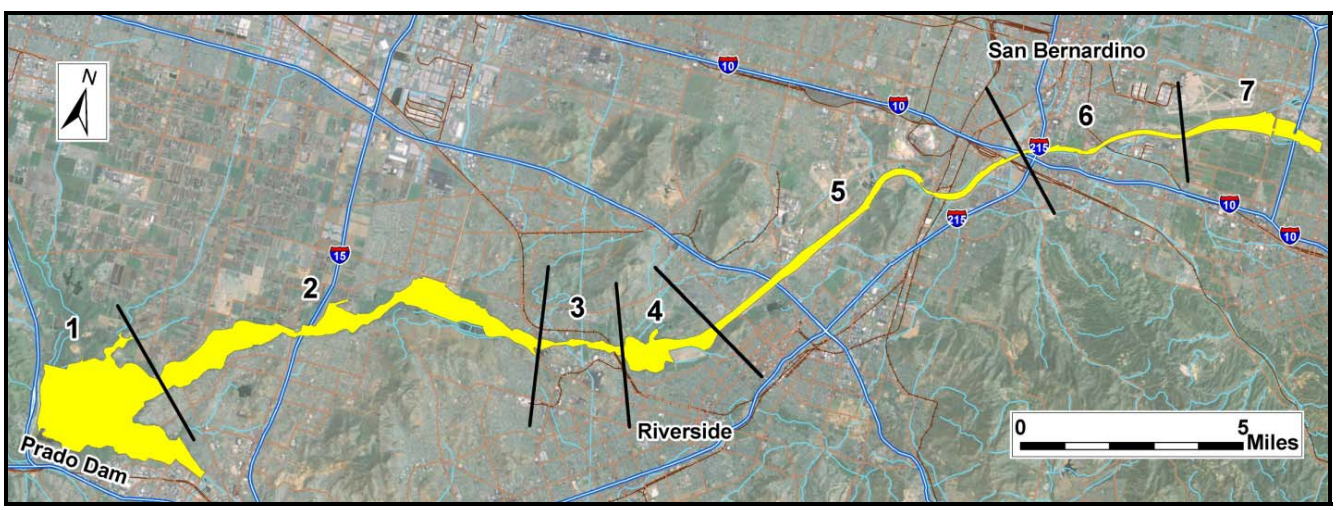


Figure 5-1.2. Santa Ana River study reaches with extent of mapped floodplain denoted in yellow.

Table 5-1.3 San Luis Rey River summary of GIS analysis.

Reach No.	Reach Length (mi)	Average Slope	Average Floodplain Width (ft)	Ave Low Flow Channel Width (ft)	Width Ratio (%)[1]	Vegetated Area (%)[2]	*Arundo* Area (%)[3]
1	0.86	0.0007	506	178	35.2%	52.9%	11.4%
2	1.66	0.0015	582	52	9.0%	80.4%	47.1%
3	5.79	0.0023	509	44	8.7%	91.4%	20.4%
4	5.53	0.0021	834	48	5.7%	85.5%	29.9%
5	0.62	0.0030	544	38	7.0%	94.7%	22.3%
6	5.07	0.0029	1232	60	4.8%	92.4%	12.8%
7	3.73	0.0037	443	37	8.4%	89.6%	7.7%
8	3.73	0.0050	1186	29	2.4%	83.7%	0.1%
9	2.03	0.0110	797	24	3.0%	86.0%	0.2%
10	2.01	0.0148	424	31	7.3%	74.4%	0.3%
11	1.16	0.0048	1157	33	2.8%	68.1%	0.0%
Weighted Average		**0.0042**	**790**	**46**	**6.8%**	**85.7%**	**14.9%**
Total	**32.19**						

1 – Width Ratio = Average Floodplain Width / Average Low Flow Channel Width
2 – Vegetated Area = Percent area of the floodplain and channel surface with more than 50% vegetation cover
3 – *Arundo* Area = Percent area of the floodplain and channel surface occupied by *Arundo* (Cal-IPC 2010b)

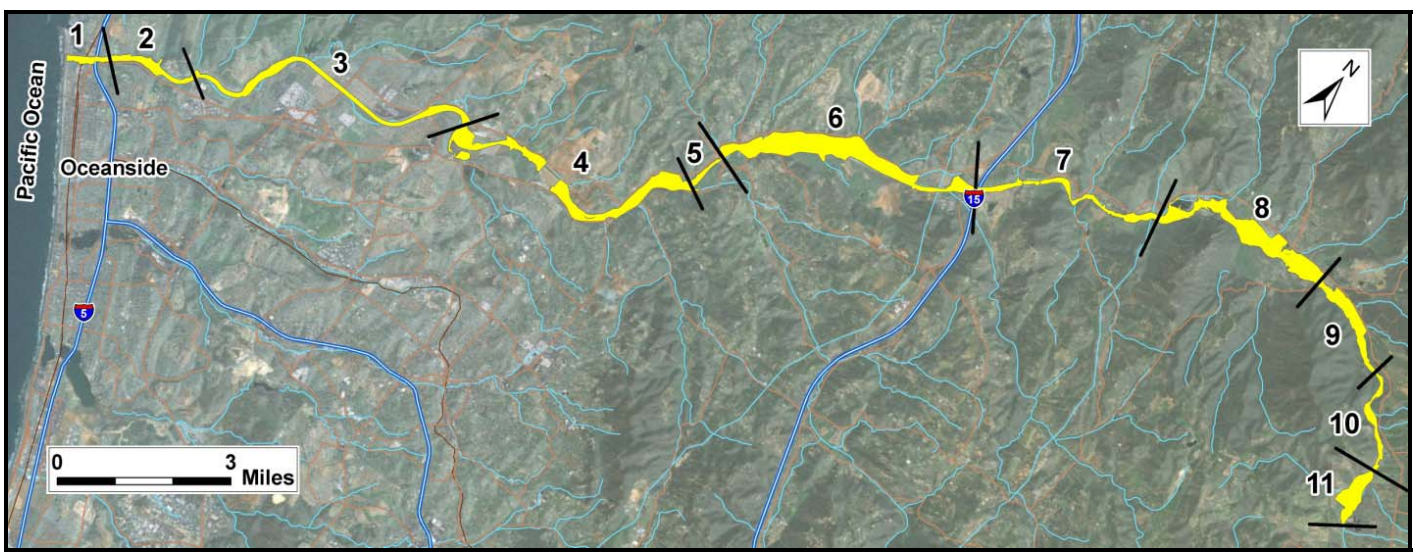


Figure 5-1.3 San Luis Rey River study reaches with extent of mapped floodplain denoted in yellow.

5.1.4. Santa Margarita River Case Study

5.1.4.1 Introduction

This chapter briefly describes the Santa Margarita River watershed, its climate and hydrology, and the morphology and historical behavior of the lower Santa Margarita River, before describing the effects of *Arundo* infestation on hydraulics, sedimentation and geomorphology. The effects of *Arundo* on these characteristics were determined from surveys, field observations, other consultant reports, and rerunning of hydraulic models developed in NHC (1997b) and NHC (2001). The NHC studies were completed during the period of maximum *Arundo* infestation, prior to the eradication programs that began in the late 1990s.

5.1.4.2 Santa Margarita Watershed

The Santa Margarita River watershed has an area of 740 square miles and drains into the Gulf of Santa Catalina (Pacific Ocean) near the city of Oceanside. Maximum elevations are about 6,825 ft at Thomas Mountain near the eastern end of the watershed. The upper watershed of the Santa Margarita River is mostly underlain by granitic rocks of pre-Cenozoic age; the central watershed, near Temecula and Murrieta, is mantled by Holocene and Pleistocene alluvial deposits (Jennings 1977). Occasional outcrops of Eocene and Jurassic marine rocks and metasedimentary and metavolcanic rocks are found in the central and lower watershed.

Three reservoirs regulate flows from the watershed. Vail Dam was completed in 1949 and regulates inflows from about 320 mi^2 of the upper Temecula watershed. Vail Lake storage capacity is about 40,000 acre-ft and it captures nearly all the winter runoff from its watershed, having overtopped only twice since the late 1940s (CDM 2003). Skinner Reservoir on Tucalota Creek, constructed in 1974 by the Metropolitan Water District (MWD), regulates a 51 mi^2 watershed and primarily stores imported water, releasing local inflows. Diamond Valley Lake Reservoir stores 800,000 acre-ft of imported water for the MWD; it reached full capacity in 2002. Skinner and Diamond Valley Lake Reservoirs have little effect on winter floods.

Lake O'Neill, operated by Camp Pendleton, provides off-stream storage for up to 1,200 acre-ft, which is diverted from the Santa Margarita River in spring and used for groundwater recharge in late fall. Releases for recharge are between 8 and 10 cfs (CDM 2003).

5.1.4.3 Climate and Hydrology

The Santa Margarita watershed has a Mediterranean climate, characterized by warm summers and cool, wet winters. Summers are dry and there are often several months without rain. About 90% of the annual precipitation falls as rain during large frontal storms that occur from November through April. Average annual precipitation is about 11 to 13 inches near the coast and over 25 inches at the highest watershed elevations, where it may include some snowfall.

The USGS has operated the Santa Margarita River at Ysidora (11046000) gage, near the mouth of the river, since 1923. Suspended sediment records were collected in the 1968-71, 1972-74 and 1977 water years. Inspection of the gage records shows an annual hydrograph where runoff primarily occurs during winter months, and is event-driven with most of the water discharge (and also most of the sediment discharge) occurring during a few, intense storms (Warrick and Rubin 2007). Annual maxima vary dramatically from year to year; annual instantaneous peaks at the Ysidora gage have ranged from zero to 44,000 cfs (Figure 5-1.4).

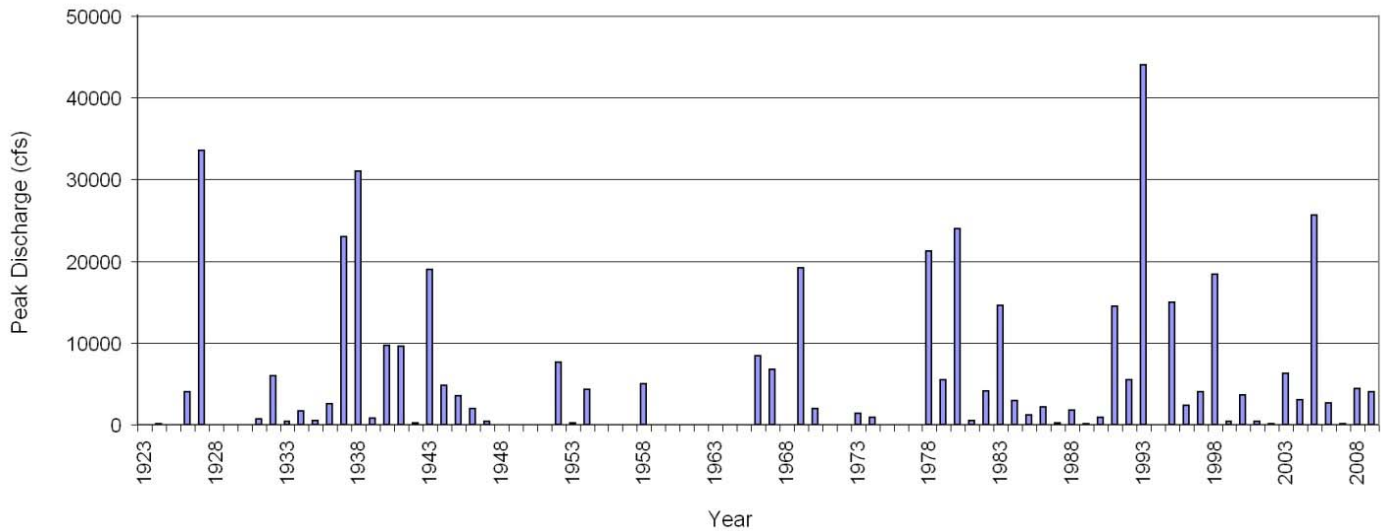


Figure 5-1.4. Annual peak discharges recorded at USGS stream gage 11046000 on Santa Margarita River near Ysidora.
Years with zero values or no data are shown as blank.

Large floods, those with return periods of more than 10 years and flows greater than 15 to 20,000 cfs, have been recorded at the gage in 1927, 1937, 1938, 1943, 1969, 1978, 1980, 1993, 1998, and 2005. Figure 5-1.4 shows a twenty-five year gap starting in the 1940s and lasting until 1969 that had no large floods. The 1993 flood was by far the largest on record; its peak discharge of 44,000 cfs is now about equivalent to the 50-year flood (USACE 1994a; Table 4.2=5-1.4). Before installation of the gage, large floods occurred in 1916 and 1884 (McGlashan and Ebert 1918). Stetson (2001) provides accounts of historical flooding and flood damages.

Most years include a long period of very low (<5 cfs) flows at the gage in the summer and fall, often extending for three or four months. Examination of decadal flow duration curves at the Ysidora gage shows a trend toward an increased duration of flows exceeding 10 cfs since the 1970s (Figure 5-1.5). This shift to a sustained, year-round, base flow is thought to be due to urbanization, water regulation since the construction of Vail Reservoir and groundwater recharge releases.

5.1.4.4 Lower Santa Margarita River

The Santa Margarita River begins at the confluence of Murrieta River and Temecula Creek near the City of Temecula. It is about 30 miles long; about 19 miles flow through Camp Pendleton near the mouth of the watershed. The lower Santa Margarita River begins at the mouth of DeLuz Canyon. Downstream, it flows through a 500 to 5,000 ft wide valley bordered by hilly terrain underlain by marine sedimentary rocks. The greatest widths are adjacent to the Marine Corps Air Station (MCAS) and at Ysidora Flats. The MCAS occupies a large part of the floodplain and is protected by a levee; otherwise the lower river valley is not developed, except for five bridges crossings and a few connecting roads.

The focus for this chapter is a 5.5 mile long project reach of the lower Santa Margarita River, which is adjacent to the MCAS and extends from De Luz Canyon to Ysidora Flats (Figure 5-1.6).

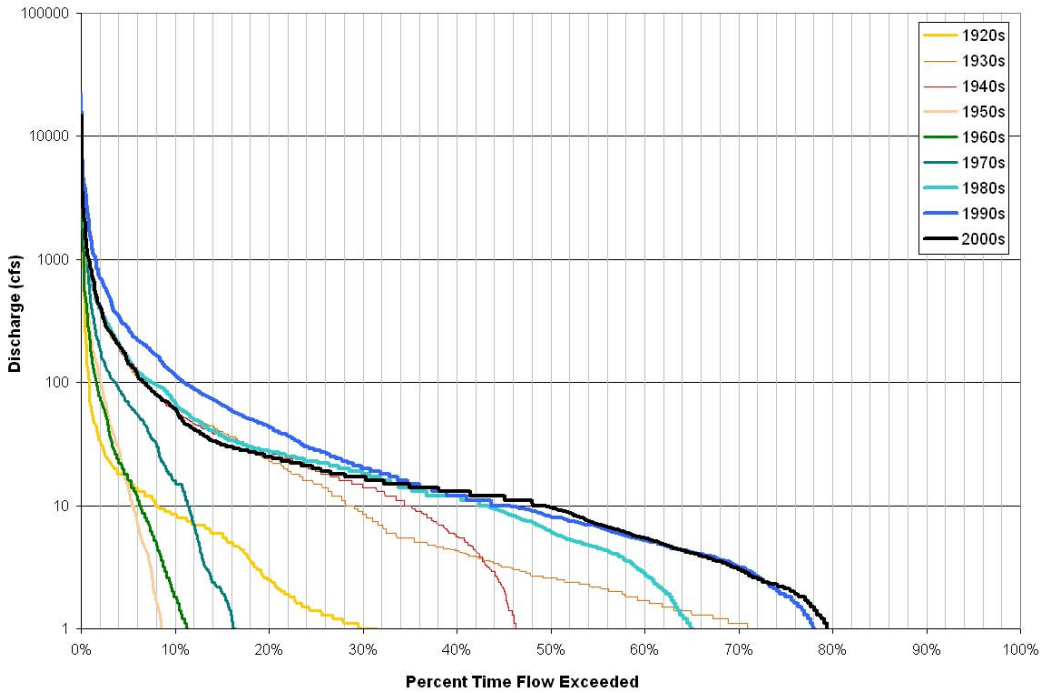


Figure 5-1.5. Flow duration curves plotted by decade at the Ysidora gage (11046000).

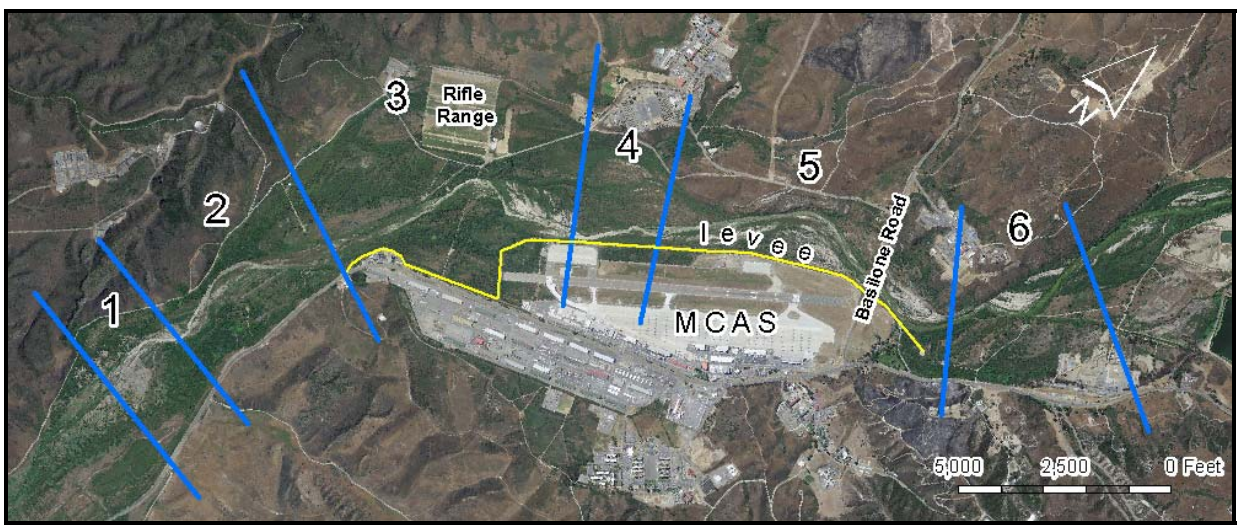


Figure 5-1.6. Sub-reaches (numbers 1 through 6) in the lower Santa Margarita River project reach.

This project reach is where NHC examined hydraulics and sediment transport capacity with mature stands of *Arundo* on the river bank and floodplain (NHC 1997a; 1997b; 2001) and covers about the same river mileage as Reaches 4 through 9 in Table 5-1.1 and Figure 5-1.1. The river floodplain is confined to varying degrees throughout the project reach, particularly upstream of the O'Neill Lake diversion and in the vicinity of Basilone Road Bridge (Table 5-1.4; Figure 5-1.6).

The sub-reach breaks on Figure 5-1.6 were set based on the degree of confinement, channel dimensions and longitudinal slope, using historical air photos, ground inspections and surveyed channel cross-

sections. Channel confinement resulted from geologic and anthropogenic features, including high bluffs, bridges, in-channel road or pipeline crossings, and levees along the MCAS. The sub-reaches are described on Table 5-1.4.

In the late 1990s, the main channel, as defined by channel banks, was typically 200 ft to 400 ft wide and bordered by moderate to abundant vegetation where the floodplain had not been developed. The main channel was generally four to eight times wider than the low flow channel defined in Table 5-1.1. The floodplain surface was generally 4 to 6 feet higher than the low flow channel invert, as indicated by field inspection and channel surveys. Small, concentrated flow paths (distributary or chute channels) were common on the floodplain and on vegetated bar surfaces throughout the project reach (Figure 5-1.7).

River banks generally consisted of loose or partially consolidated sand and were between four and six feet high. Stream bed materials consisted of coarse and medium sands with some fine gravel. Sands and silts were the common deposits observed on overbank floodplain areas.

Figure 5-1.7. View of the Santa Margarita River in Sub-Reaches 2 & 3 (view is upstream) taken on May 16, 1995.

Table 5-1.4. Description of the lower Santa Margarita project sub-reaches.

Sub-Reach	Reach Length (ft)	Slope (ft/ft)	Average Floodplain Width (ft)	Ave Channel Width (ft)	General Observations
Sub-Reach 1 (sta. 0 to sta. 18+61) *Downstream sub-reach*	1,900 ft	0.0011	3,200 ft	205 ft	Narrow active channel bed flowing in an undeveloped and well vegetated floodplain.
Sub-Reach 2 (sta. 18+61 to sta. 71+07)	5,250 ft	0.0023	1,900 ft	350 ft	Valley narrows due to adjacent hillslopes through this undeveloped sub-reach located just downstream of the MCAS airfield.
Sub-Reach 3 (sta. 71+07 to sta. 143+98)	7,300 ft	0.0023	3,500 ft	405 ft	Wide valley section with broad floodplain partly confined by MCAS levee and the Rifle Range and Rifle Range Road crossing.
Sub-Reach 4 (sta. 143+98 to sta. 162+66)	1,900 ft	0.0025	2,300 ft	310 ft	Short reach of intermediate width connecting the very wide sub-reach 3 with narrow sub-reach 5
Sub-Reach 5 (sta. 162+66 to sta. 241+58)	7,900 ft	0.0022	1,100 ft	325 ft	Narrow floodplain sub-reach due to the Basilone Road crossing and MCAS levee along the right bank.
Sub-Reach 6 (sta. 241+58 to sta. 274+55) *Upstream sub-reach*	3,300 ft	0.0030	1,500 ft	345 ft	Narrow floodplain sub-reach due to flow confinement and infrastructure on the south side of the valley.

5.1.4.5 Historical Changes in the Project Reach

Planform

NHC (1997a) examined the position of the lower Santa Margarita River on historical air photos and maps and found that it maintained the same overall course since 1938. Its course had been more or less straight, except where it followed the natural curvature of valley walls or was guided by levees along the MCAS. The channel mostly lay on the northwestern portion of the valley bottom, due to encroachment by the MCAS facilities.

Within this general alignment, the main or active channel has shifted several hundred feet at some locations and exhibited a general decrease in width since 1938, interrupted by dramatic increases in channel width following large floods, such as in 1969 (NHC 1997a; see also Figure 5-1.8). Large floods also restored multiple flow channels and braid bars in the project reach. Vegetation encroached on recently deposited bar and overbank sediments and a single channel re-established over time.

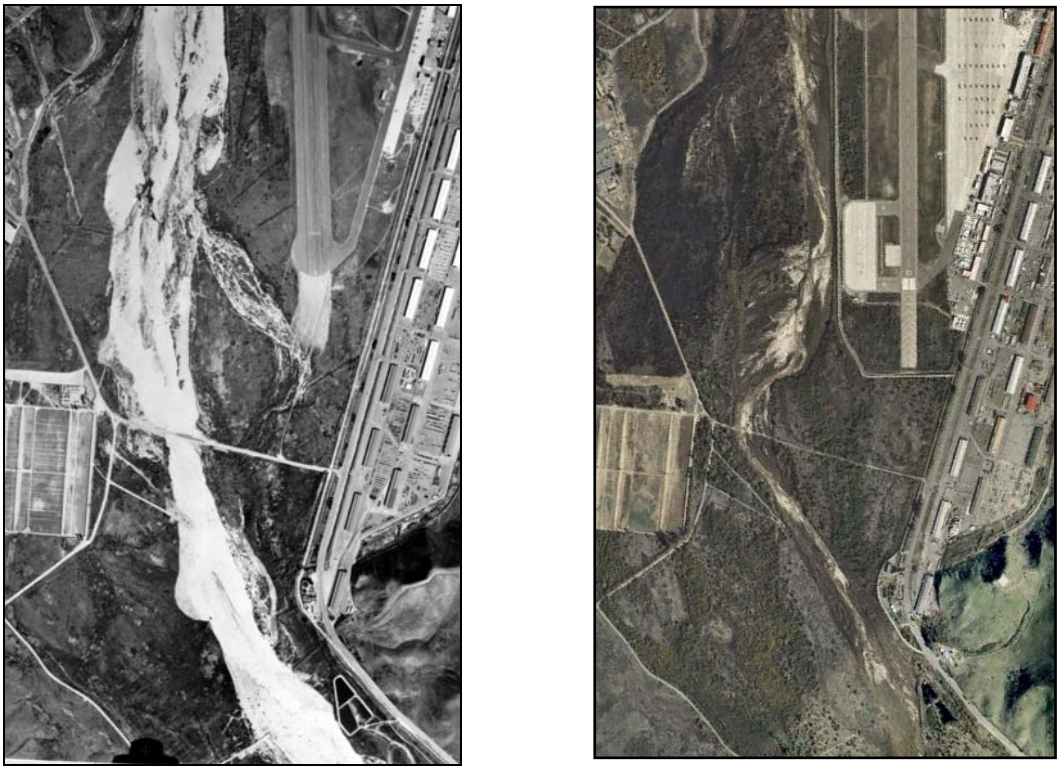


Figure 5-1.8. Comparison of 1970 (left) and 2008 (right) air photos of Sub-reach 3.

Bed Profiles

NHC (1997b) compared channel invert (thalweg) profiles from 1946 to 1994 and found no consistent trend in elevations. Rather, the sub-reaches showed bed elevations that varied around a mean value over time, suggesting a relatively stable profile that responded to large floods, bar development, scour and sediment deposition. No channel invert elevation surveys have been completed since 1994, and a profile that shows the potential effects of recent *Arundo* eradication on channel elevations has not been surveyed.

NHC (1997a) concluded that there was no clear evidence of recent aggradation or incision along the lower Santa Margarita River. However, numerical modeling of long-term sediment transport suggested aggradation rates of 1.5 ft per 100 years, as a result of the lower bed slopes in the downstream end of the project reach (Table 5-1.4).

Floodplain Vegetation

Figure 5-1.8 compares air photos of Sub-reach 3 from 1970 and 2008. The non-vegetated active channel bed is several times wider in 1970 than 2008, despite the recent *Arundo* eradication. Channel and floodplain conditions in the 1970 air photo resulted from the 1969 flood, which followed a twenty-five period with no significant floods. Stetson Engineers (2001) reported that large floods in 1927 and 1993 also scoured much of the valley bottom and dramatically enlarged the active channel in Deluz Canyon just upstream of the project reach.

Interestingly, the 2008 air photos were taken not long after the 2005 flood, whose peak was slightly greater than that in 1969. Despite this, the 2008 channel shows no evidence that it had recently enlarged to the width observed after the 1969 flood. This different behavior is assumed to result from changes in the riparian vegetation in the channel and on the floodplain, or changes in channel and floodplain geometry, that resulted in greater bank and floodplain resistance to erosion.

While intriguing, such behavior is not well documented or understood. However, it suggests that the large floods that once greatly altered the channel and floodplain vegetation on the lower Santa Margarita River conditions may not be as effective under current conditions.

***Arundo* Eradication Programs**

Efforts to control *Arundo* in the Santa Margarita River watershed began in 1997 (Lawson et al. 2005), and eradication has proceeded upstream to downstream, beginning at Interstate 15 in the middle watershed. *Arundo* removal continued for over a decade until 2009 when the river mouth was reached. The distribution of *Arundo* along the lower Santa Margarita River and the years when stands were removed are documented in a GIS database prepared by the California Invasive Plant Council (Cal-IPC 2010b).

The total area of *Arundo* stands in the project reach near Camp Pendleton was estimated to be about 400 acres in 1997 (Cal-IPC 2010b). Cal-IPC (J. Giessow, pers. comm.) provided a comparison of the 1997 and 2010 geomorphology in the project reach (See section 5.2.4), noting that the area of low flow channel and unvegetated bar or floodplain had increased from 120 acres in 1997 to 360 acres in 2010. Bed level changes or adjustments associated with the increased width for the main channel have not been documented.

5.1.4.6 Project Reach Hydraulics

HEC-RAS Model

In the late 1990s, NHC developed a calibrated, steady, one-dimensional HEC-RAS model (USACE 2010) of the Santa Margarita River project reach, as part of studies for a new levee (NHC 2001). The model was based on 62 cross-sections in the project reach, an average of one every 470 ft, developed either from July 1998 LiDAR, September 1996 air photos or June and July 1998 cross section surveys (Figure 5-1.9).

Figure 5-1.9. Location of HEC-RAS model cross-sections (in yellow) (NHC 2001).

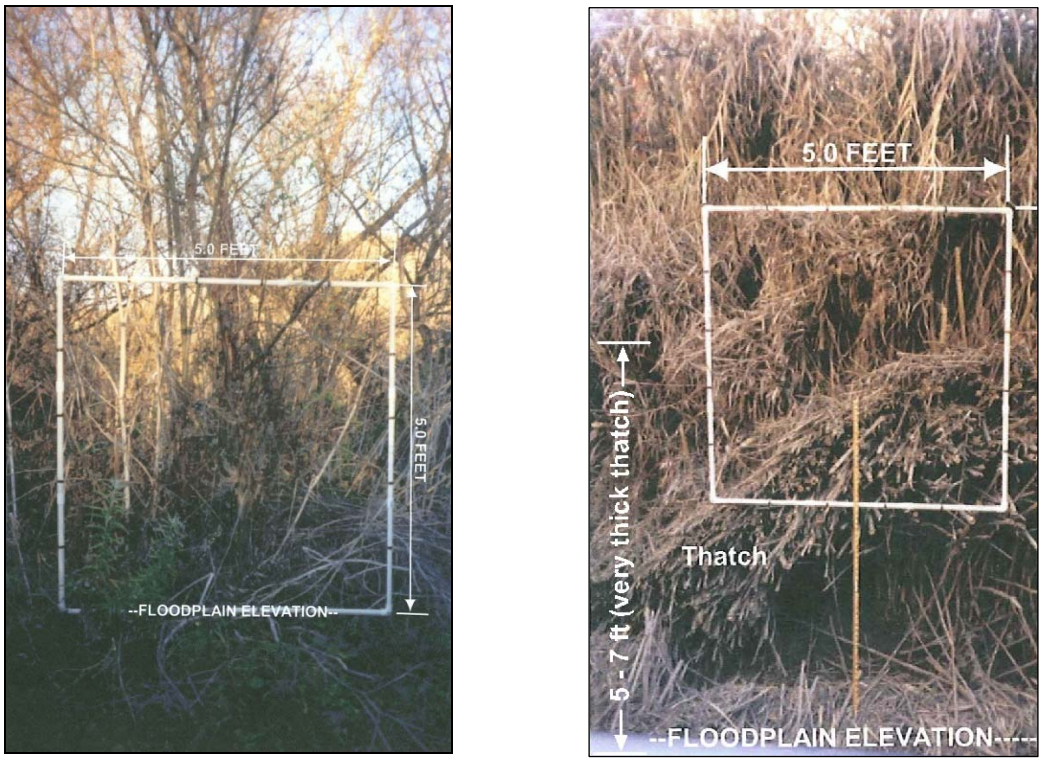
Model Calibration

The HEC-RAS model was calibrated to high water marks surveyed after the 1993 (44,000 cfs) and 1998 (18,400 cfs) floods. Calibration consisted of adjusting Manning's roughness and floodplain characteristics until calculated water surface profiles matched those observed during the floods. The initial calibration in *Arundo* infested areas resulted in Manning's n value on the floodplain that seemed unreasonably high, as much as 0.35 to 0.40, and were considerably higher than typical published values for roughness on vegetated floodplains.

Field observations of mature *Arundo* stands showed an extremely dense thatch of interlocking plant stems that extended 5 to 7 feet above the ground surface that effectively blocked conveyance on the floodplain (Figure 5-1.10). Above that elevation, the *Arundo* stems were not as interlocked or densely spaced and appeared to be able to bend in the flow, similar to native plant species such as willow. However, the *Arundo* exhibited a much higher density of stalks or stems than native willow species (Figure 5-1.10).

These observations led to a modified approach to hydraulic modeling in thick *Arundo* stands on the overbank or floodplain. The calibrated model eliminated flow conveyance in the first 5 feet in mature *Arundo* stands and used an average Manning's n value of 0.15 for water levels over 5 ft from the ground (NHC 2001). This range of roughness was in general agreement with the results of flume measurements of Manning's n for woody vegetation that included tamarisk (Freeman et al. 2000).

Additionally, a Manning's n of 0.10 was adopted for native vegetation on the floodplain and one of 0.05 for bare (un-vegetated) floodplain. A Manning's n of 0.04 to 0.06 was adopted for the low flow or main channel.



ti i i t ti b t t *Arundo*

Figure 5-1.10. Photographs of floodplain vegetation on the Santa Margarita River (1/4/1999).

Model Scenarios

The floodplain roughness in the calibrated HEC-RAS model described above was then adjusted to predict hydraulic characteristics over a range of flows for four different floodplain vegetation scenarios. These were:

- *Scenario 1 – Total Mature Arundo Infestation:* This scenario represents the ultimate extent of *Arundo* infestation, where the entire floodplain surface is covered by mature, monotypic stands.
- *Scenario 2 – Native Vegetation*: This scenario assumes that native vegetation covers the entire floodplain surface and that no *Arundo* is present.
- *Scenario 3 – Bare Floodplain:* This scenario assumes a floodplain surface where floodplain sediments are exposed as a result of fire, *Arundo* eradication, or a large flood event.
- *Scenario 4 – 1997 Floodplain:* This scenario represents the mix of *Arundo*, native vegetation, and bare surface on the floodplain observed in 1997, as interpreted from aerial photos onto the cross sections. Manning's n values vary across the floodplain in each cross section, based on the appropriate values adopted for the different vegetation types observed in the 1997 air photos.

In those scenarios where *Arundo* was present, floodplain elevations were raised 5 ft to simulate zero conveyance in mature *Arundo* stands (Scenarios 1 and 4). Otherwise, the low flow or main channel geometry and floodplain geometry were not altered and remain as described for the NHC (2001) model.

Peak Flows

Table 5-1.5 summarizes the peak flows adopted for the steady state HEC-RAS model runs that were performed as part this study.

Table 5-1.5. Peak flows adopted for the project reach (USACE 1994).

Return Period (years)	***Peak Discharge (cfs)***
2	3,000
5	9,400
10	17,000
25	31,500
50	46,000
100	64,000

Hydraulic Model Results for the 4 Scenarios

Table 5-1.6 provides a general summary of the variation in reach-averaged hydraulic variables for the various scenarios, compared to the native vegetation scenario (Scenario 2).

Table 5-1.6. Differences in hydraulic characteristics between scenarios.

Scenario	**Wetted Width[1]**	**Average Depth**	**Average Flow Velocity**	
			Channel	**Overbank**
1 – *Arundo* Infestation	Wider	Deeper	Faster	Slower
2 – Native Vegetation	*(baseline)*	*(baseline)*	*(baseline)*	*(baseline)*
3 – Bare Floodplain	Narrower	Shallower	Slower	Faster
4 – 1997 Floodplain	Variable	Variable	Variable	Variable

[1] Wetted Width – width of the wetted channel cross-section for a given flow discharge

The ratios of values for Scenarios 1 and 3 compared to Scenario 2 are generally consistent throughout the range of peak flows in Table 5-1.5. The ratios comparing Scenario 4 (1997 vegetation) to Scenario 2 vary. This occurs because the floodplain roughness varies from one cross section to another largely because the extent of the total floodplain area occupied by *Arundo* varies from one sub-reach to another (Table 5-1.7).

Table 5-1.7. Extent of *Arundo* by sub-reach as of 1997.

Sub-Reach [1]	***Floodplain Area (ac)***	***Arundo (ac)***	***Percentage***
1	128	24	19
2	210	93	44
3	396	112	28
4	113	62	55
5	203	90	45
6	59	11	18

[1] See Figure 5-1.6 for location of sub-reaches.

Design Water Surface Profiles

Figure 5-1.11 shows the project reach water surface profiles for the 100-year flood for each of the four scenarios. For the 1997 floodplain vegetation scenario (Scenario 4), 100-year water levels are typically close to that for native vegetation, but rise two to three feet in sub-reaches 4 and 5 where the infestation is dense (Table 5-1.7). Complete coverage by *Arundo* (Scenario 1) raises flood levels by 4 to 5 feet above those for native vegetation throughout the project reach; bare soil or no floodplain vegetation (Scenario 3) lowers them 2 to 3 feet throughout the project reach.

Water surface profiles for the 5-year flood show a similar pattern to that for the 100-year flood, but have smaller differences in stage. The full *Arundo* coverage scenario (Scenario 1) raises water levels up to 3 ft above those for native vegetation, whereas bare soil or no floodplain vegetation (Scenario 3) lowers them about 1 ft. The 5-year water levels for the 1997 vegetation scenario (Scenario 4) are close to those for complete native vegetation coverage, but rise one to two feet in sub-reaches where the infestation is particularly concentrated.

Comparison of results from Scenarios 1 and 4 to those from Scenario 2 suggests that there is a threshold for floodplain coverage by mature *Arundo*, below which impacts on average depths and water surface profiles are relatively insignificant. A rough idea of the threshold can be obtained by comparing *Arundo* densities in Sub-reaches 4 and 5 to those further downstream (Table 5-1.7). On this basis, percent *Arundo* coverage somewhere over 30% generally results in significant adjustments to the water surface profile.

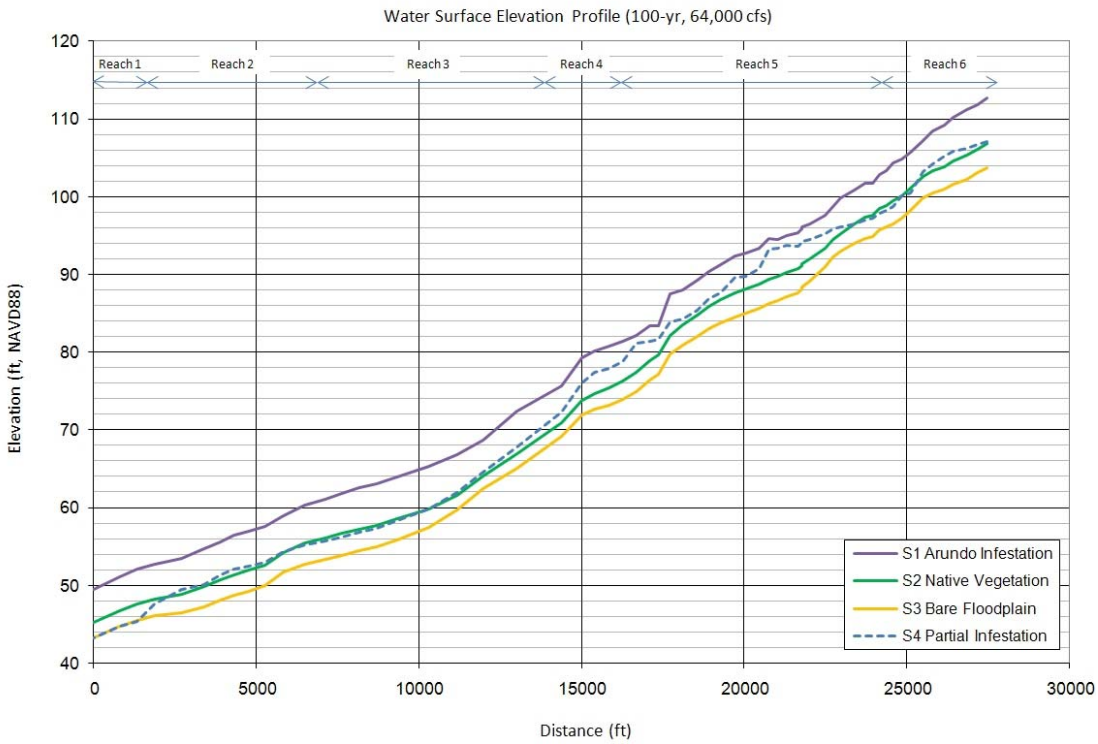


Figure 5-1.11. Project reach water surface profiles for scenarios 1 to 4: 100-year peak flow.

Channel and Floodplain Velocities

Table 5-1.6 indicated that complete coverage by *Arundo* results in the deepest flows and greatest velocities in the main channel and the slowest velocities on the floodplain. This illustrates a key characteristic of dense vegetation, such as *Arundo,* in the hydraulic model: flows are concentrated in the main channel by dense stands along the stream banks, resulting in deeper and faster flow through the main channel for a given discharge.

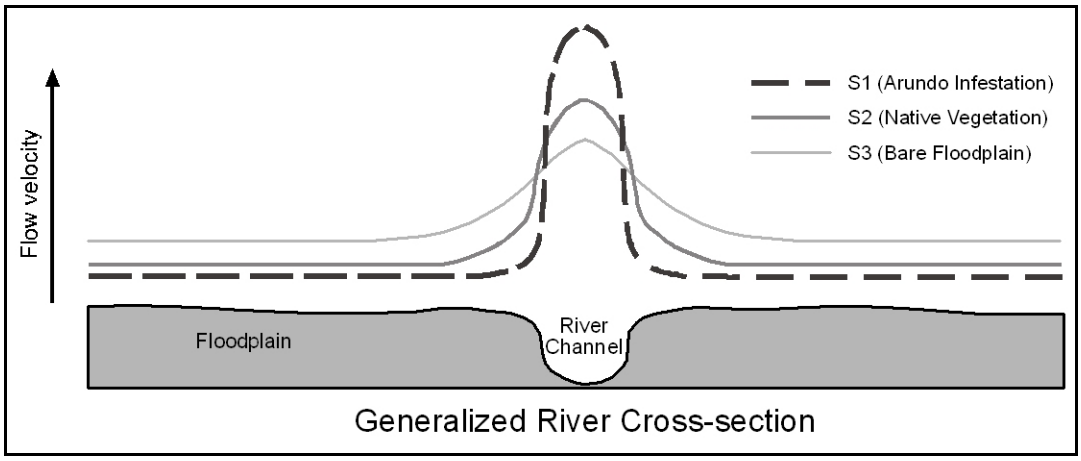


Figure 5-1.12. Generalized illustration of the effects of floodplain roughness (dense vegetation) on velocity across the section for Scenarios 1, 2, and 3.

In contrast, removal of floodplain vegetation results in the lowest average velocities in the main channel. Main channel velocities with floodplain vegetation removed would be lower still if channel widening due to the lower bank strength was incorporated in the RAS model. These observations are summarized in Figure 5-1.12.

Results by Sub-Reach

Table 5-1.8 compares hydraulic characteristics for the four scenarios for Sub-reaches 3 and 5. Sub-reach 5 has a 100-year floodplain width of about 1,100 feet; Sub-reach 3 is less confined and its floodplain width averages 3,500 feet (Table 5-1.4). As expected, the narrower Sub-reach 5 has greater average depths and velocities in the channel and on the floodplain than the wider Sub-reach 3 at the 100-year peak for all the scenarios. However, the percentage increases in average depths and velocities in Sub-reach 5, when comparing Scenario 1 to Scenario 2, are smaller than in Sub-reach 3. This is thought to occur because the main channel, whose roughness is not affected by differing vegetation types, occupies a larger portion of the total floodplain width and conveys a greater portion of the total flow. When Scenario 4 is compared to Scenario 2, the results are complicated by the different *Arundo* coverage percentages, but velocities increase in Sub-reach 3 and decrease in Sub-reach 5. In sub-reach 5, the increased floodplain roughness seems to be accommodated more by increased depths than velocities in the main channel, potentially as a result of backwater from Sub-reach 4.

Table 5-1.8. Depths and Velocities in Sub-reach 3 (wide floodplain) and Sub-reach 5 (narrow floodplain) for the 100-year peak flow.

Scenario	Sub-Reach 3 (wide floodplain)					Sub-Reach 5 (narrow floodplain)				
	Wetted Width (ft)[1]	Average Flow Depth (ft)		Average Flow Velocity (ft/s)		Wetted Width (ft)[1]	Average Flow Depth (ft)		Average Flow Velocity (ft/s)	
		CH	OB	CH	OB		CH	OB	CH	OB
1 – *Arundo* Infestation	3,530	17.5	7.5[2]	10.3	1.5	1,150	20.2	10.5[2]	13.4	2.3
2 – Native Vegetation	3,480	12.3	7.2	8.0	2.2	1,140	15.7	10.4	11.8	3.6
3 – Bare Floodplain	3,400	9.9	4.9	7.2	3.6	1,120	12.9	7.8	10.4	6.0
4 – 1997 Floodplain	3,280	12.2	6.6	8.4	2.5	1,140	17.5	10.0	10.9	3.7

[1] Wetted Width – width of the wetted channel cross-section for a given flow discharge
[2] Represents depth of active flow conveyance area only, and does not include 5 ft thickness of ineffective flow in *Arundo* areas.
Note: CH = Channel; OB = Overbank or floodplain

As noted earlier, the above results assume the same geometry for the main channel and floodplain for each scenario; only roughness changes from one scenario to another.

5.1.4.7 Project Reach Sediment Budget

Introduction and Context

Sediment transport in rivers is complex and this chapter considers only two of its components. This section discusses reach-based sediment budgets and addresses the question of whether *Arundo* infestation might reduce sediment delivery to downstream reaches and, ultimately, to the Pacific Ocean. This section also discusses the potential changes in sediment transport capacity that might result from the altered hydraulics discussed in the previous section and considers the likely channel response. The analyses are speculative for both of these components.

Sediment Budget Considerations

The sediment budget for a particular reach – such as the project reach on the Santa Margarita River – can be expressed as follows:

$$\text{Sediment}_{\text{Out}} = \text{Sediment}_{\text{In}} \pm \Delta\text{Storage} \qquad (1)$$

In (1), the change in sediment storage in the reach over time (ΔStorage) can be either negative (erosion from the reach) or positive (deposition in the reach), with erosion increasing the sediment output; deposition reducing it.

The budget can be constructed for various time periods or grain size classes. The analysis for the project reach focuses on long-term averages and the transport of sand. In the Santa Margarita River, sand makes up much of the bed material. It is transported both in suspension and as bed load (Slagel and Griggs 2006).

If we can assume that the sediment delivered to the project reach is reasonably constant over the long-term then the sediment that leaves the reach will differ from that arriving as a result of changes in sediment storage within the reach, including those that result from *Arundo* establishment. Changes in storage within the reach are best measured by comparing repeated surveys of channel and floodplain cross sections to define volumes and by sediment sampling to define the size distribution of the materials that have been eroded or deposited. Such information is not available on the Santa Margarita River and is seldom available for large rivers in Southern California. Instead, we rely on observations in other reports to roughly define the changes in sediment storage expected with *Arundo* infestation and sediment delivery studies to define the long-term sediment input to the stream reach.

Santa Margarita River Sediment Loads

Previous studies (Slagel and Griggs 2006, Inman and Jenkins 1999) have estimated annual sediment transport in the Santa Margarita River from sediment gaging at the Ysidora gage, which is downstream of the project reach. Average annual transport was between 50 and 70 acre-feet (65,000 and 80,000 m^3) in the two studies. Slagel and Griggs (2006) also concluded that average annual sand transport was about 20 acre-feet (25,000 m^3), or about 30 to 40% of the total transport.

Sediment Capture by *Arundo*

Previous studies (see Section 5.1.2) indicate that deposition occurs on the floodplain as *Arundo* stands establish and mature. Rates have not been measured on the Santa Margarita River but the average annual accretion rates discussed in Chapter 2 ranged from about 0.3 to 0.7 feet per year. Given these rates, the average annual storage in the *Arundo* stands on the floodplain might then be from 120 to 280 acre-feet over the 400 acres of *Arundo* growth that was present in 1997. Roughly one-third of the total is sand (see

Slagel and Griggs 2006), or about 40 to 90 acre-feet. This represents the average annual loss of sand in transport to storage in *Arundo* stands. Sediment deposition is also likely to occur on the remainder of the floodplain but this has been ignored in the simple budget constructed to evaluate *Arundo* impacts.

It is not known how long the above average rates of accretion or deposition might continue. Rates may be curtailed as the floodplain and braid channels fill with sediment, particularly because the channel thalweg does not seem to be aggrading on the Santa Margarita River.

Adding the above annual estimate of sand trapped on the floodplain to the transport observed at the Ysidora gage (the sediment leaving the reach) indicates that the annual sand inflow to the project reach might have been 60 to 110 acre-feet during the period of *Arundo* establishment and growth. On this basis, the sediment output from the reach was reduced to one-third or less of the sediment input by storage in the *Arundo* stands. This suggests that *Arundo* establishment and growth on the floodplain of the project reach has the potential to capture a substantial portion of the sediment delivery from the upper watershed. As discussed in the next section, losses to deposition on the floodplain may be partly compensated for by erosion from the channel bed.

Erosion in the Main Channel from *Arundo* Growth

Based on the literature review, at the same time as the *Arundo* stands on the floodplain are trapping sediment in transport, the main channel can be expected to narrow. We have no good measurements of the change in width that occurred as *Arundo* stands established and dominated the riparian and floodplain vegetation on the Santa Margarita River. However, measurements by Cal-IPC (Section 4.5) show that the main channel width about tripled in width following *Arundo* eradication. Assuming that the same results would occur in reverse during *Arundo* establishment and growth, the main channel with *Arundo* infestation might be about one-third to one-half as wide as it was prior to *Arundo* establishment.

As the channel narrows it would be expected to deepen to pass typical floods, as is commonly observed in regime studies. Such a response was not observed often in the literature review but that may be because the channel bed or thalweg rose as the floodplain filled but to a lesser extent, creating a deeper flow channel. It is not known how channel depths have changed on the Santa Margarita River following *Arundo* infestation.

A rough estimate of the increased depth required to pass typical floods as the channel narrows can be obtained by applying Blench's (1969) regime equation. It suggests that the increase in channel depth for the above reductions in width might be about 50 to 100%. The typical channel depth before *Arundo* establishment is not known, but the observed channel bank height in the project reach as of 1997 or so, with *Arundo* in place, was about 4 to 6 feet, consistent with calculated average depths at the 2-year flood. Based on the ratio above, it appears that the channel may now be 2 to 3 feet deeper than it was prior to *Arundo* establishment. The greater channel depth might result from bed erosion, increased floodplain height adjacent to the channel, or a combination of the two processes.

The area of the main channel in 1997 was 118 acres and the bed material was sand. Assuming that 2 to 3 feet of erosion occurred over twenty years, the average annual net loss of bed material from the reach could be as much as 12 to 18 acre-feet over the project reach. As noted above, the net erosion might be zero if the channel deepens by filling on the floodplain rather than by eroding its bed.

Project Reach Sediment Budget Summary

The above suggests that annual trapping of sand on the floodplain during *Arundo* establishment and growth in the project reach was about 40 to 90 acre-feet; the erosion from the channel bed as it adjusted

to narrower widths is expected to be less than 20 acre-feet. The above estimates are based on accretion and erosion rates from the literature rather than from measurements on the Santa Margarita River. However, they suggest that *Arundo* establishment and growth is likely to reduce the volume of sand transported through the project reach to the coast. As noted above, two-thirds of the sand transported from the upper Santa Margarita River watershed might be trapped in *Arundo* stands in the project reach during their establishment and growth.

After *Arundo* has established and reached its maximum coverage, we anticipate that accretion of sediment on the floodplain will slow, unless the channel fills rapidly so that flood waters continue to spill onto the higher floodplain. As the accretion on the floodplain slows or stops, the adjustment of channel depth to the narrower channel width will also slow or stop. At this point, sand transport out of the reach will be in equilibrium with sediment supply.

The observed difference between losses to sediment storage and gains from bed erosion in the Santa Margarita River may not be the same in other Southern California Rivers with different overall geomorphology. Where the floodplain is narrower than in the Santa Margarita River, bed erosion may be a large portion of storage and the reduction in sand transport towards the coast with *Arundo* establishment may be smaller. Where the floodplain is much wider, the opposite result may occur.

5.1.4.8 Project Reach Sediment Transport Capacity

Introduction and Context

Suspended sediment transport has been measured at the Ysidora gage on the Santa Margarita River; however, there are no measurements of bed load transport. Bed load and bed material load transport have been modeled by NHC (1997b) and West Consultants (2000) but only for the *Arundo* coverage that existed in the late 1990s. Consequently, an evaluation of the potential effects of varying *Arundo* coverage or *Arundo* eradication on sediment transport capacity must be calculated from the hydraulic output from the HEC-RAS model runs.

The RAS model runs have some limitations for calculating sediment transport capacity for different conditions. The actual channel and floodplain geometries under different vegetation scenarios are not known; nor do we know if the size of material on the channel bed differs for these scenarios. Instead, as described earlier, the RAS model adopted the channel and floodplain geometry from 1997 for all the scenarios, altering the floodplain roughness and conveyance to simulate different vegetation scenarios, and assumed the same bed material distribution.

Approach to Transport Capacity

We have adopted stream power as the best proxy for sediment transport capacity differences among the four floodplain vegetation scenarios (Bagnold 1966; Vanoni 1975). Stream power per unit length of channel, which is essentially a measure of the energy available to transport sediment once a critical threshold for mobility is passed, is defined as:

$$\Omega = \rho g Q S \qquad (2)$$

where Ω is stream power, ρ is the density of water, g is the acceleration due to gravity, Q is a discharge and S is energy slope, roughly parallel to the bed slope. For calculations from the model output, $Q = wdv$, where w is channel width, d is average channel depth and v is average sectional velocity, was substituted into Equation (2) and terms regrouped as:

$$\Omega = \tau v w \qquad (3)$$

In Equation (3), τ is the average bed shear stress. Stream power was calculated separately for the channel and floodplain for each of the four scenarios, for the 5-year through 100-year peak flows (see Table 4.2). Average annual stream powers were then calculated based on an expression reported in USACE (1995) that incorporates the stream power exerted by floods up to the 100-year return period and approximates the area under the annual probability-event yield curve.

Stream Power for Different Scenarios

Table 5-1.9 summarizes the stream power calculated for Scenarios 1, 3, and 4 as a ratio to that calculated for Scenario 2 (Native Vegetation), the adopted baseline or index condition. Numbers >1 indicate more power and greater sediment transport, and numbers <1 indicate less power and sediment transport. This table shows that the ratios of the stream power to that for Scenario 2 are not particularly sensitive to the magnitude of the flood, under the model assumption of fixed channel and floodplain geometry. In the Santa Margarita River we expect that the channel will respond rapidly to increased stream power, altering its depth, width (where geometry permits) or bed material size until thresholds for transport are increased or bed stresses are reduced. Thus, the observed differences may not persist for the frequent floods, but are likely to persist for the largest ones.

Table 5-1.9 is helpful when considering potential channel and floodplain responses to changes in floodplain vegetation. For example, it suggests that as vegetation changes from native to a mixture of *Arundo*, native vegetation and bare soil (Scenario 4) the stream power exerted in the main channel will increase and, hence, it will begin to deepen. Stream power exerted on the floodplain will decrease and filling of secondary channels and deposition on the floodplain might be anticipated. When floodplain changes from a vegetated state to bare soil (Scenario 3), as it would under the *Arundo* eradication program, the stream power exerted in the main channel reduces and deposition or channel filling might occur. On the floodplain, stream power is greatly increased and rapid development of channel braids would be expected, returning the channel form to a braided appearance, such as has been observed in the Santa Margarita River. This assumes that the *Arundo* root mass has been removed or that it does not affect stability of the sediments. Areas with rhizome mats still in place would be expected to be more erosion resistant than bare soil, and might reduce or prevent geomorphic change.

Table 5-1.9. Summary of relative differences in stream power by scenario for entire study area, (S2: native is baseline).
>1 = more power and sediment transport, <1 = less power and sediment transport

	Channel				Floodplain			
Flow Event	**S1 *Arundo***	**S2 Native**	**S3 Bare**	**S4 Mix-1997**	**S1 *Arundo***	**S2 Native**	**S3 Bare**	**S4 Mix-1997**
5-year	**1.41**	1.00	0.88	**1.02**	**0.23**	1.00	1.33	**0.95**
10-year	**1.59**	1.00	0.86	**1.06**	**0.38**	1.00	1.22	**0.92**
25-year	**1.51**	1.00	0.80	**1.10**	**0.50**	1.00	1.17	**0.89**
50-year	**1.50**	1.00	0.77	**1.13**	**0.59**	1.00	1.16	**0.92**
100-year	**1.50**	1.00	0.74	**1.14**	**0.66**	1.00	1.15	**0.95**
Average Annual	**1.50**	**1.00**	**0.83**	**1.07**	**0.49**	**1.00**	**1.20**	**0.93**

S1=all *Arundo*, S2=all native, S3=all bare, S4=1997 site conditions (mix of *Arundo*, native, bare).

Stream Power by Sub-Reach

In a similar fashion to the hydraulic characteristics, the relative changes in stream power also vary from sub-reach to sub-reach, depending on floodplain width. A narrow sub-reach (5) and a wider sub-reach (3) are presented in Table 5-1.10 to illustrate this.

Where the floodplain is wide relative to the channel there are potentially greater changes in stream power in the main channel with complete *Arundo* coverage (Scenario 1). Thus, a greater channel response (power and sediment transport) would be expected in wider floodplain reaches with complete *Arundo* coverage than in narrower ones, which is confirmed in Table 5-1.10. The lower power/sediment trapping effect on floodplains is more pronounced in narrower sub-reaches (S1 and S4 are lower). This may be off-set by the spatial extent of floodplains, however, as there is more invaded floodplain in sub-reach 3 to catch sediment, wider floodplain seems to balance in terms of sediment transport, narrower reaches may trap more.

Table 5-1.10. Differences in relative stream power for sub-reaches 3 and 5.

Sub-reach 3 (wider floodplain)

	Channel				Floodplain (overbank)				Total			
Flow Event	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix'97	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix'97	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix'97
10-year	**1.75**	1.00	0.82	**1.09**	**0.42**	1.00	1.18	**1.02**	**0.99**	1.00	1.02	**1.05**
10o-year	**1.78**	1.00	0.82	**1.20**	**0.72**	1.00	1.18	**1.09**	**0.99**	1.00	1.09	**1.12**

Sub-reach 5 (narrower floodplain)

	Channel				Floodplain (overbank)				Total			
Flow Event	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix'97	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix'97	**S1** *Arundo*	**S2** Native	**S3** Bare	**S4** Mix'97
10-year	**1.30**	1.00	0.86	**0.89**	0.28	1.00	1.28	**0.68**	**0.90**	1.00	1.02	**0.81**
10o-year	**1.33**	1.00	0.73	**0.83**	0.57	1.00	1.22	**0.69**	**0.91**	1.00	1.00	**0.76**

S1=all *Arundo*, S2=all native, S3=all bare, S4=1997 site conditions (mix of *Arundo*, native, bare).

5.1.4.9 Case Study Summary

This section summarizes our understanding of the effects of *Arundo* establishment on hydraulics, sediment transport and geomorphology, based on the case study in the lower Santa Margarita River project reach.

Similar to other rivers in Southern California and throughout the American Southwest, the establishment and spread of *Arundo* on the lower Santa Margarita River has narrowed the active river channel and simplified its river cross-section. This has resulted in a shift from a wide, braided river planform to a single channel with defined banks and few bare active geomorphic surfaces. The narrowing trend has been interrupted by occasional large floods which remove floodplain vegetation and widen the channel, such as occurred in 1969 and 1993. It is not understood or known what the minimum channel width might be in the absence of large floods.

Inspection of historical air photos suggest that there has been much less channel widening from recent large floods than occurred in 1969, presumably because of different erosion resistance of the floodplain since the *Arundo* stands have been established. Little is known of the hydraulic forces that can be withstood by the *Arundo* stands in various types of floodplain deposits (soils) so there is no good understanding of how large a flood would be required to remove stems, erode the root mass, and reset the floodplain vegetation. In any event, it appears that *Arundo* will out-compete native vegetation on the disturbed floodplains and re-establish mature stands on much of the floodplain in the time interval between very large floods.

The mature *Arundo* stands essentially eliminated flow conveyance during low and moderate floods on the portions of the floodplain that they occupy, increasing the portion of the flow passing through the low flow or active channel. During large peak flows, when water levels are more than 5 feet or so over the floodplain surface, flow is conveyed over the mature *Arundo* stands but considerable roughness is

created by the stems and leaves. During very great flows, the *Arundo* stems may be broken off and carried downstream, substantially altering local resistance to flow.

Hydraulic modeling of four different floodplain vegetation scenarios (all *Arundo*, all native, all bare, 1997 field conditions) suggested that the conversion from native vegetation to complete coverage by mature *Arundo* stands would have three important implications. First, 100-year water levels are raised by 3 or 4 feet from the increased roughness. Second, the portion of the total discharge carried in the main channel increases and, thus, depths and velocities also increase for a particular return period flood. Third, the (modeled) conveyance on the floodplain is much less with *Arundo* infestation.

There are some interesting and significant subtleties suggested by the hydraulic modeling. First, there appears to be a threshold for *Arundo* coverage before there are significant effects on hydraulics. The exact portion of the floodplain that must be occupied for a significant effect is not fully understood. Second, the magnitude of the effect on hydraulics of *Arundo* infestation and the threshold for observing significant effects depends on the overall floodplain and channel width. Narrow total widths show less effect for a particular flood than wide ones, likely because there is less conveyance on the narrow floodplains for the native vegetation scenario, so there is a smaller increase in flows in the main channel when *Arundo* coverage is complete. Note that velocities are higher in the narrower reaches; the above differences refer only to the observed percentage increases with the *Arundo* scenario in the hydraulic model.

The results of the hydraulic model studies are limited because they do not account for channel adjustments that are expected to occur rapidly in response to the altered hydraulics on the floodplain and in the main channel. Stream power calculations, which were adopted as a proxy for sediment transport, show greatly increased stream power in the main channel and greatly reduced stream power exerted on the floodplain under complete *Arundo* coverage, when compared to native vegetation, and a smaller increase and smaller decrease for partial coverage (Scenario 4). The consequences of the changes in stream power (or any measure of forces exerted on the bed) when banks are less erodible because of *Arundo* establishment are expected to be increased depths of the main channel and sediment trapping and accretion on the floodplain and in overbank areas. Regime considerations suggest that average depths might increase by about 50% to 100% for frequent floods to compensate for the narrowed channel. However, this is only a rough estimate and has not been confirmed with field surveys or measurements.

Both of the channel responses described above change the sediment storage in the project reach on the Santa Margarita River and potentially affect the delivery of sediment from the upper watershed to downstream reaches and the Pacific Ocean. Considering only the sediment balance for sand, and relying on accretion rates observed in the literature, it appears that the annual loss of sand to trapping on the floodplain during *Arundo* establishment is much larger than the compensating erosion from the adjustments of the channel. In the Santa Margarita River project reach, the net deposition on the floodplain is a very large portion of the sand carried down from the upper watershed. As discussed, different conclusions might be drawn for rivers with much wider or much narrower floodplains.

Once *Arundo* reaches its maximum coverage, floodplain trapping and channel adjustments will eventually cease, and delivery from the upper watershed to the reach will equal that which passes through to downstream reaches and the Pacific Ocean.

5.1.5. Study Stream Arundo Responses

5.1.5.1 Introduction

This section applies the results of the literature review (section 5.1.3) and the case study analysis (section 5.1.4) to develop a method to qualitatively assess the potential impacts of *Arundo* infestation on river hydraulics, sediment transport capacity and geomorphology. Once developed, the method is applied to the Santa Margarita, Santa Ana and San Luis Rey Rivers, utilizing the river and riparian vegetation characteristics provided in Chapter 5.1.3. Stream responses to *Arundo* discussed in this chapter are based on the maximum extent of *Arundo* mapped in these study reaches by Cal-IPC, as presented in Chapter 5.1.3.

5.1.5.2 *Arundo* Impact Scoring System

The potential impacts of *Arundo* infestation on river characteristics and, to some extent, the potential impacts of reach characteristics on the maximum extent of *Arundo* coverage, were qualitatively assessed by totaling scores that were developed from the key findings and observations from the literature review, Santa Margarita River case study and GIS mapping effort (Chapter 5.1.3).

The Width Ratio and *Arundo* Coverage scores express the potential for modification of the river as a result of *Arundo* Infestation. The Changes in Floodplain Width and Bed Slope, and Other Features scores express the potential for *Arundo* to dominate the riparian vegetation on the floodplain in the reach. We have defined the *Arundo* Impact Score to be the sum of the individual scores, as defined below. As scores increase, significant changes in river characteristics become more likely and differences between the *Arundo* and native vegetation river characteristics become greater. The specific impacts of *Arundo* on river characteristics are likely to be different in each stream reach and river system; however, the general effects will be similar to those described in Sections 5.1.2.4 and 5.1.4.9.

Width Ratio Score

The Santa Margarita River case study demonstrated that wider floodplain reaches may have a greater hydraulic response to *Arundo* infestation than narrower ones. A score was developed based on this observation using the Width Ratio (see Chapter 5.1.3), which is the ratio of the low flow channel width to the floodplain width (Table 5-1.11).

Table 5-1.11. Width ratio score.

Width Ratio	Width Ratio Factor	Comment
Below 4%	2	Wide floodplain reach
4% - 8%	0	Average width floodplain reach
Above 8%	-1	Narrow floodplain reach, typically confined by either topography or levees

Width ratios of 4% and 8% were selected as the cut-offs between wide, average, and narrow floodplain categories, based on the differences observed between Sub-reach 3 (wide floodplain) and Sub-reach 5 (narrow floodplain) in the Santa Margarita case study. Note that Sub-reach 3 is Reach 6 (width ratio =

3.8%) and Sub-reach 5 is Reach 8 (width ratio = 7.0%) in Table 5-1.1. The scores assigned to the different width ratios is shown in Table 5-1.11.

Arundo Coverage Score

The Santa Margarita case study suggested that a threshold of floodplain coverage by mature *Arundo* exists, below which impacts on average depths and water surface profiles are relatively insignificant. This percent coverage seemed to be between 28% and 45% *Arundo* coverage for the case study river (see Section 5.1.4.6). Table 5-1.12 shows the scoring that was developed based on the percent *Arundo* Coverage mapped for each reach in section 5.1.3. Cut-off points of 25% and 40% were selected for scoring the impact of percent *Arundo* cover on river characteristics.

Table 5-1.12. *Arundo* coverage score.

% *Arundo* Coverage	*Arundo* Coverage Factor	Comment
Below 25%	0	The effects of *Arundo* on hydraulics may not be significant in this reach
25% - 40%	1	This range of *Arundo* coverage represents a transition zone within which significant impacts to the water surface profile and consequently river hydraulics and sediment transport and geomorphology may occur
Above 40%	3	High percent *Arundo* coverage suggests this reach provides optimal conditions for *Arundo* establishment and changes in hydraulic, sediment transport and geomorphic effects are likely to be significant

Changes in Floodplain Width and Bed Slope Scores

The GIS analysis in Section 5.1.3 showed a relationship between the maximum percent *Arundo* coverage observed in a reach by Cal-IPC and changes in floodplain width and bed slope relative to the reach upstream. As previously discussed, large increases in floodplain width and declines in bed slope contribute to decreased flow velocities and sediment transport capacity. This promotes deposition and increases the likelihood of *Arundo* dispersal in that reach. Conversely, abrupt declines in floodplain width or increases in bed slope may promote the opposite effect and limit *Arundo* propagules from depositing.

Chapter 5.1.3 also noted there may be an upper slope limit for significant *Arundo* coverage in the floodplain vegetation that may be a proxy for a number of other factors. Also, the above discussion does not apply to river estuary reaches where salt water intrusion restricts *Arundo* growth and coverage. This is a narrow range, however, as *Arundo* tolerates up to 90% salt water.

Large increases (>100%) in floodplain width relative to the reach upstream are observed in Reach 7 of the Santa Margarita River, Reach 6 of the San Luis Rey, and Reaches 2 and 4 of the Santa Ana River. Each reach exhibits either a large (>50%) increase in *Arundo* cover from the reach upstream and more than 40% total *Arundo* cover. Conversely, Reach 3 of the Santa Ana River exhibits a 100% decline in floodplain width and nearly 50% decline in percent *Arundo* cover relative to the reach upstream. The scores associated with changes in floodplain width are summarized in Table 5-1.13.

Large decreases (>33%) in bed slope relative to the reach upstream are observed in Reach 7 of the Santa Margarita River, Reaches 2, 4 and 8 of the San Luis Rey, and Reach 3 of the Santa Ana River. Reach 7 exhibits greater than 45% *Arundo* cover and Reaches 2 and 4 exhibit large (>33%) increases in percent *Arundo* cover relative to the reach upstream. Reach 3 shows a decline in percent *Arundo* cover, possibly because of a large decline in floodplain width, and Reach 8 has negligible *Arundo* cover as does the reach upstream. The effect of changes in channel bed slope on the *Arundo* impact score are summarized in Table 5-1.14.

Table 5-1.13. Floodplain width score.

% Change in Floodplain Width	Floodplain Width Factor	Comment
>100% Decrease	-1	Flow confinement promotes higher average flow velocity, limiting the potential for deposition of *Arundo* propagules in this reach
Less than 100% Change	0	Changes in floodplain width may be significant in affecting the deposition of *Arundo* propagules but do not show a clear impact.
>100% Increase	1	Floodplain widening promotes a decline in average flow velocity and promotes deposition of *Arundo* propagules in this reach.

Table 5-1.14. Bed slope score.

% Change in Bed Slope	Bed Slope Factor	Comment
>33% Decrease	1	Decreases in bed slope promote lower average flow velocity which favors the deposition of *Arundo* propagules in this reach.
Less than 33% Change	0	Changes in bed slope may be significant in affecting the deposition of *Arundo* propagules but do not show a clear impact.
>33% Increase	-1	Increases in bed slope promote higher average flow velocity, limiting the potential for deposition of *Arundo* propagules in this reach

Other Features

Other features not already incorporated into the *Arundo* impact score are also indentified and, if present, provide an additional factor of '1' or '-1' depending on the feature observed. These include salt water intrusion that limits *Arundo* growth at the river mouth, and anthropogenic features that could potentially influence *Arundo* impacts on a river reach. Features specific to each stream are discussed in the next section.

5.1.5.3 Santa Margarita River

Table 5.5 shows the *Arundo* impact scores for the Santa Margarita River study reaches (Figure 5-1.1 shows reaches). Note that the case study Sub-reaches 1 through 6 conform to Reaches 4 through 9 in the GIS mapping in Chapter 5.1.3.

Table 5-1.15. Santa Margarita River *Arundo* impact scores.

Reach	Reach length (mi)	Case Study Sub-Reach	*Total Score*	*Arundo* Impact Scores				
				Width Ratio	*Arundo* Coverage	Floodplain Width	Bed Slope	Other Features
1	1.52		***-1***	-1	0	0	1	-1
2	1.47		***-1***	-1	0	0	0	0
3	1.70		***0***	0	0	0	0	0
4	0.42	1	***2***	2	0	0	0	0
5	0.90	2	***6***	2	3	0	1	0
6	1.30	3	***2***	2	1	0	-1	0
7	0.42	4	***7***	2	3	1	1	0
8	1.60	5	***4***	0	3	0	0	1
9	0.77	6	***0***	-1	0	0	0	1
10	1.21		***0***	-1	0	0	0	1
11	1.89		***-1***	-1	0	0	0	0
12	4.11		***-1***	-1	0	n/a	n/a	0

Table 5-1.15 shows that Reaches 4 through 8 (Sub-reaches 1 through 5) are the most susceptible to changes in river form and process from *Arundo* infestation. For the most part, these reaches have low slopes, wide floodplains with abundant opportunity for *Arundo* establishment and propagation, and historically large areas of *Arundo* stands. Other features that affect *Arundo* distribution and potential impacts on river characteristics includes salt water that limits *Arundo* growth in Reach 1 and groundwater recharge from Lake O'Neill and infiltration ponds in Reaches 8, 9 and 10 that provides additional water.

Table 5-1.15 identifies sub-reaches 2 and 4 as those where *Arundo* is likely to exert the greatest impact on river characteristics. Such a result is reasonably consistent with the case study observations in section 5.1.4. Sub-reach 4 does show a rise in the water surface profile compared to the base case (Figure 5-1.11) and other modifications to the reach hydraulics occur. Sub-reach 2 shows no rise in the water surface profile (Figure 5-1.11); instead, the increased flow through the main channel is accommodated by increases in velocities. The highest scoring contiguous river sections (Reaches 4 to 8) is about 8 miles long. This is a significant portion of the river.

5.1.5.4 San Luis Rey River

Table 5-1.16 shows the *Arundo* impact scores for the San Luis Rey study reaches. Based on this table, the greatest modification to river characteristics from *Arundo* impacts are expected to be in Reaches 2 and 4. *Arundo* has also historically been well established in Reaches 3 and 5 but they do not score very high due to floodplain confinement by urban levees. Further upstream, in Reaches 8 through 11, a score of -3 was assigned in Other Features to reflect that these steeper reaches have little or no *Arundo* in their floodplain vegetations, suggesting that *Arundo* has not successfully colonized this area. This may be a

result of steep bed slopes in these upper reaches that reduce opportunities for *Arundo* establishment, or lack of source propagules or plants.

The overall scores for the San Luis Rey River reaches are considerable less than for the Santa Margarita River reaches suggesting that *Arundo* impacts on river forms and processes may be less significant. However, Reaches 2, 4 and 6 constitute most of the functional lower river (9 mi), and these areas are impacted. Reaches 3 and 5 only function to convey water, and they have limited geomorphic or biologic function.

Table 5-1.16. San Luis Rey *Arundo* impact scores.

Reach	Reach length (mi)	*Total Score*	***Arundo* Impact Scores**				
			Width Ratio	***Arundo* Coverage**	**Floodplain Width**	**Bed Slope**	**Other Features**
1	0.86	***-1***	-1	0	0	1	-1
2	1.66	***3***	-1	3	0	1	0
3	5.79	***-1***	-1	0	0	0	0
4	5.53	***2***	0	1	0	1	0
5	0.62	***-1***	0	0	-1	0	0
6	5.07	***1***	0	0	1	0	0
7	3.73	***-2***	-1	0	-1	0	0
8	3.73	***0***	2	0	0	1	-3
9	2.03	***-1***	2	0	0	0	-3
10	2.01	***-5***	0	0	-1	-1	-3
11	1.16	***-1***	2	0	n/a	n/a	-3

5.1.5.5 Santa Ana River

Table 5-1.17 summarizes the *Arundo* Impact scores for the Santa Ana River reaches (Figure 3-2 shows reaches). Based on these scores, the greatest modification to river processes and form are expected to occur in Reaches 1 and 2. Note that Reach 1 is in the Prado Flood Control Basin and *Arundo* establishment and spread will be different than in other reaches because of basin filling during large runoff events and long-term sediment deposition.

Reach 2 has a meandering channel that flows through a shallow valley. The wide floodplain provides substantial opportunity for *Arundo* establishment and the gradual reduction in slope down the reach and its location downstream of a steeper, more confined Reach 3 also contribute to the high score. Impacts of *Arundo* on river form and process are expected to similar to those observed in the Santa Margarita River here. It should be noted that Reach 2 is very long (8 mi), equaling the length of 3-5 reaches on the San Luis Rey or Santa Margarita. Impacts to reaches 1 and 2 total 10 miles, and this is most of the broad floodplain on the river.

Table 5-1.17. Santa Ana River *Arundo* impact scores.

Reach	Reach length (mi)	*Total Score*	*Arundo* Impact Scores				
			Width Ratio	*Arundo* Coverage	Floodplain Width	Bed Slope	Other Features
1	3.16	***5***	2	0	1	1	1
2	12.17	***4***	0	3	1	0	0
3	2.08	***-1***	-1	0	-1	1	0
4	2.35	***0***	-1	0	1	0	0
5	9.67	***0***	-1	0	0	1	0
6	3.98	***-2***	-1	0	-1	0	0
7	3.44	***-1***	-1	0	n/a	n/a	0

5.1.5.6 Application of Scoring System

The scoring system proposed above is preliminary and might be modified based on experience and further analyses of river response to *Arundo* infestation by adjusting scoring or weighting of the different scores. At this time, the scoring system can be used to identify and rank those river reaches where *Arundo* establishment is likely to have significant effects on river hydraulics, sediment transport and morphology. This could be used to prioritize areas for additional monitoring to look at: flood risk damage (bridges and overbank), sediment retention and loss, as well as setting control priorities and/or temporary reduction of vegetation to maintain flows.

5.1.6. Conclusions and Recommendations

The overall goal of this study was to describe the potential effects of *Arundo* establishment and growth on the hydraulics, sediment transport characteristics and morphology in Southern California Rivers. The study results are based on literature review, GIS analysis of river and floodplain vegetation characteristics, and hydraulic modeling of four floodplain vegetation scenarios on the Santa Margarita River.

Arundo is a highly aggressive, non-native plant species that has invaded riparian areas and floodplains of the sandy, braided Southern California Rivers, displacing native plants and degrading habitats. These historically braided and laterally unstable channels are transformed by *Arundo* into narrower, more laterally stable single thread channels with root-stabilized, steep banks. Inspection of historical air photos suggest that there has been much less channel widening from recent large floods than occurred earlier, presumably because of the replacement of native floodplain vegetation with much denser *Arundo* stands. In any event, it appears that if sufficient soil moisture is available *Arundo* will out-compete native vegetation on the disturbed floodplains and re-establish mature stands on much of the floodplain in the time interval between very large floods.

Plant colonization stabilizes bar and floodplain surfaces, increasing channel roughness and sediment trapping efficiency, thereby creating a mechanism for further sediment capture, deposition and vertical accretion. Long-term observed rates of vertical accretion on the floodplain vary widely in the reported literature but are as high as 0.8 ft/yr. Several feet may accumulate locally during a large flood.

Accretion rates likely vary with the volume of sediment in transport as well as the specific river conditions. There may be an upper limit on vertical accretion, which would about correspond to the elevations of typical floods. This may be reached fairly soon if the channel bed incises or does not accrete as rapidly as the floodplain. If the channel bed fills as the floodplain accretes, this limit may not be reached for a long time. Human modification to upstream and downstream reaches (such as levees or bridges) and to flood flows and sediment supply (such as by reservoir construction or groundwater recharge) may alter river and *Arundo* establishment processes and affect the above observations on river response to *Arundo* establishment and growth.

Hydraulic modeling and field inspection suggests that the mature *Arundo* stands essentially eliminate flow conveyance during low and moderate floods on the portions of the floodplain that they occupy, increasing the portion of the flow passing through the low flow or active channel. During large peak flows, when water levels are about 5 feet higher than the floodplain surface, flow that is conveyed over the mature *Arundo* stands also slows as considerable roughness is created by the stems and leaves. During very large flow events, the *Arundo* rhizomes and stems may be carried downstream, substantially altering local resistance to flow. Modeling of different floodplain vegetation scenarios suggested that the conversion from native vegetation to complete coverage by mature *Arundo* stands has three important implications. First, 100-year water levels are raised by the increased roughness. Second, the portion of the total discharge carried in the main channel increases and, thus, depths and velocities for a particular return period flood. Third the conveyance on the floodplain is much less. The hydraulic model does not include morphologic change that results from the altered depths and velocities and these may eventually mute the increases in water levels during floods.

There are some interesting subtleties suggested by the hydraulic modeling. First, there appears to be a threshold for *Arundo* coverage before there are significant effects on hydraulics. The exact portion of the floodplain that must be occupied for a significant effect is not fully understood. Second, the threshold for observing significant effects and the percentage increase in velocities and sediment transport capacity in the main channel seems to depend on the ratio of the main channel width and floodplain width. Where the channel is wide relative to the floodplain, there is less effect on velocities and sediment transport capacity for a particular flood than where the channel is narrow compared to the floodplain. This is thought to occur because there is less conveyance on the narrower floodplains compared to the main channel, so there is a smaller increase in flows in the main channel when *Arundo* coverage is complete and conveyance on the floodplain is reduced.

The results of the hydraulic model studies are limited because they do not account for the channel adjustments that are likely to occur rapidly in response to the altered hydraulics on the floodplain and in the main channel. Stream power calculations, which were adopted as a proxy for sediment transport, show greatly increased stream power in the main channel and greatly reduced stream power exerted on the floodplain under complete *Arundo* coverage, when compared to native vegetation, and a smaller increase and smaller decrease for partial coverage (Scenario 4). The consequences of the changes in stream power when banks are less erodible because of *Arundo* establishment are expected to be increased depths in the main channel and sediment trapping and accretion on the floodplain and in overbank areas. Regime considerations suggest that channel depths should increase to accommodate frequent floods, as compensation for the narrowed channel. Part of this increase may result from higher floodplain elevations rather than from channel incision or bed lowering.

Both channel responses described above change the sediment storage in the project reach on the Santa Margarita River and potentially affect the delivery of sediment from the upper watershed to downstream reaches and the Pacific Ocean. Considering the sediment balance for sand, and basing accretion rates on those observed in the literature, it appears that the trapping of sand on the floodplain in *Arundo* stands is large compared to the inflow from the upper watershed. The trapping on the floodplain may be partly

compensated by erosion of the stream bed to accommodate flood flows with the narrower channel but this gain to downstream reaches appears to be considerably smaller than the trapping on the floodplain. These conclusions are also appropriate for the Santa Ana and San Luis Rey Rivers but different ones might be drawn for rivers with much wider or much narrower floodplains, or those where channel filling or other conditions allows extensive floodplain accretion. In the long-term, as accretion on the floodplain slows, the sand transported out of the study reaches will return to being about equal to the supply from the upper watershed.

Based on the above results, the study developed a qualitative scoring system that can be applied to measured river and floodplain vegetation characteristics to identify those reaches where significant impacts on river processes may occur. Total scores that reflect potential *Arundo* impacts were developed by summing scores for the ratio of low flow channel width to floodplain width, the percentage of *Arundo* on the floodplain and the changes in floodplain width and channel slope from one reach to the next downstream one. The scoring system was reasonably consistent with the modeled hydraulic impacts on the Santa Margarita River and thus was thought to be appropriate for the Santa Ana and San Luis Rey Rivers.

Application of the scoring systems suggests that impacts on river form and process are less significant in the Santa Ana and San Luis Rey Rivers than in the Santa Margarita River project reaches, with the possible exception of Reach 2 of the Santa Ana River.

While the scoring system is preliminary it provides a simple procedure to identify those reaches where the riverine response to *Arundo* infestation may be most severe and also provides a useful tool to identify those reaches where monitoring may be concentrated.

5.2 Geomorphology and Hydrology: Spatial Analysis

5.2.1 Arundo's Distribution Within Geomorphic Forms

5.2.1.1 Methods

Geomorphology Attributes and Methods

Methods used to delineate floodplain geomorphic forms involved visual interpretation of imagery and topological data within a GIS. Due to time constraints and budget, groundtruthing and follow-up field *surveys were not possible at this time. Guidelines for defining geomorphic forms were based on the Riparian Ecosystem Restoration Plan for the Otay River Watershed (Army Corps of Engineers 2006) and consultations from staff at NHC.* Issues involving criteria for delineating terraces within the floodplain and the subjectivity of this classification was thoroughly discussed. Considering the subjectivity, several rounds of sample data and images were reviewed to determine the efficacy in characterizing geomorphic forms for each analysis. The most recently available imagery was used for each watershed.

San Luis Rey was used as a test case to work through the methodology. Other watersheds were completed after an approach was established. Using base imagery from ESRI, Google Earth, and Bing 3D pictometry (where available), areas of interest were reviewed to develop visual recognition of the potential terrace structures. Additionally, several sample locations and field photos taken by the analyst previously from the *Arundo* field mapping exercise were used to further visually train the analyst in the

separation of terrace forms. A significant number of images were gathered including several panoramas of the river valley that illustrate elevation changes.

The mapping delineation always started within the low flow channel and built out from this classification using the *Auto-Complete Polygon* tool in ArcGIS. The digitization was completed at a scale of 1:5,000. The following classifications (as described in Section 5.1.3.3) were selected:

- *Low Flow Channel* – The part of the main channel where water was flowing at the time of the aerial photos. In those cases where the riverbed is dry, the area appearing to have the most recent flows were delineated as low flow.
- *Bar / Channel / Floodplain - unvegetated* – Main channel or floodplain areas with less than 50% vegetation cover, usually consisting of bar surfaces, dry channel beds, or recent deposition or scour.
- *Floodplain - vegetated* – Areas on the river floodplain with more than 50% vegetation cover.
- *Floodplain / Low Terrace – vegetated* – Areas on either the river floodplain or an adjacent low terrace with more than 50% vegetation cover.
- *Upper Terrace - vegetated* – Areas on higher ground adjacent to the low terraces with more than 50% vegetation cover. This classification was rarely used in part because nearly all of the upper terrace areas on most rivers had been leveed or developed. The mapping did not go beyond levees or roads in most cases. In some specific areas where there were *Arundo* records, the levee sides were marked using this category. Hillslopes were typically not tagged unless they were surrounded by an apparent floodplain or if *Arundo* was present.

Terraces edges were extremely subjective because the field verification was not feasible and high-resolution elevation data was not available for all areas. One of several visual cues used to help delineate between terraces was based on the type and amount of vegetation present (USACE ref.).

There were instances where the imagery used to map geomorphology (usually 2006) did not match the same time period in which *Arundo* was mapped. These temporal mismatches caused alignment problems when *Arundo* stand mapping was compared to geomorphology mapping. Initial mapping/analysis placed large historical stands of *Arundo* in what are now the main low flow channel or sand bars. But in the time period when the *Arundo* stands were present, these areas were floodplain. The two rivers with the largest number of mismatched data were the San Luis Rey and Santa Margarita, which have had significant *Arundo* control. Both rivers had mapping data from the late 1990's and early 2000's reflecting areas that were controlled. Therefore, select geomorphic records were altered to match their historical form based on imagery that matched the mapping date of the *Arundo*. *Arundo* removal on the Santa Margarita has influenced the river channel geomorphology to change course and in many cases it allowed the river to revert back to having more open bars and seasonal channels.

5.2.1.2 Results

The area of interest (AOI) covers the six most *Arundo* invaded watersheds within the study area. This represents 77% of the gross *Arundo* acreage calculated for the entire study area (Figures 5-2.1 & 5-2.2). Since these are the most invaded areas, it is important to examine the distribution of *Arundo* within geomorphic forms found in the riparian zone.

The overall level of *Arundo* invasion for the AOI was 13% cover of the riparian zone (all geomorphic forms) (Figure 5-2.3, Table 5-2.1). Invasion levels of *Arundo* ranged from 8% to 16% cover for the AOI on the watersheds examined. There seem to be two levels of invasion on these large, broad watersheds: a higher level of 12-18%, and a lower level of 8-9%. Individual reaches within a riparian system can have much higher *Arundo* cover. Highly invaded reaches on Santa Ana and Santa Margarita had

invasion levels >40%. Establishing a 'peak level' of invasion over large areas is difficult to assess, but an upper range of 40-45% seems plausible (as the Santa Margarita River illustrates – Section 5.1).

An examination of *Arundo*'s distribution across geomorphic forms reveals that *Arundo* is relatively absent from the low flow channel (Figures 5-2.4 & 5-2.5, Tables 5-2.2 & 5-2.3). If *Arundo* was evenly distributed across geomorphic forms in proportion to a geomorphic class's acreage, it would have a distribution shown in Figures 5-2.6 to 5-2.11. There is less *Arundo* on all watersheds in the channel areas than would be predicted. This represents the high energy and dynamic riparian zone that has flows every year. Establishment and persistence of *Arundo* is difficult and little *Arundo* acreage (52 acres or 1.5%) of this form is invaded. Each watershed's geomorphic structure is shown in Figure 5-2.4 and Table 5-2.2 to allow examination of which forms dominate each system.

The bar/channel zone also has low cover of *Arundo* (102 acres of 6,575 acres, or 1.5 %). Much lower cover is present on each watershed than would be predicted if an even distribution of *Arundo* occurred (Figures 5-2.5 to 5-2.10). This is an active portion of the riparian floodplain with little vegetation, so it would be expected to have low cover of *Arundo*.

Most *Arundo* acreage is found in the floodplain and low terrace geomorphic forms (Figure 5-2.3, Tables 5-2.2 & 5-2.3). Floodplains have consistently high levels of invasion with an average of 19.7. As presented by watershed, *Arundo* cover exceeds predicted levels of distribution on all six watersheds (Figures 5-2.5 to 5-2.10). This is an important observation, as high *Arundo* cover in this geomorphic form tends to lock the low flow channel in a set location (Section 5.1).

Low terraces were also found to have high *Arundo* cover, averaging 15.4% (Table 5-2.3). Observed acreage was equivalent to, or higher than what would be predicted if an even distribution of *Arundo* occurred on most, but not all systems (Figures 5-2.5 to 5-2.10). Lower terraces, as a geomorphic form, vary significantly in acreage between watersheds (Figure 5-2.4, Table 5-2.2). Salinas and Santa Margarita have a significant proportion of this form, while Santa Ana has little. This is reflected in the *Arundo* acreages found on low terraces within these systems. Santa Clara is distinctly different due to a very low proportion of floodplain and terrace acreage. However, the floodplain and terrace acreage that does occur within a system is highly invaded with *Arundo*. Floodplain and low terrace geomorphic forms are a subjective distinction. These are essentially the more stable portions of the floodplain. They could be combined, but separating them helps characterize different watersheds.

Upper terraces comprise a small proportion of overall geomorphic composition for most watersheds (Figure 5-2.4, Table 5-2.3). Many of these areas have been developed or modified and are no longer part of the riparian system (examined in section 5.2.2). Where upper terraces do exist, they have a lower proportion of *Arundo* acreage than would be predicted if *Arundo* were evenly distributed. This is likely a result of the high elevation, which makes establishment and persistence of *Arundo* less common than the more hydrologically favorable floodplains and lower terraces

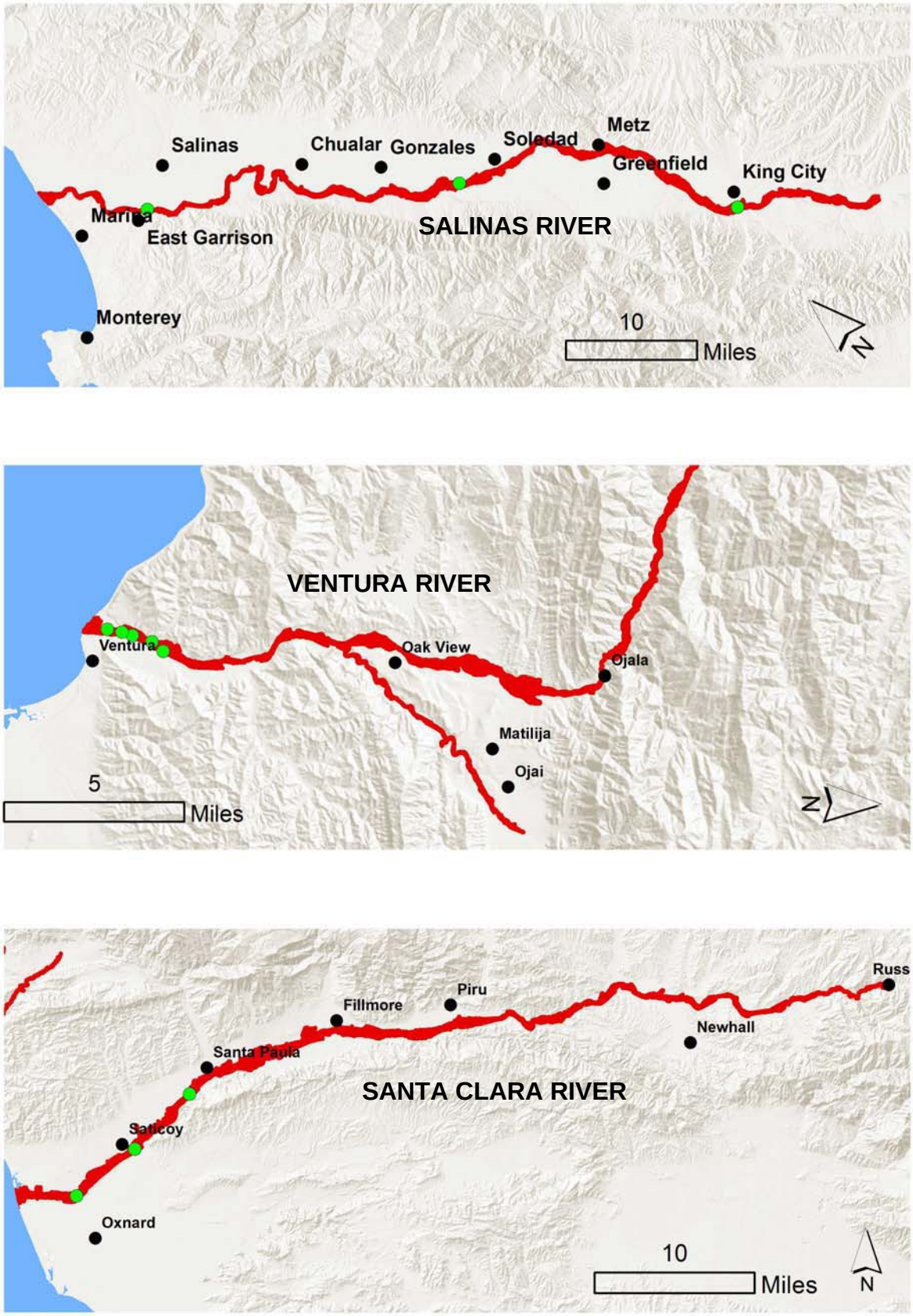


Figure 5-2.1. Location of the Area of Interest and cross-sections (northern watersheds).

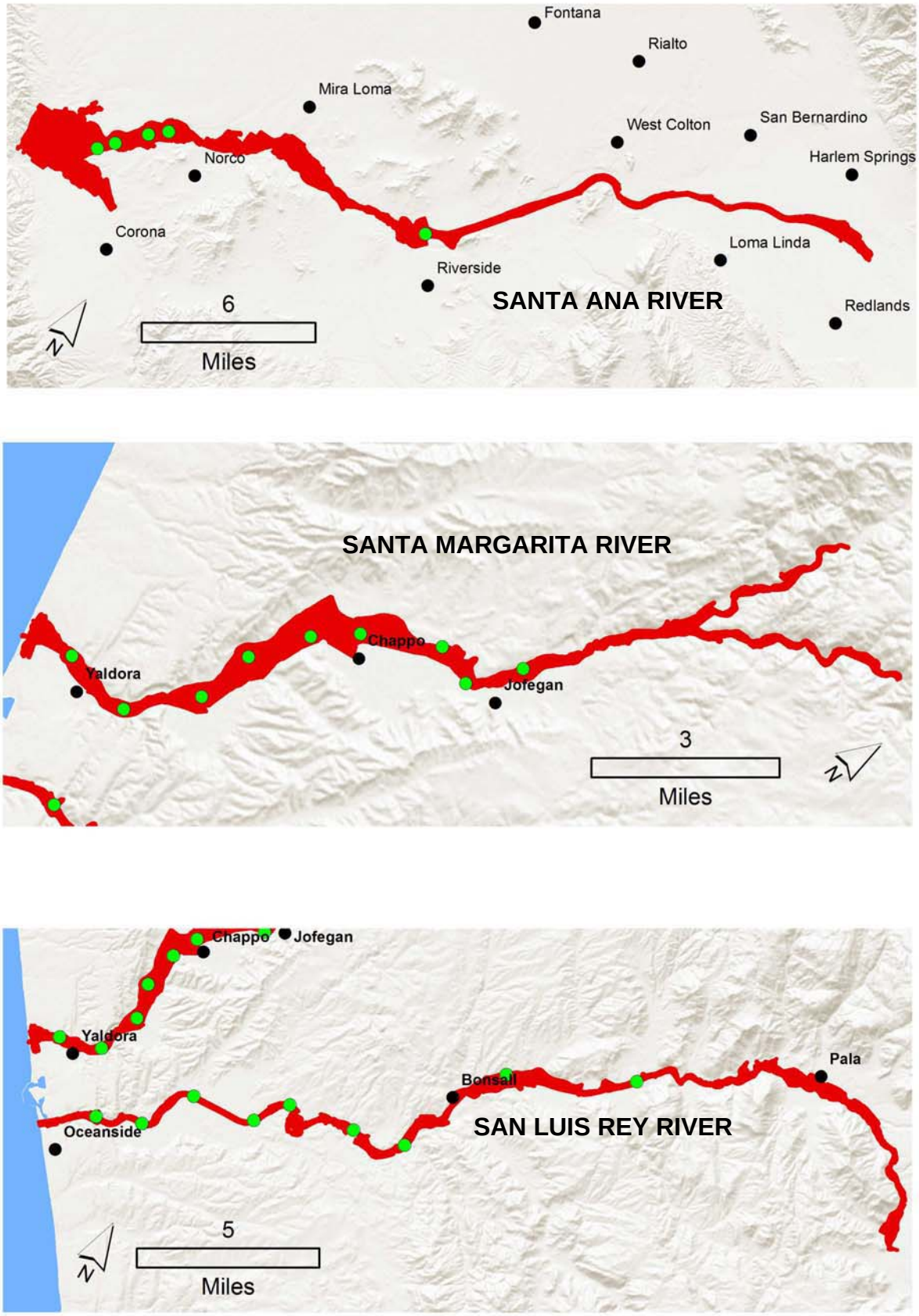


Figure 5-2.2. Location of the Area of Interest and cross-sections (southern watersheds).

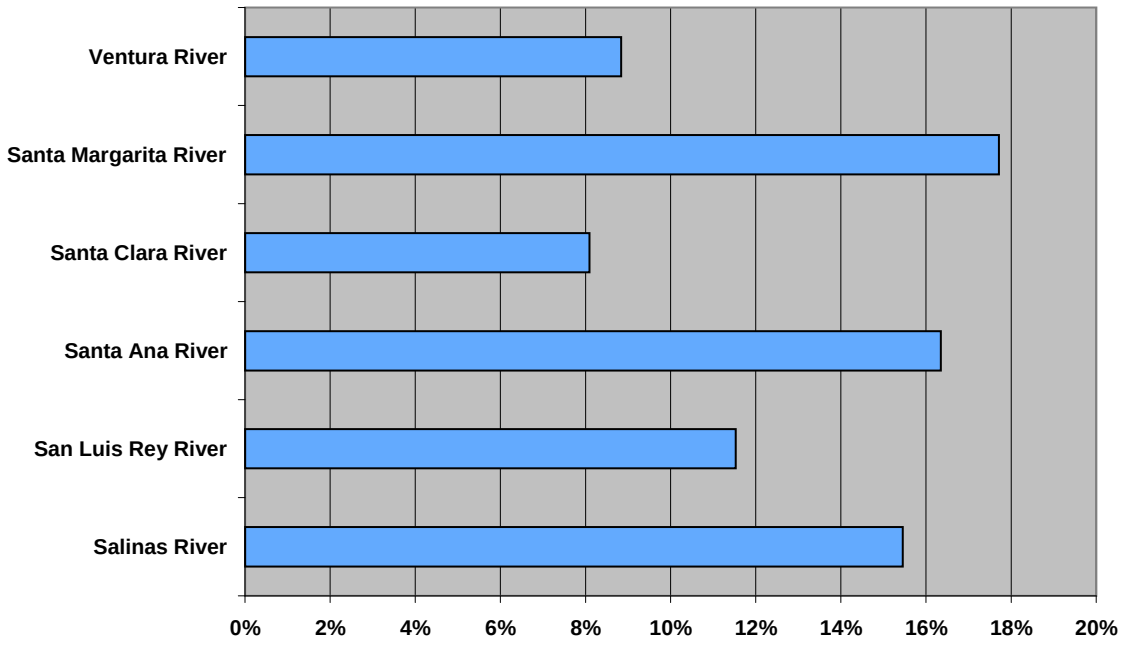


Figure 5-2.3. *Arundo* acreage as a percent of system acreage within the Area of Interest (AOI).

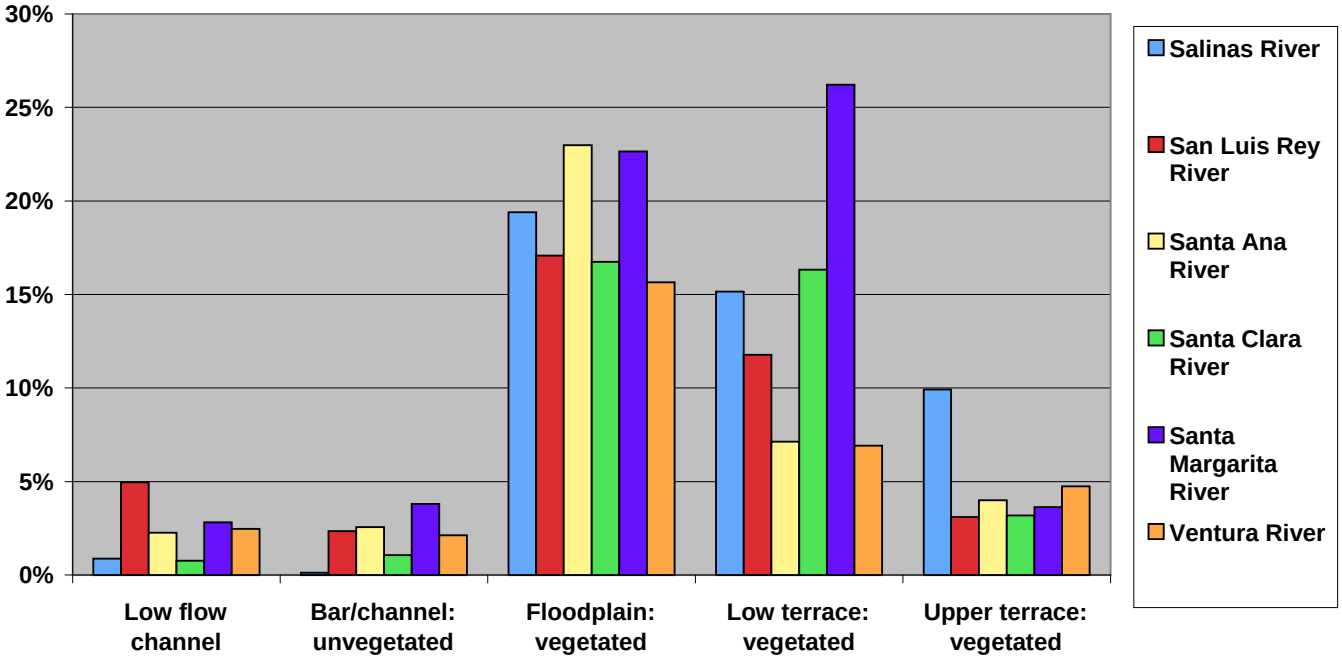


Figure 5-2.4. Percent of geomorphic form invaded by *Arundo* for the Area of Interest (AOI). This shows that the highest levels of invasion are in the floodplain and low-terrace geomorphic forms, regardless of the acreage of the geomorphic form itself.

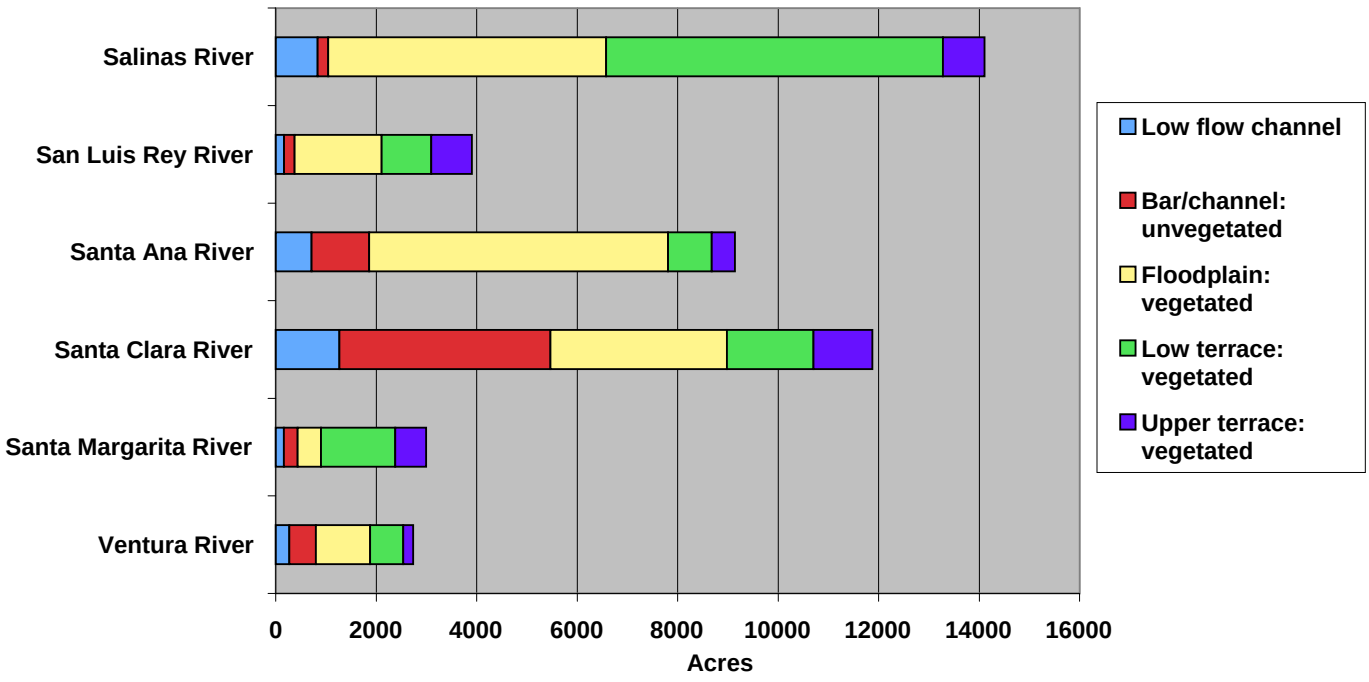


Figure 5-2.5. Acreage of geomorphic forms mapped within the Area of Interest (AOI). This shows that the floodplain and terrace forms dominate most systems (within the AOI).

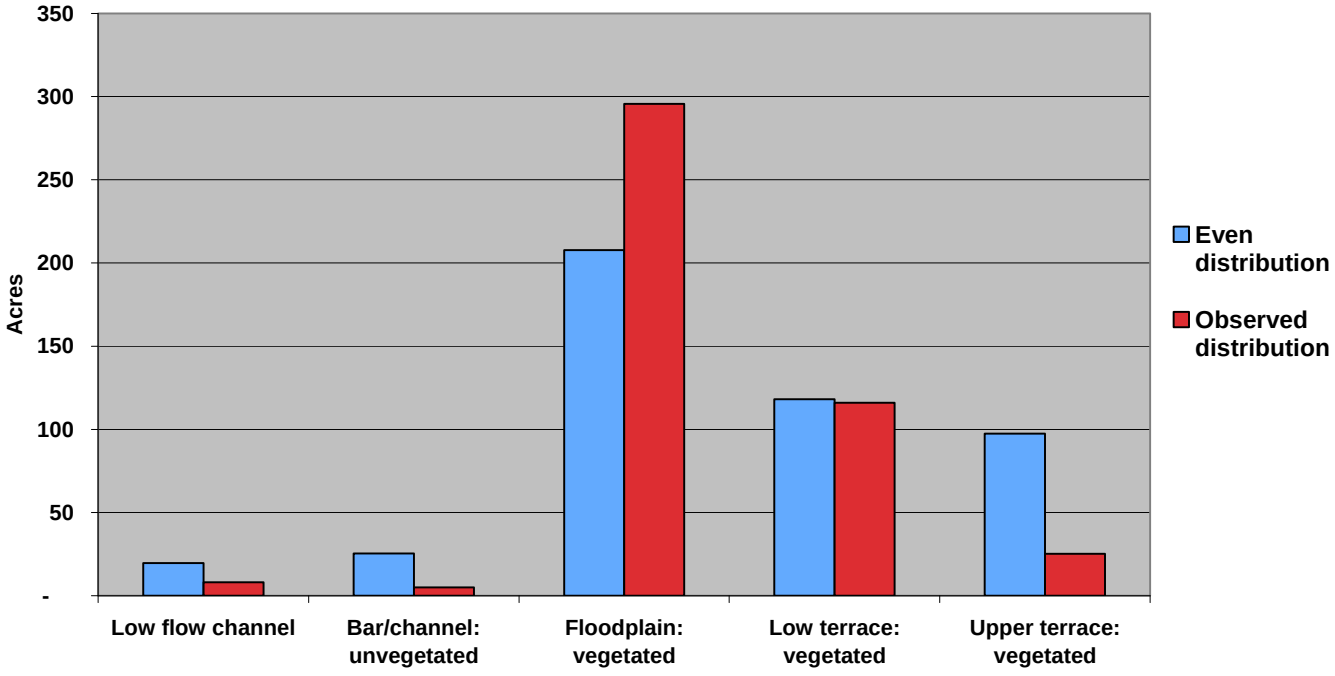


Figure 5-2.6. Observed and expected even distribution of *Arundo* acreage on the San Luis Rey watershed by geomorphic class.

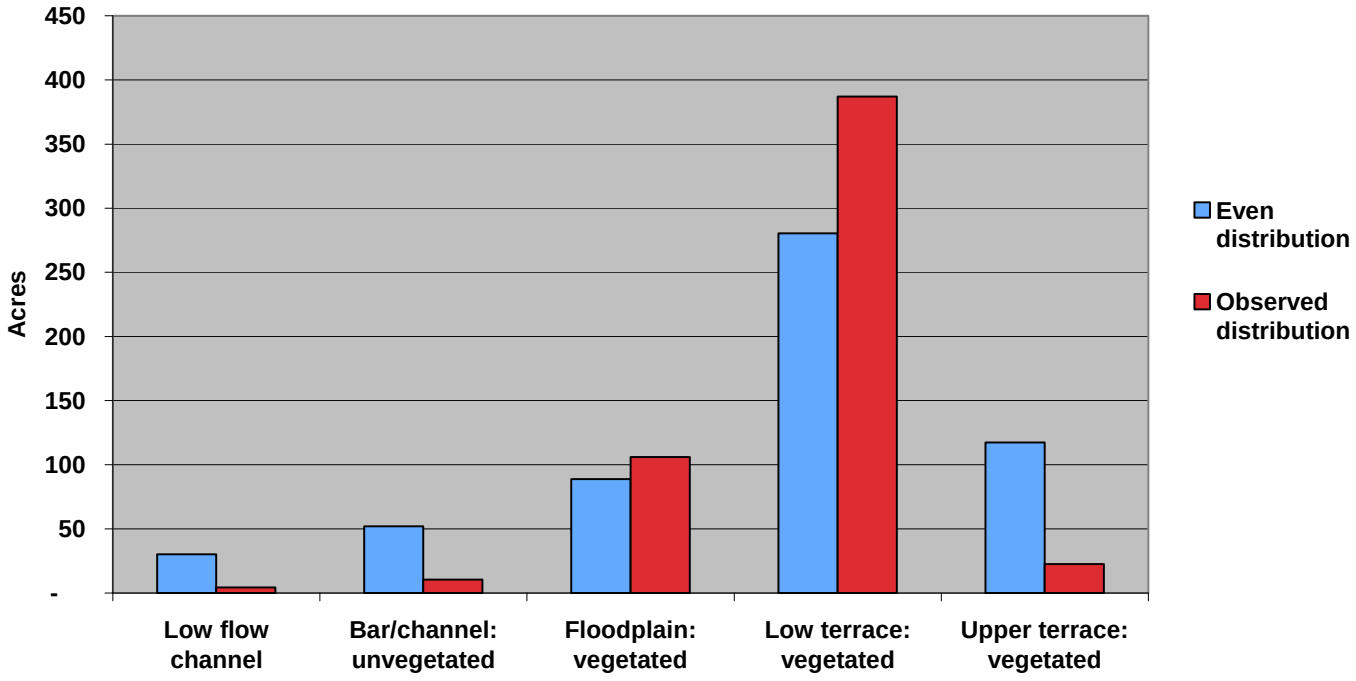


Figure 5-2.7. Observed and expected even distribution of *Arundo* acreage on the Santa Margarita watershed by geomorphic class.

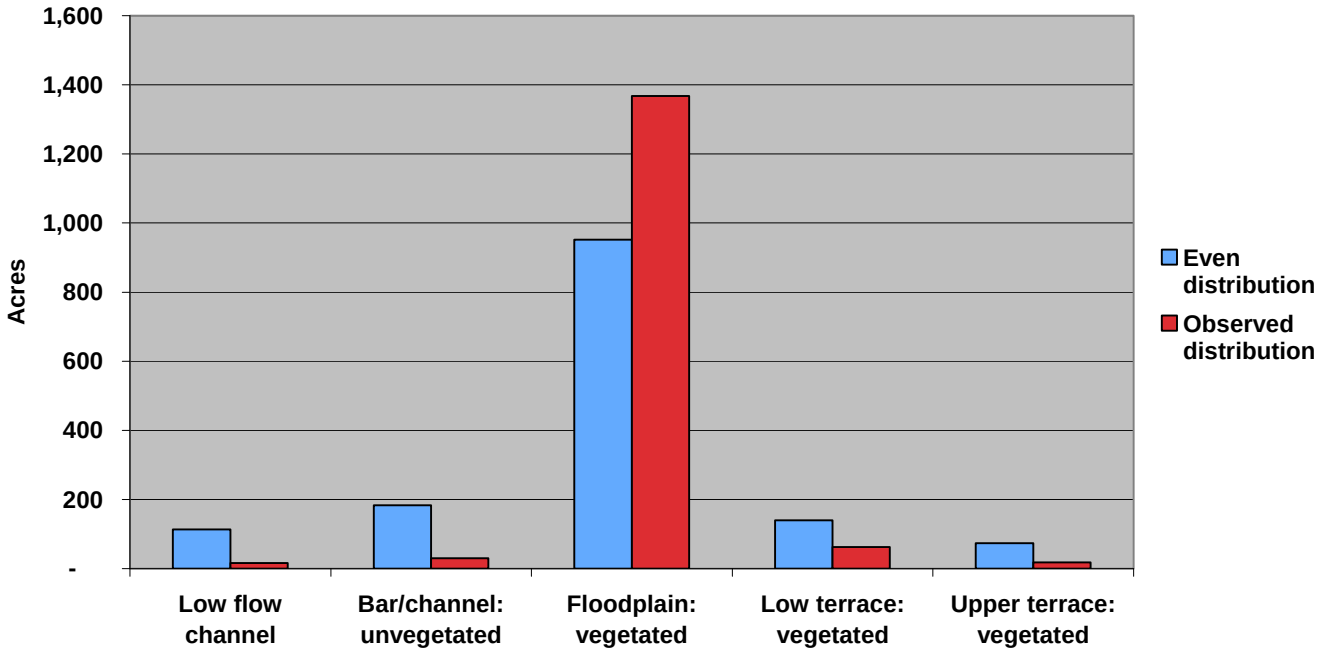


Figure 5-2.8. Observed and expected even distribution of *Arundo* acreage on the Santa Ana watershed by geomorphic class.

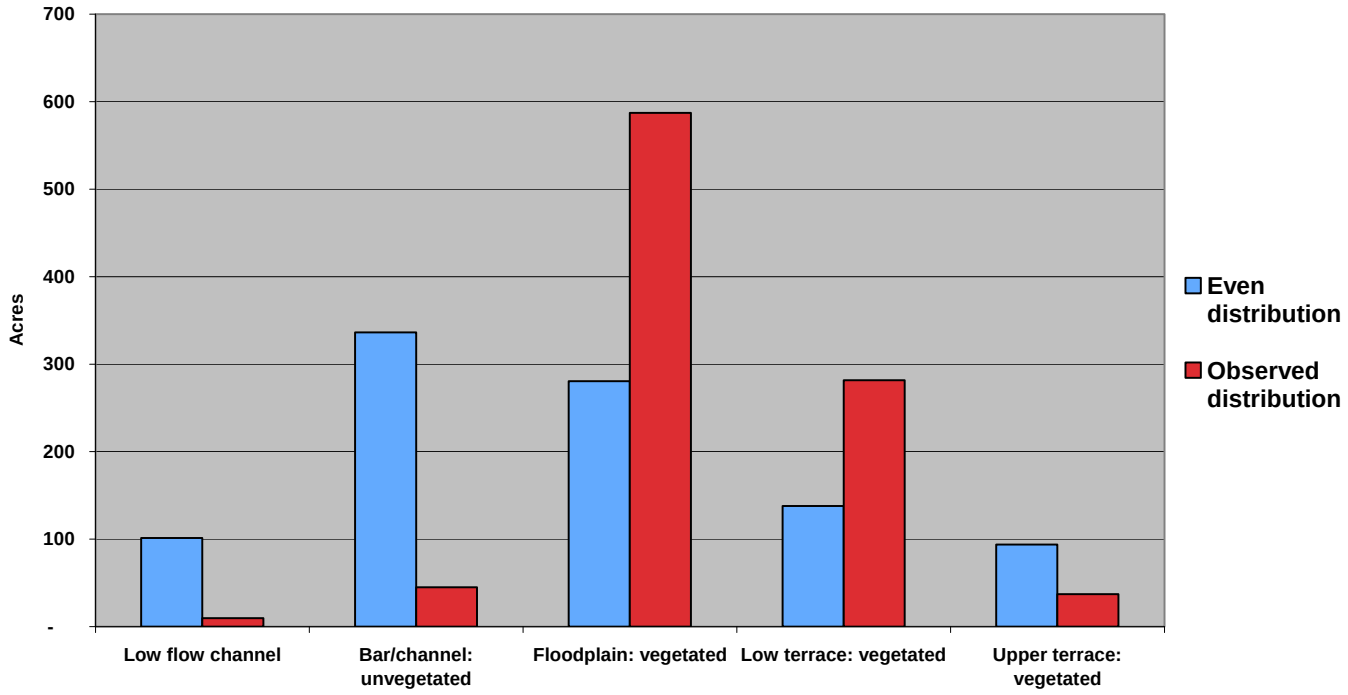


Figure 5-2.9. Observed and expected even distribution of *Arundo* acreage on the Santa Clara watershed by geomorphic class.
Santa Clara has much more low flow channel and bar/channel than the other systems.

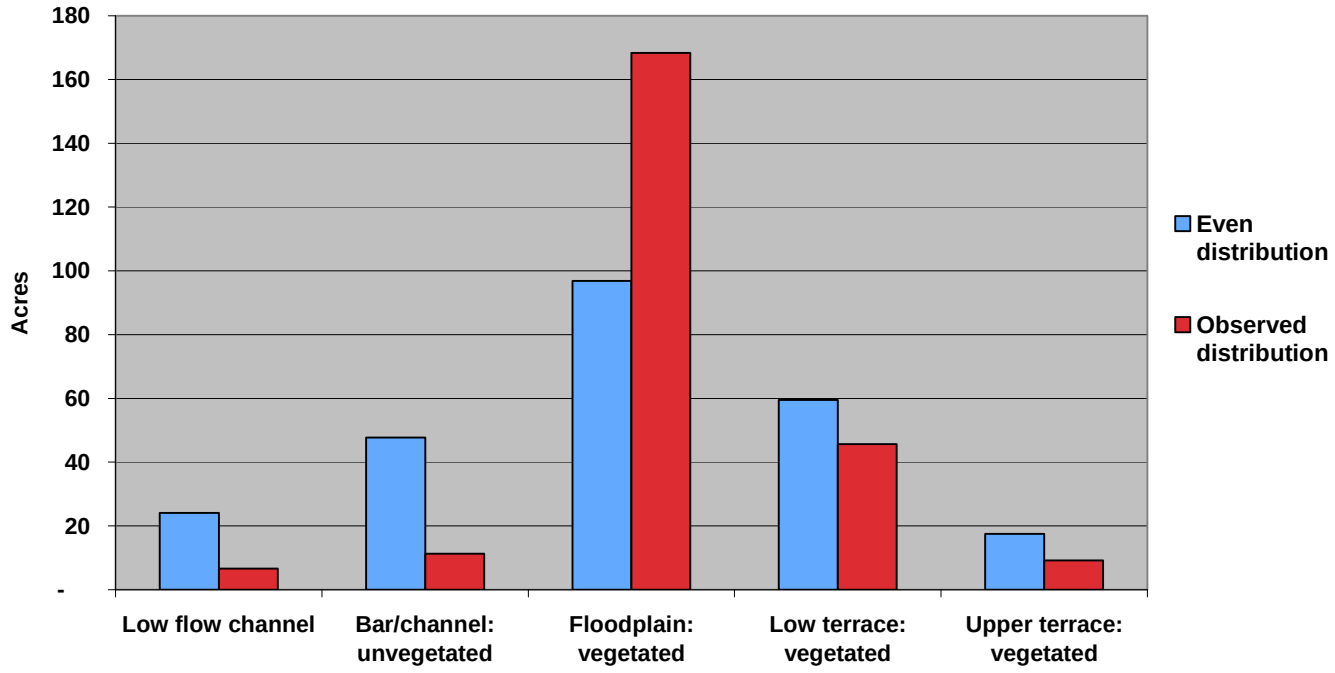


Figure 5-2.10. Observed and expected even distribution of *Arundo* acreage on the Ventura watershed by geomorphic class.

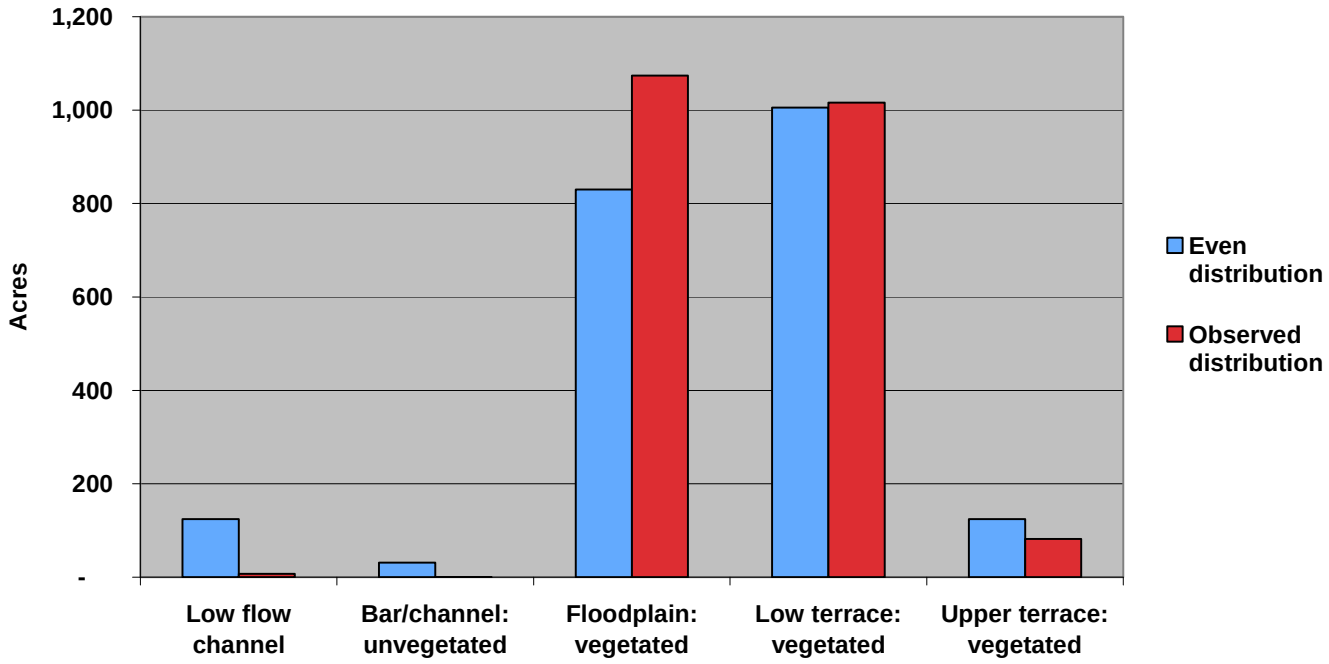


Figure 5-2.11. Observed and expected even distribution of *Arundo* acreage on the Salinas watershed by geomorphic class.

Table 5-2.1. *Arundo* and geomorphic acreage within the Area of Interest (AOI) for six selected watersheds.

Watershed (AOI area only)	*Arundo* Gross Acres	*Arundo* Net Acres	Geomorph Acres[1]	*Arundo* ac % system (net)
Salinas River	2,845	2,180	14,105	15%
San Luis Rey River	450	450	3,903	12%
Santa Ana River	1,674	1,493	9,136	16%
Santa Clara River	1,011	961	11,874	8%
Santa Margarita River	530	530	2,994	18%
Ventura River	321	241	2,730	9%
Total:	**6,831**	**5,855**	**44,741**	**13%**

[1]Geomorph areas: the acreage where geomorphic form was mapped within the AOI.

Table 5-2.2. *Arundo* and geomorphic class acreage within the AOI of six selected watersheds.

Watershed (AOI only)	Geomorphology Class	*Arundo* Gross Acres	*Arundo* Net Acres	Geomorph Gross Acres	% of geo class w/ *Arundo*
Salinas River	Low flow channel	8	7	829	1%
Salinas River	Bar/channel	0.4	0.3	209	0%
Salinas River	Floodplain	1,476	1,074	5,535	19%
Salinas River	Low terrace	1,269	1,016	6,704	15%
Salinas River	Upper terrace	92	82	828	10%
San Luis Rey River	Low flow channel	8	8	164	5%
San Luis Rey River	Bar/channel	5	5	211	2%
San Luis Rey River	Floodplain	296	296	1,731	17%
San Luis Rey River	Low terrace	116	116	984	12%
San Luis Rey River	Upper terrace	25	25	812	3%
Santa Ana River	Low flow channel	20	16	709	2%
Santa Ana River	Bar/channel	76	30	1,146	3%
Santa Ana River	Floodplain	1,492	1,367	5,948	23%
Santa Ana River	Low terrace	67	62	873	7%
Santa Ana River	Upper terrace	20	18	459	4%
Santa Clara River	Low flow channel	13	10	1,266	1%
Santa Clara River	Bar/channel	52	45	4,204	1%
Santa Clara River	Floodplain	624	587	3,506	17%
Santa Clara River	Low terrace	286	282	1,726	16%
Santa Clara River	Upper terrace	37	37	1,173	3%
S. Margarita River	Low flow channel	4	4	158	3%
S. Margarita River	Bar/channel	10	10	274	4%
S. Margarita River	Floodplain	106	106	468	23%
S. Margarita River	Low terrace	387	387	1476	26%
S. Margarita River	Upper terrace	22	22	618	4%
Ventura River	Low flow channel	10	7	267	2%
Ventura River	Bar/channel	21	11	530	2%
Ventura River	Floodplain	228	168	1,076	16%
Ventura River	Low terrace	52	46	661	7%
Ventura River	Upper terrace	9	9	194	5%
	Total:	**6,831**	**5,855**	**44,741**	**13%**

Table 5-2.3. *Arundo* and geomorphic class acreage for the entire AOI (all seven watersheds).

Geomorphologic Class	*Arundo* Present: Gross Acres	*Arundo* Present: Net Acres	Geomorphology Mapped (Current Day): Gross Acres	% *Arundo* (Net)
Low flow channel	63	52	3,393	1.5%
Bar/channel	165	102	6,575	1.5%
Floodplain	4,221	3,598	18,263	19.7%
Low terrace	2,176	1,909	12,424	15.4%
Upper terrace	206	195	4,085	4.8%
Total:	**6,831**	**5,855**	**44,741**	**13.1%**

5.2.1.3 Discussion

The most important observation is that *Arundo* has high cover in the floodplain and low terrace geomorphic forms, and low cover in the low flow and bar/channel forms, within each of the six systems examined. Given that *Arundo* has a similar distribution across geomorphic forms on all systems, it is likely that similar mechanisms are at play in the systems. It is also likely that *Arundo* is having the same impacts associated with its presence in floodplains. This is important in that it makes observations from the specific case study of the Santa Margarita River (section 5.1) applicable to other systems in the study area.

Arundo's ability to form dense monotypic stands on floodplains in all of the major systems within the study area is likely having significant impacts to channel form, channel depth, flow conveyance, and sediment transport, as well as putting infrastructure at risk. *Arundo*'s impacts on these abiotic processes has biotic impacts as well by affecting habitat for flora and fauna. The documented abundance of *Arundo* within systems, and its higher growth within specific geomorphic forms, helps to demonstrate that impacts to organisms are also transferable from system to system.

Reproductive strategies used by *Arundo* are strongly reflected in distribution data by geomorphic form. Channel and bar areas are too dynamic to sustain plant survival, growth and establishment. Floodplain and low terrace are optimal, with favorable hydrology and less frequent flow events that would remove newly established plants. Upper terraces only periodically receive reproductive material (rhizome fragments), and hydrology is not optimal for their establishment and survival.

Understanding geomorphic composition and *Arundo* distribution would be aided by a historical evaluation of geomorphic forms over time, as well as an examination of vegetation cover. It would be useful to know if current geomorphic form and vegetation condition are comparable to past conditions.

5.2.2 Geomorphology Historic Analysis

In the previous section, the distribution of *Arundo* within geomorphic forms was examined using recent or current conditions within the AOI. The current acreage of geomorphic forms within each river system was also given. But acreage and proportion of geomorphic forms is not set as they respond to flood events and human activities. This chapter section will examine how each watershed's

geomorphology has changed over time, using historic air photos and cross-section based-data. In addition to change in geomorphic class, we will also examine the abundance of woody vegetation (open versus dense) within the floodplain and lower terrace areas. This will help characterize the hydrology of the system over time.

5.2.2.1 Methods

To quantify the changes in the river systems over time, a historical cross-section analysis was undertaken. Historic photography was aggregated from the UCSB Library, HistoricAerials.com, Google Earth, CaSIL (California Spatial Information Library) and the USGS. For each river system, the availability of imagery was evaluated on the range of years and reaches of the river where imagery timeframes overlapped. The number of photos was narrowed down to have optimal time differences of 10-15 years between samples, and equal distribution across as much of the river's extent as possible (where *Arundo* occurred). The San Luis Rey River had the widest array of images available by both area and year. Image availability dictated the extent of areas available for analysis on each river. Cross-section locations were at times determined by limited imagery coverage overlap on rivers, other than the San Luis Rey and Santa Margarita. Within each area of imagery coverage, a cross-section was digitized into the GIS (Figures 5-2.1&2). These areas were selected based on: a) the earliest available imagery showing a floodplain that was not naturally constrained by a narrows or other impediment, and b) when possible, level distribution across the full extent of the available imagery time sequence. Each cross-section was drawn perpendicular to the current channel. The length of each cross section was determined by where the upper terrace of the floodplain ended on both the oldest and most recent imagery (Figures 5-2.12&13). This takes into account flood events that eroded bluffs or hillslope in the intervening years. Cross-sections were opportunistically placed at locations along the river where: a) *Arundo* was abundantly present, b) the area was representational of changes over time, and c) cross-sections being perpendicular to the current channel line would not create a diagonal in the historic floodplains, as this would amplify any constriction or expansion of the river. Random or equidistant placement may have put cross-sections in areas that had little change due to geomorphic landform constraints like a narrows.

With the cross-section lines in place, the historical imagery was then georeferenced. Spatial inaccuracies may occur where ground control was not easily identifiable. It should also be noted that imagery varied in scale, which may affect the spatial and attribute accuracy of the interpretation. Each digitized cross-section was duplicated for each year of imagery. Using a scale of 1:3,000, the length of the line was split into pieces as it crossed each geomorphic form in the photo. Because linear cross-sections were used in place of generalized polygons[2], a higher level of detail was captured in the fluvial landforms. For instance, the polygon interpretation methodology (used to delineate current-day geomorphology) may broadly group a mixture of bare sand and scrub as one class *(Bar/Channel:Unvegetated),* while the cross-section method broke those same strips of bare sand and scrub into separate classes (*Bar/Channel:Unvegetated* and *Floodplain:Vegetated*). This level of detail was captured in an attempt to keep the mapping consistent over time and limit the amount of subjectivity in the interpretation across the variety of historical imagery.

Additional classes were added to this analysis so that cross-sections were the same length for each time period and all situations of floodplain changes could be described. These added classes include:

- Floodplain Modified: sand mining, grading /channelizing of the floodplain, and agriculture fields in the floodplain that are not protected by levees.

[2] Polygon interpretation was not feasible with the time constraints and budget available for the historical analysis.

- Levee Protected Agriculture[3]: levees may be dirt or armored with rock.
- Levee Protected Developed[3]: usually a rock-armored levee with housing, industry or airport development. On two occasions, this class includes water treatment or storage ponds.

[3] The "Levee protected" classes do not appear in the charts because they, like the hillslope, are no longer part of the floodplain.

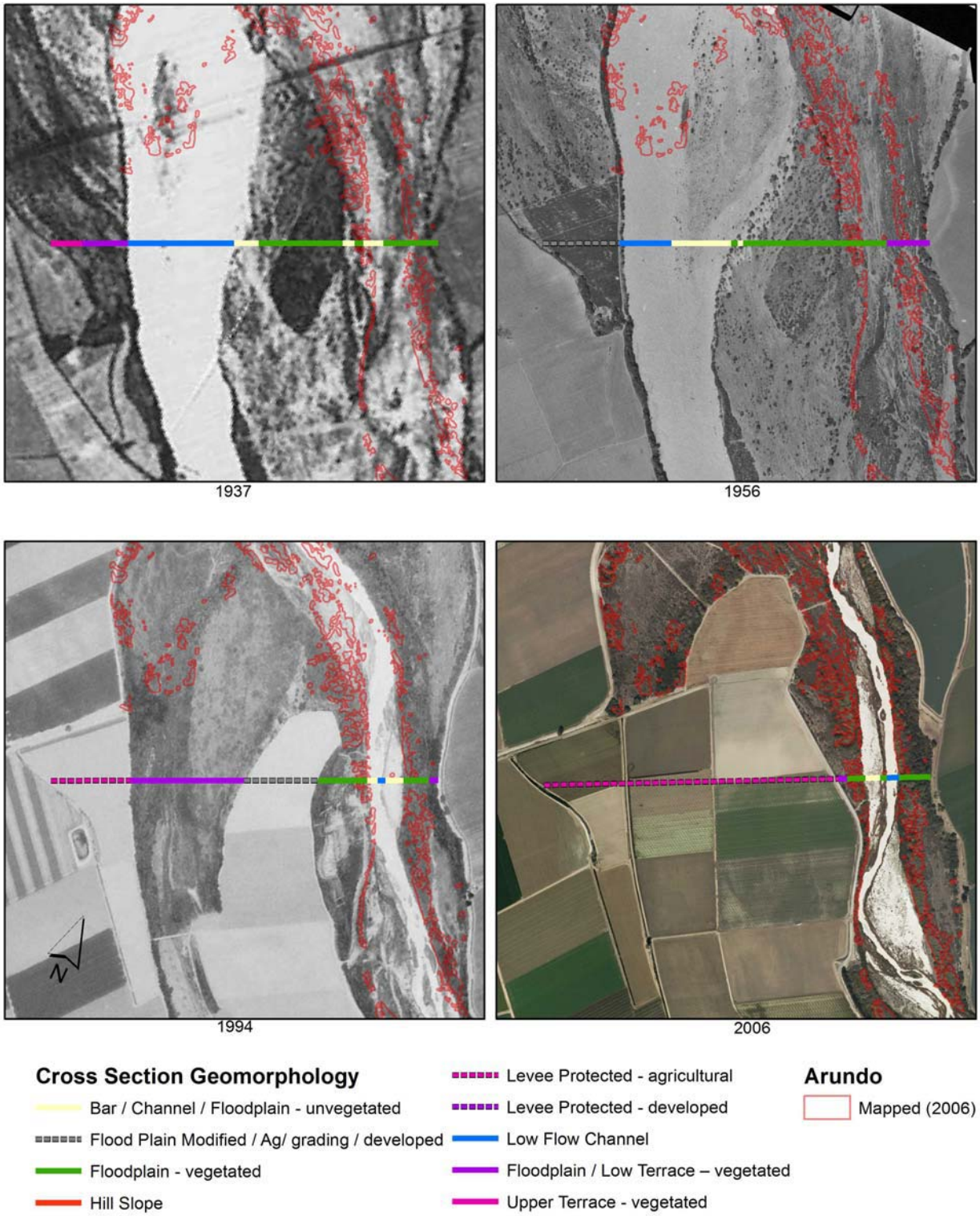


Figure 5-2.12. Cross-section geomorphology using historic aerial imagery on the Salinas watershed from 1937 to 2006.

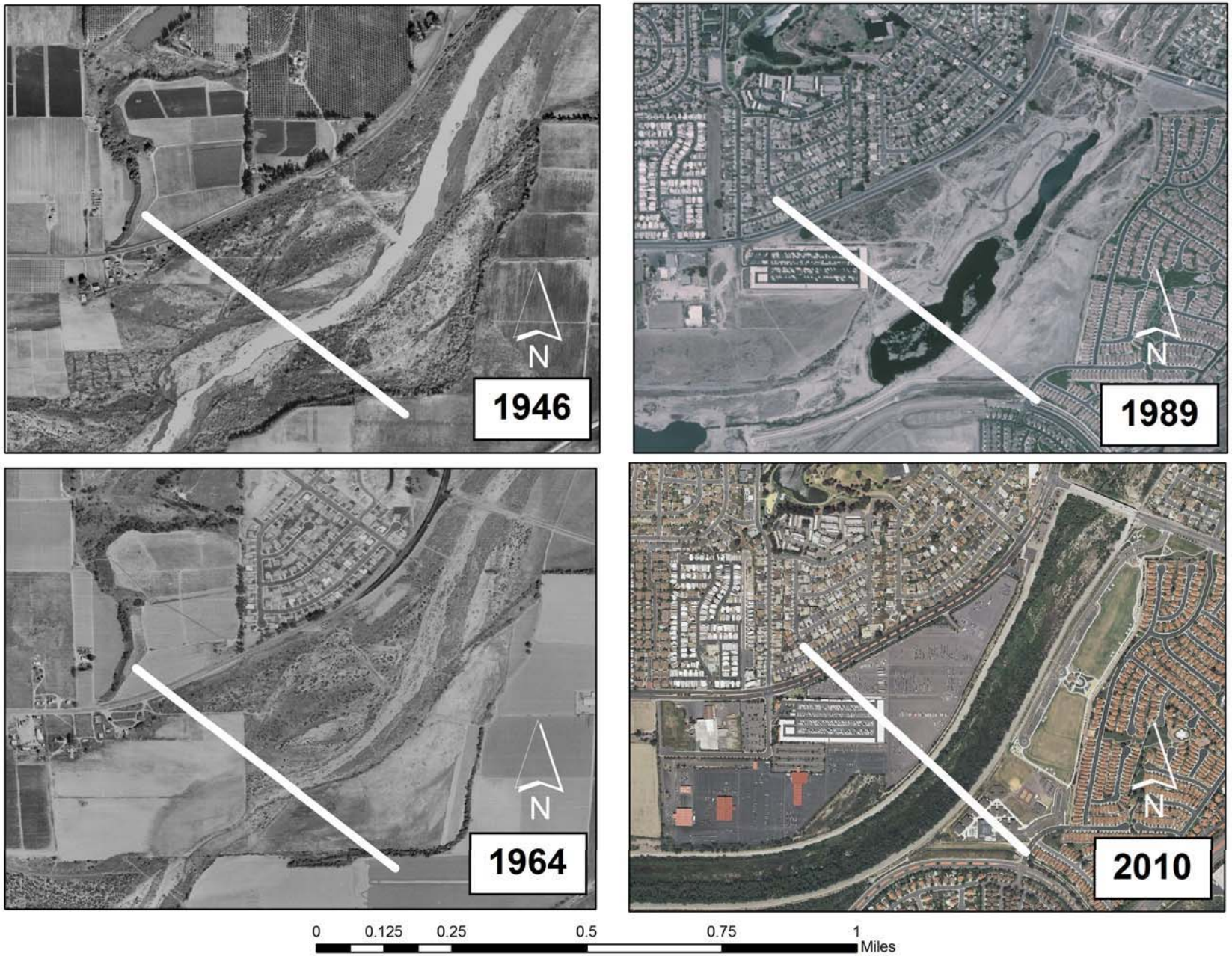


Figure 5-2.13. Historic photo analysis of geomorphic and hydrologic cross-sections on the San Luis Rey River from 1946 to 2010.

5.2.2.2 Results

There have been many changes to river systems over the past 100 years. These changes will be aggregated into two basic categories: 1) drastic increases of water in the system (from urbanization and agriculture) and 2) removal/modification of riverine areas (from development, agriculture, levees, water/flood management). High levels of water importation have transformed ephemeral riverine systems into perennial systems in southern California. This transformation occurred over time, but for the study area, this study suggests the 1960s-70s as a tipping point for most watersheds. At the same time that more water was imported and released into coastal watersheds, the functional riparian zone was reduced and modified. Use of floodplains for farming and sand mining has occurred for over 100 years. Historically these uses were not physically protected from river flows by levees and berms, so the area of activity was still functionally connected to the river. When floods occurred, these areas were inundated. However, in the 1950s and 60s permanent levees and berms were constructed in many systems. This resulted in the removal of geomorphic structure and habitat, as well as a significantly narrowing of the floodplain/riparian zone. Increased importation of water and development of riverine areas (urban or agriculture) are correlated, with both forms of development tied to increased water use.

San Luis Rey: Nine cross-sections were used. The San Luis Rey Watershed exhibited significant loss of over two-thirds of its riverine habitat from 1938 to 2010 (Figure 5-2.14). Lower and upper terraces are now nearly absent. Historic use and modification of floodplains occurred throughout the early portion of the time frame, but much of the use (agriculture and sand mining) has stopped or been permanently removed from the system. Urbanization is a significant pressure. Specifically note that open bar/channel area has drastically reduced over time (2,161m in 1938 to 175m in 2010, a 92.5% reduction; Figure 5-2.14), while floodplains are of equal, or greater, extent.

Santa Margarita: Nine cross-sections were used. The Santa Margarita Watershed has had very little riparian habitat development or permanent habitat removal. The Department of Defense manages all of the area examined in this review. This makes the Santa Margarita interesting in that is separates the two factors: loss of habitat and increased water input. As seen on the San Luis Rey, channel and bar was a large proportion of the system in 1938 (50%, 3,500m; Figure 5-2.15). A steady decline has occurred over time, and by 1997 channel/bar was 8% (of 700m) of the system. Removal of many *Arundo* stands from 1998 to 2006 may have resulted in the modest increase of channel/bar in 2010. Floodplain and terrace areas expanded from 1938 to 2010.

Santa Ana: Five cross-sections were used. The Santa Ana Watershed also had low levels of permanent development and land use change within the riverine areas of the AOI between 1938 and 2010. This is in part due to high bluffs that separate the river from upland areas. Upland areas have become highly developed, but the river bottom has not. The cessation of agriculture and sand mining activities, which was significant from the 1940's to the 1960's, has allowed most of the river to function as natural riverine areas. Trends are less clear on Santa Ana (Figure 5-2.16). Low flow channel and channel/bar areas were greatest in 1938. Ten years later they were significantly less, in part due to modification. Current and recent low flow channel and channel/bar areas are still a low proportion of the total riverine area, but it is not low as was observed on the San Luis Rey and Santa Margarita Rivers. The proportion of floodplain and terrace has been consistently high since 1980.

Ventura: Five cross-sections used. The Ventura River shows a similar pattern of permanent conversion of habitat to development and agricultural use (separated by levee) as seen on the San Luis Rey, with a 50% loss of riverine areas. Unlike San Luis Rey and Santa Margarita, Ventura has retained a large proportion of channel and bar areas (Figure 5-2.17). However, terrace areas as a class was effectively removed from the system through development and agriculture.

Santa Clara: Three cross-sections were used. The Santa Clara River has had significant development protected behind levees. The permanent land use change started as agriculture, but since 1970, it has become increasingly urbanized. Santa Clara appears to be a higher energy system than the other watersheds. A larger proportion of the system is maintained as low flow channel and bar/channel in all years (Figure 5-2.18). A slight decrease in this class has occurred, but it has been stable over the last 30 years and it is still well represented. Floodplain and terrace forms appear to be less abundant. The river has maintained open channel/bar areas, but lost floodplain and terraces, especially in comparison to 1927 and 1938.

Salinas: Three cross-sections were used. Aerial photography was difficult to obtain for the system. 1971 data is presented even though the data set was incomplete (2 of 3 cross-sections). Land use change has significantly reduced the riverine portion of the system. Protection of agriculture with levees started prior to 1971 and accelerated between 1994 and 2006. Low flow channel and channel/bar areas have decreased substantially, and the decline is linear (Figure 5-2.19). Dams have significantly reduced the riverine portion of the system. Floodplain areas are less abundant, while terrace areas have remained relatively constant.

5.2.2.3 Conclusions

Overall patterns of historical change in geomorphic forms on the six watersheds (Table 5-2.4) indicate the following:

- Significant reduction of riverine habitat (levee-protected permanent land use change) - systems are smaller (4 of 6 systems).
- A large decline of low flow channel and channel/bar (active low elevation areas) was seen on three systems.
- The retention/expansion of floodplains as a proportion of the system was observed on four of the six systems.

The long-term geomorphic changes observed on other larger river systems in the Southwest are evident on southern California coastal watersheds.

Table 5-2.4. Summary of geomorphic changes by watersheds.

Trend	San Luis Rey	Santa Margarita	Santa Ana	Santa Clara	Ventura	Salinas
Reduction in functional riverine areas	Yes >50%	No <10%	No <5%	Yes >50%	Yes >50%	Yes >50%
Reduction of low flow channel and channel/bar (in length & proportion)	Yes >70%	Yes >60%	No	Minor	No	Yes >60%
Proportion of riverine habitat that is floodplain & low terrace is stable or larger	Yes	Yes	Yes	No	No	Yes

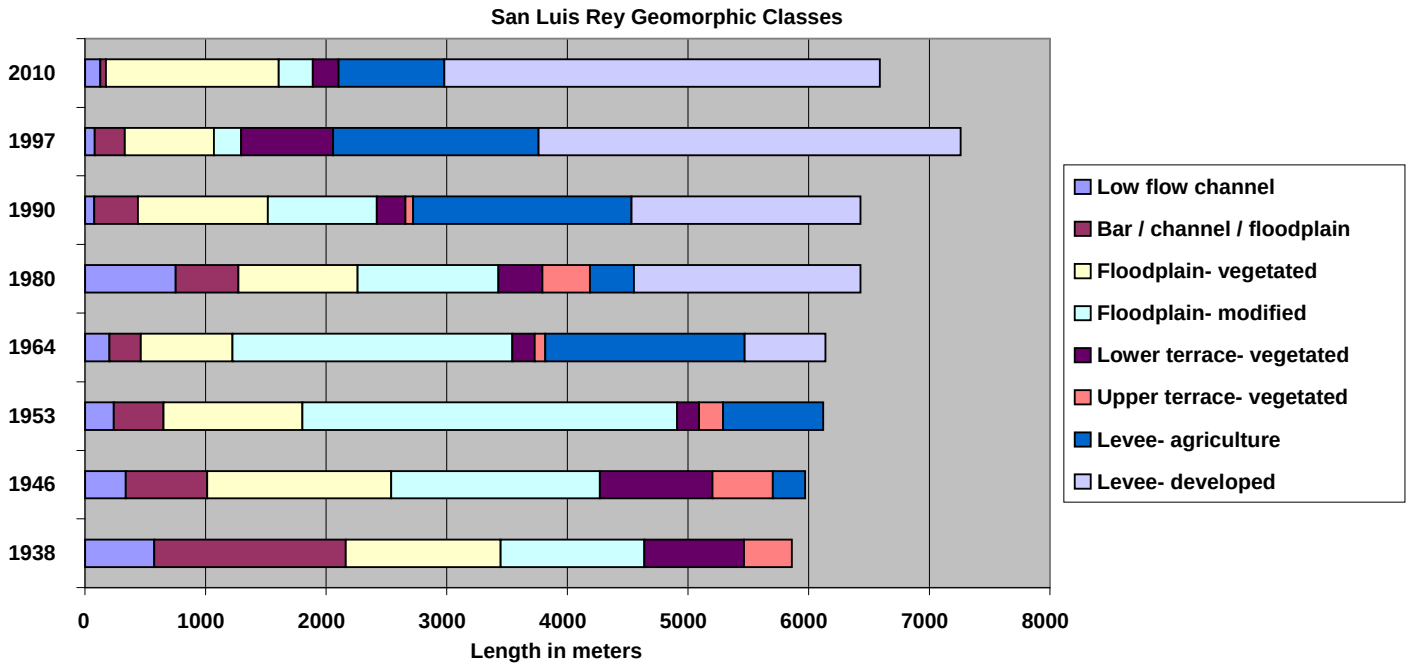


Figure 5-2.14. San Luis Rey geomorphic forms from 1938 to 2010.

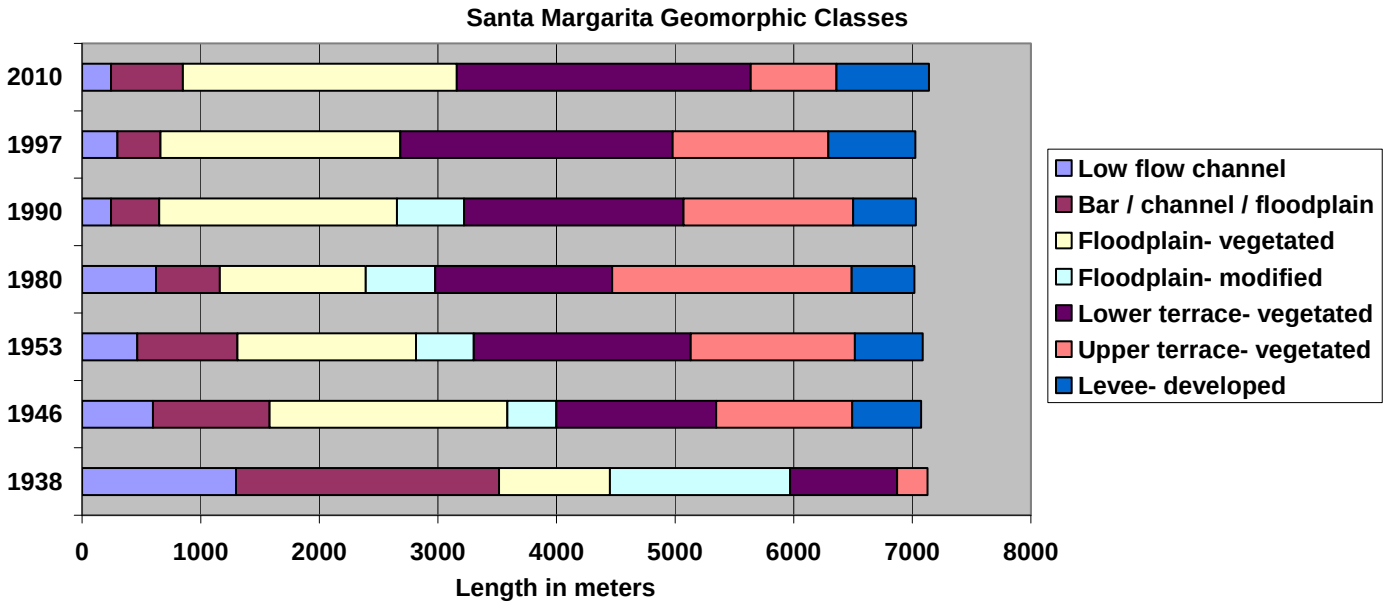


Figure 5-2.15. Santa Margarita geomorphic forms from 1938 to 2010.

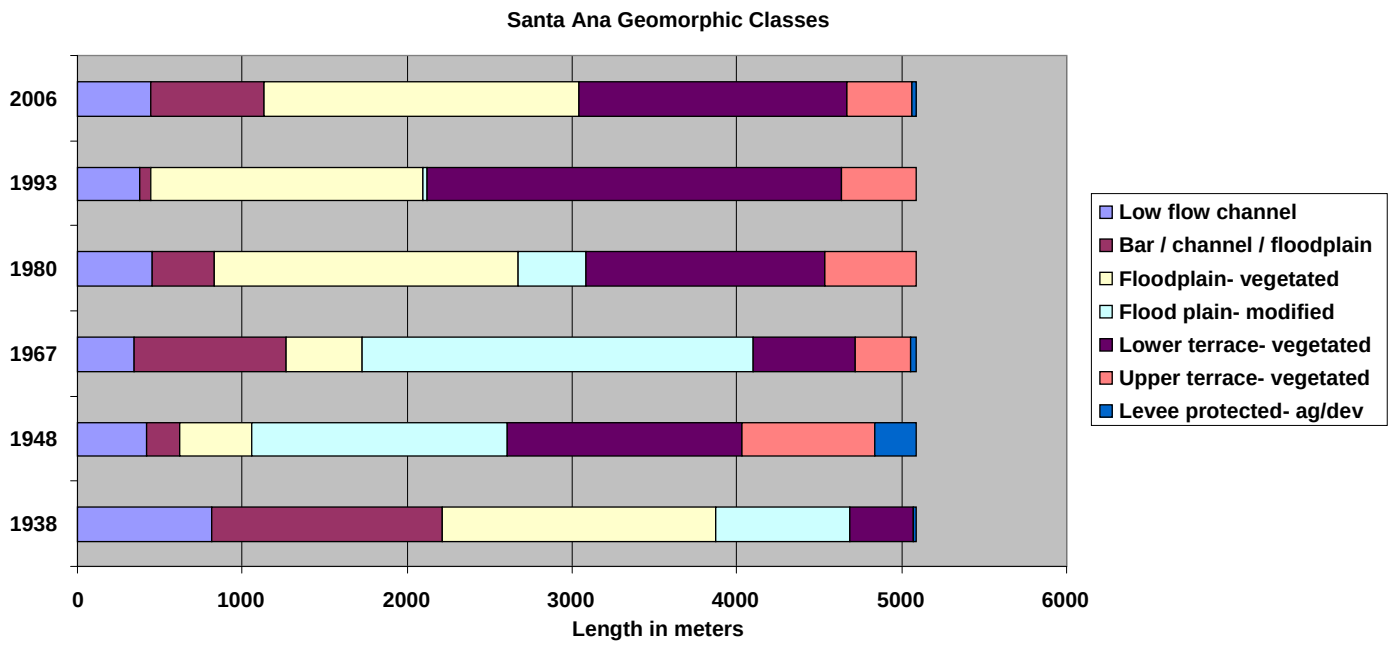


Figure 5-2.16. Santa Ana geomorphic forms from 1938 to 2006.

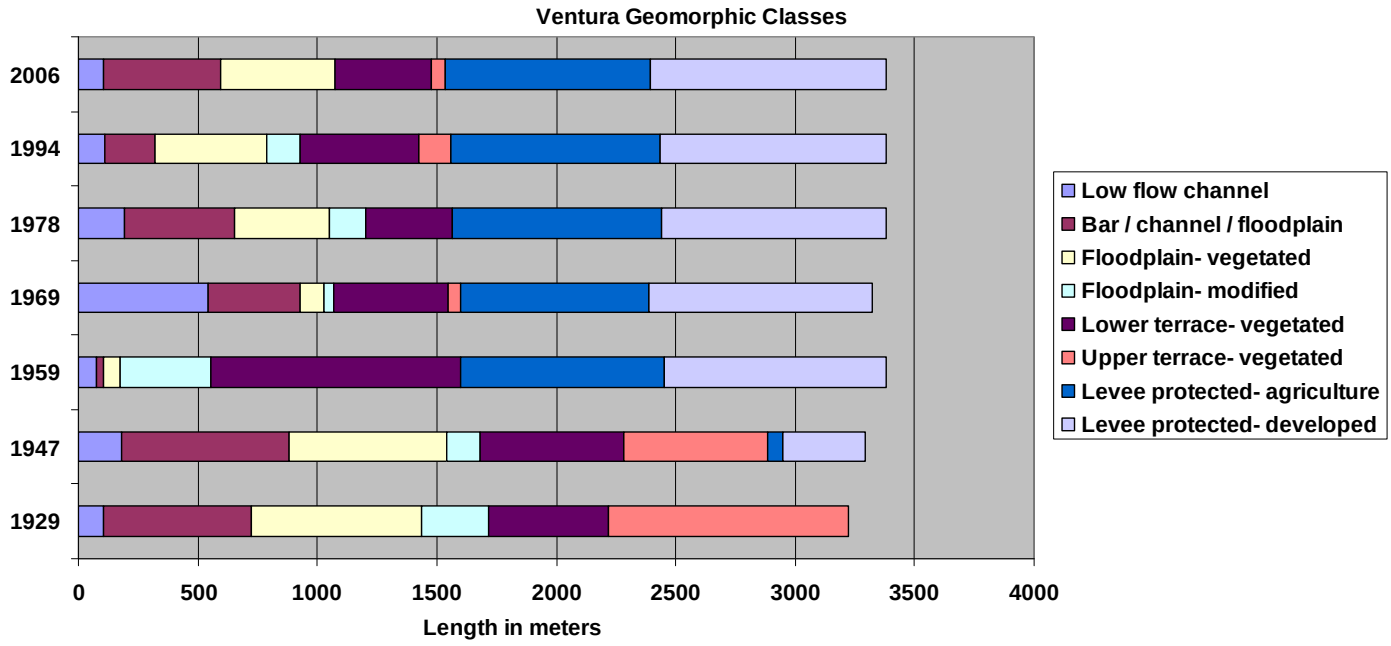


Figure 5-2.17. Ventura geomorphic forms from 1929 to 2006.

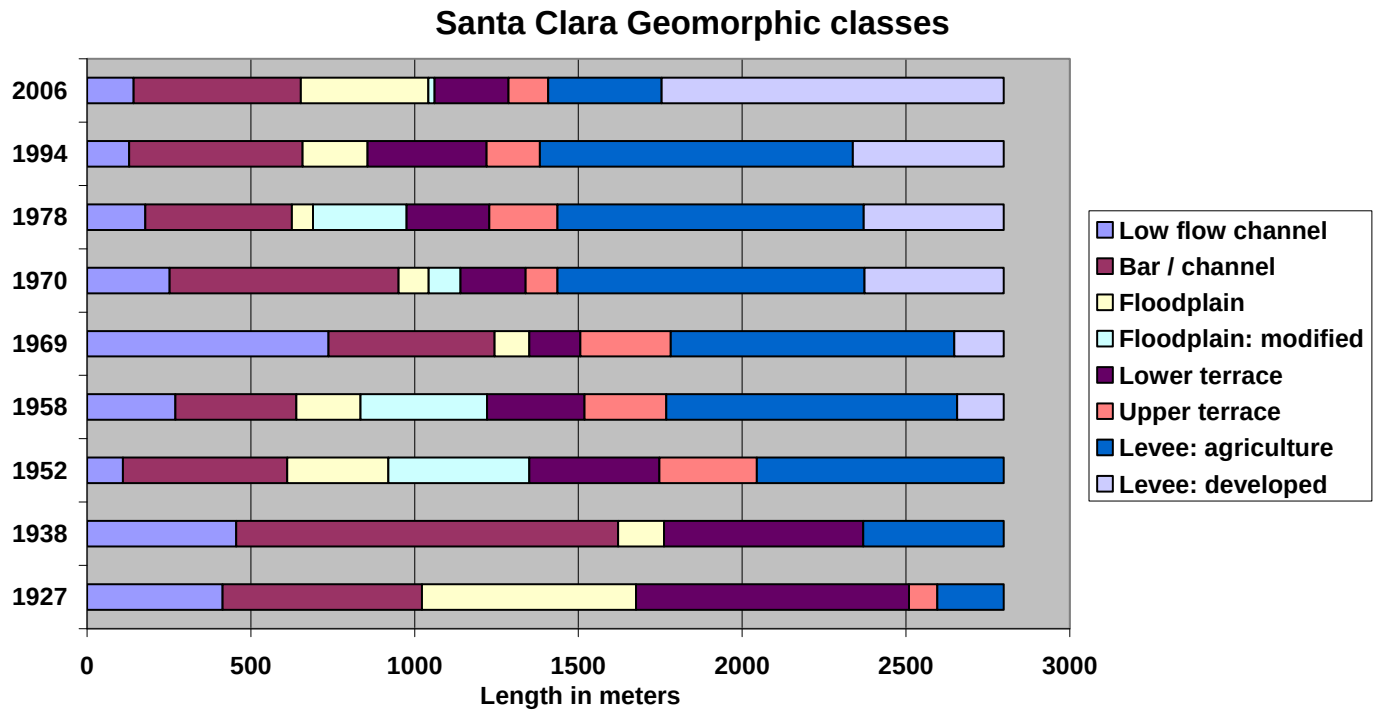


Figure 5-2.18. Santa Clara geomorphic forms from 1927 to 2006.

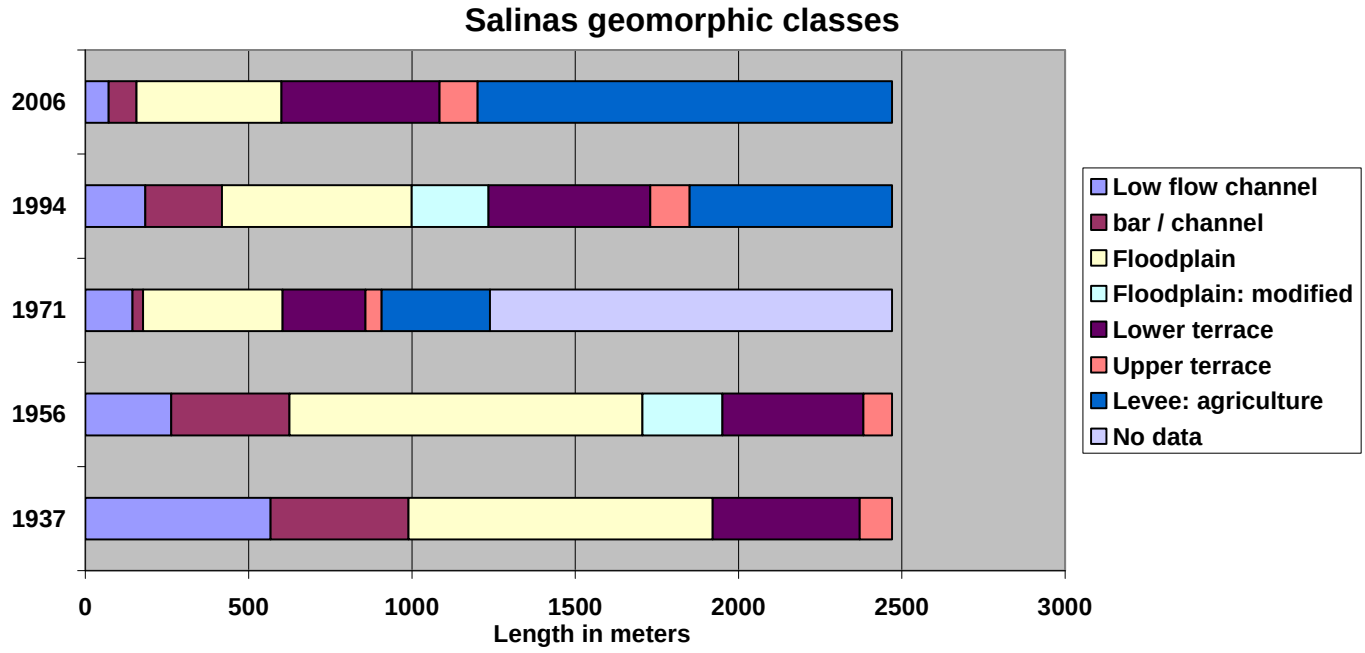


Figure 5-2.19. Salinas geomorphic forms from 1937 to 2006.

5.2.3 Vegetation Cover Historic Analysis

5.2.3.1 Methods

Preparing historic imagery for analysis reinforced a theory that many of the river systems have converted to a more heavily vegetated state over time. Supporting data was captured during the historical cross-section analysis. An attribute was added to the *Floodplain-Vegetated* and *Floodplain/ Low Terrace–Vegetated* geomorphic forms. The attribute values "dense" and "open" were used to describe the conditions and types of vegetation within these forms (see definitions below). Based on observations from the *Arundo* field mapping, the "dense" classification is the most likely place for *Arundo* to thrive, and thus, it was classified as such. An example of aerial imagery showing floodplain and terrace areas with dense and open vegetation classes marked is shown in Figure 5-2.20.

Definitions:

Dense – High woody/*Arundo* vegetation cover (>50%, typically >80%) of large, well-developed vegetation including plants like cottonwoods, sycamores, willows, mulefat and *Arundo*.

Open – Low woody/*Arundo* vegetation cover. Typically these are bare open areas, or areas with annual herbaceous cover. Areas with scattered woody vegetation and clumps of *Arundo* are also included in this category.

5.2.3.2 Results

The characterization of vegetation on the floodplains reveals a strong pattern of increasing cover of dense *Arundo* and woody vegetation. Dense woody/*Arundo* vegetation is taken to be an indicator of high water availability that allows dense vegetation to develop. Individual watersheds are illustrated over 80-90 year periods (Figures 5-2.21 to 5-2.26, Table 5-2.5). Most systems initially show low cover of dense vegetation on floodplains and terraces, except for Santa Margarita and Salinas. Over time dense vegetation cover increases, particularly on the San Luis Rey, Santa Ana, Ventura and Santa Clara from 1980 forward. The increase in proportion (percentage) of "dense" vegetation to "open" is shown in Figures 5-2.27 and 5-2.28 for all watersheds studied. A clear shift in vegetation cover is occurring. Dense cover was typically 10-30% in the 1920s and 1930s, but by the 1990s/2010 most systems were >75%. High R^2 and steep trendlines are apparent for most systems. All data aggregated show a clear upward trend, but systems apparently have different equilibrium points.

5.2.3.3 Conclusions

The strong historic trend toward greater vegetation cover on floodplain and terrace portions of river systems indicates that a major hydrologic shift has occurred within the study area. *Arundo* comprises a significant proportion of this dense vegetation. This overly vegetated condition, compared to 1928-50, seems to be moving these systems toward a more fixed geomorphic and vegetative state, with both fewer smaller size fluvial re-setting events and a faster return to a heavily vegetated state after major events. The dense growth of *Arundo* is likely compounding this effect by holding the low flow channel in a set position which converts systems from a braided unstable form to a narrow single thread that is laterally stable. The availability of water all year within riverine systems has allowed *Arundo* to drastically expand in cover. Although difficult to detect in pre-1990 aerial imagery, *Arundo* is clearly not a dominant vegetation form on systems prior to 1980. By 2000 *Arundo* has become abundant with over 40% cover on reaches of selected systems (section 5.1) and an average cover of 13% on the lower gradient floodplain areas as a whole (Table 5-2.1).

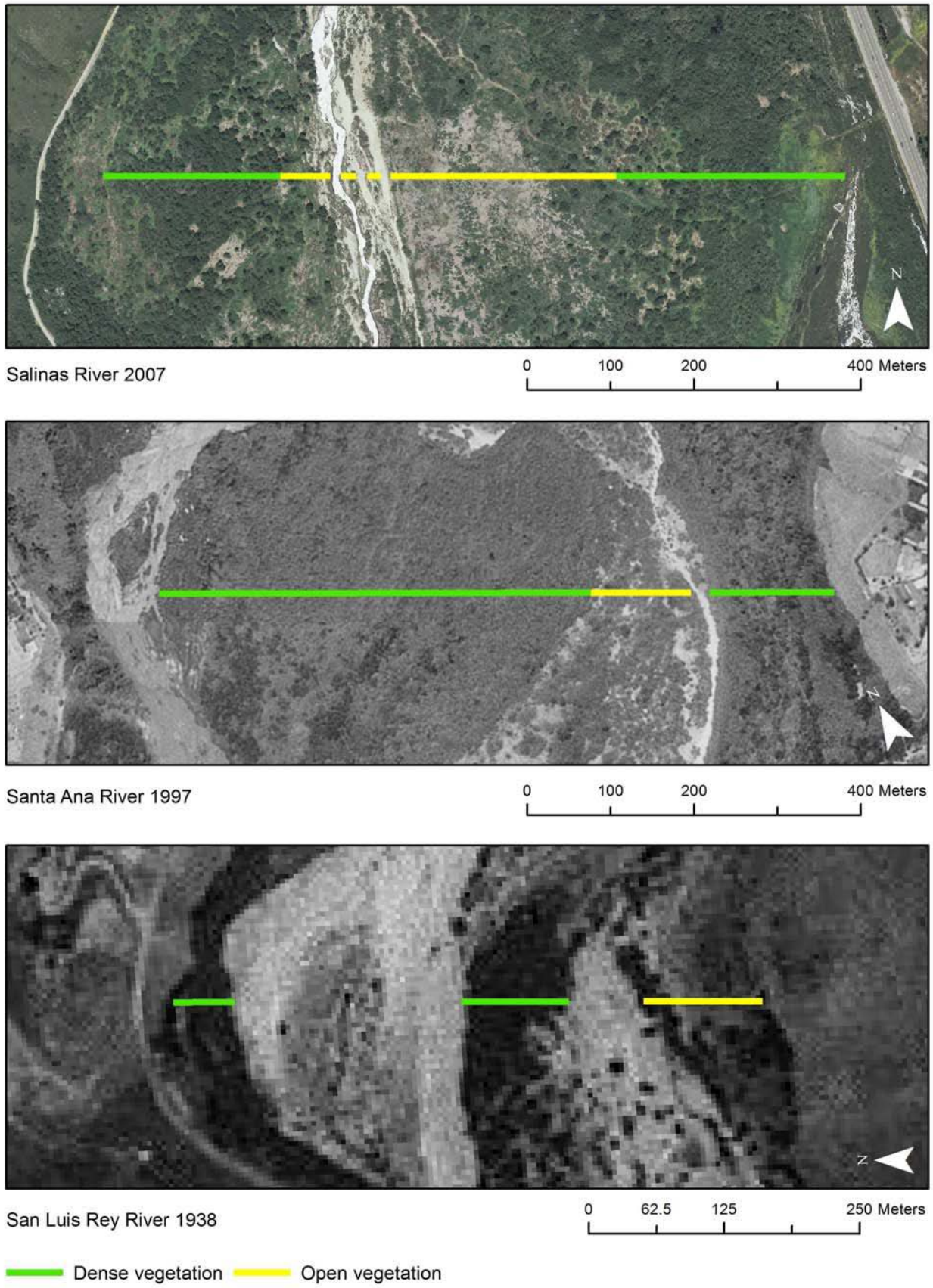


Figure 5-2.20. Aerial imagery showing floodplain and terrace areas with dense and open vegetation classes marked.

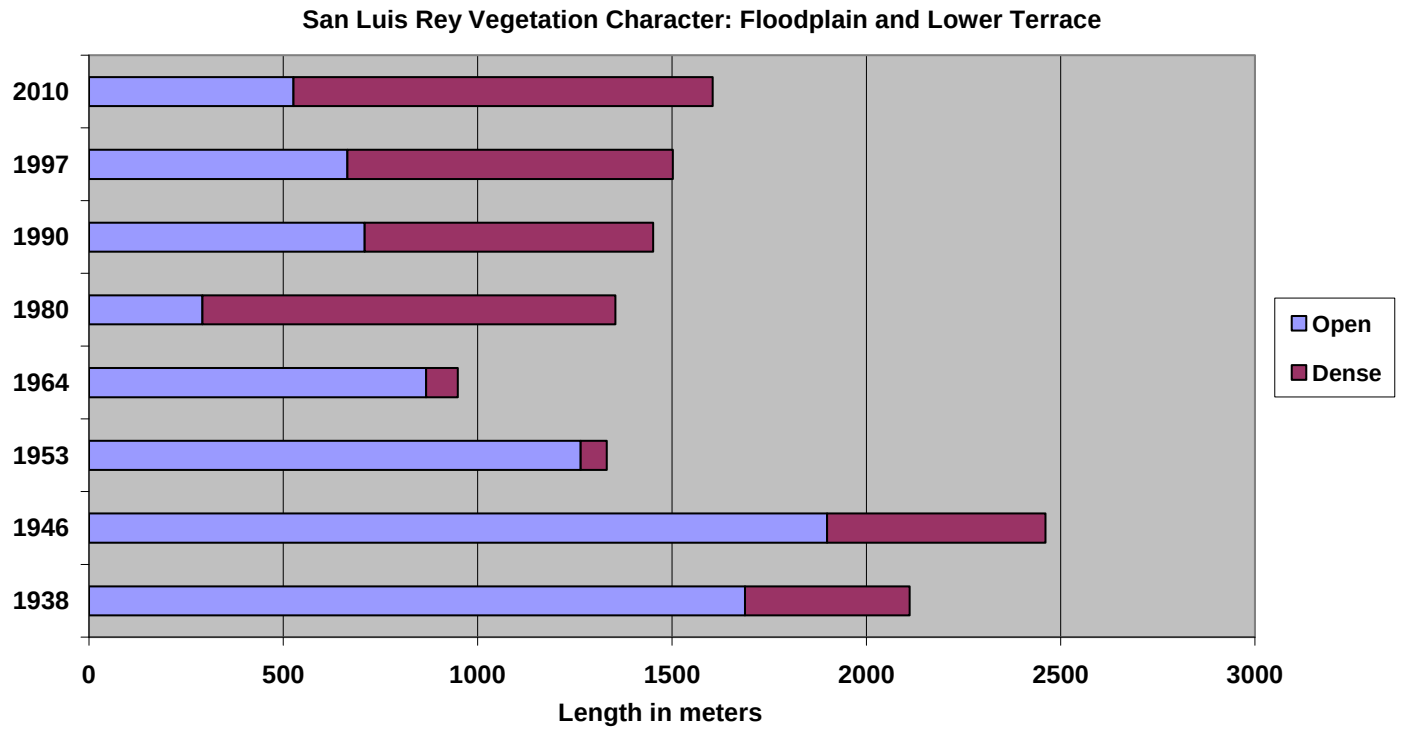


Figure 5-2.21. San Luis Rey open and dense vegetation classification on floodplain and lower terrace areas from 1938 to 2010.

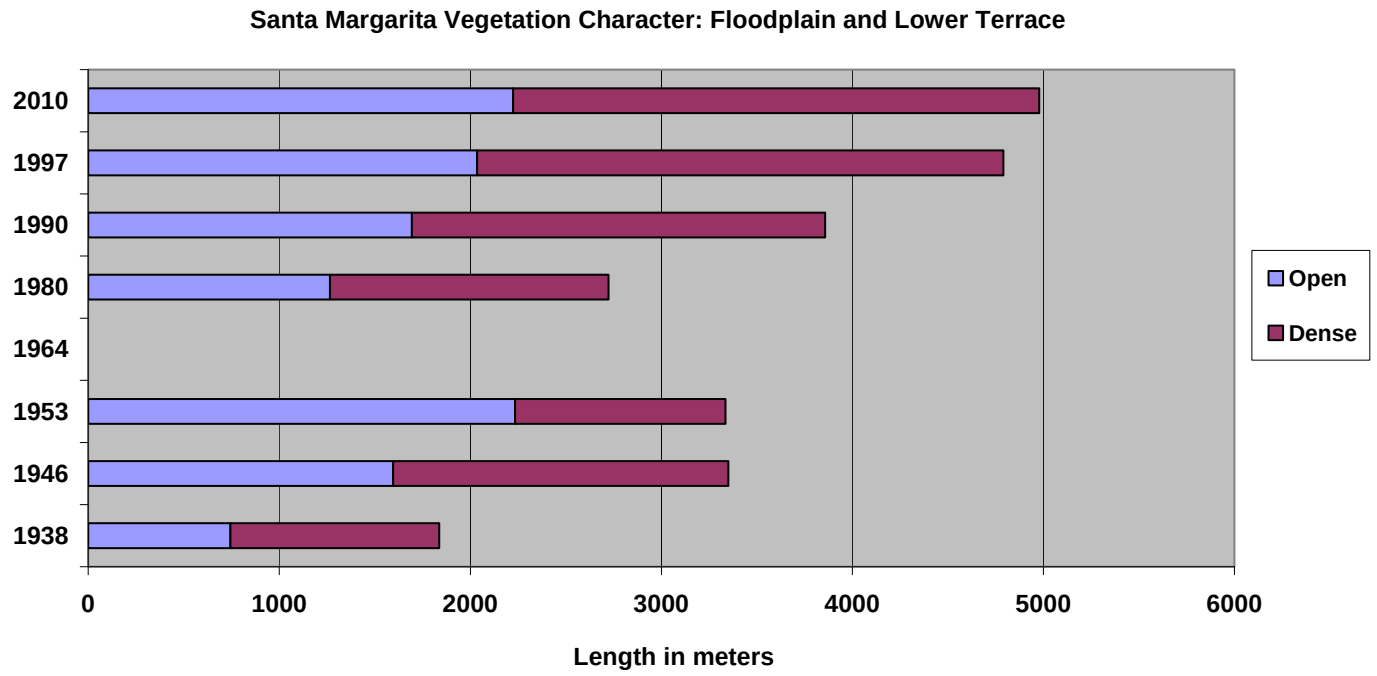


Figure 5-2.22. Santa Margarita open and dense vegetation classification on floodplain and lower terrace areas from 1938 to 2010.

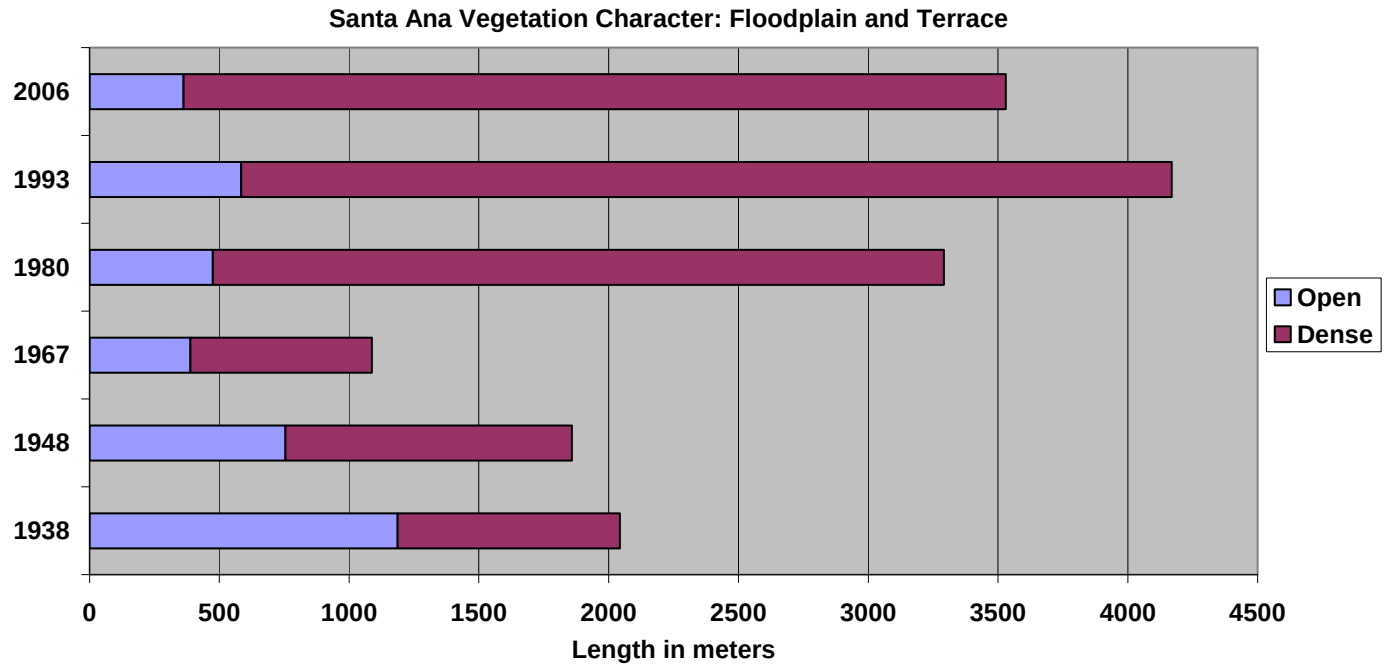


Figure 5-2.23. Santa Ana open and dense vegetation classification on floodplain and lower terrace areas from 1938 to 2006.

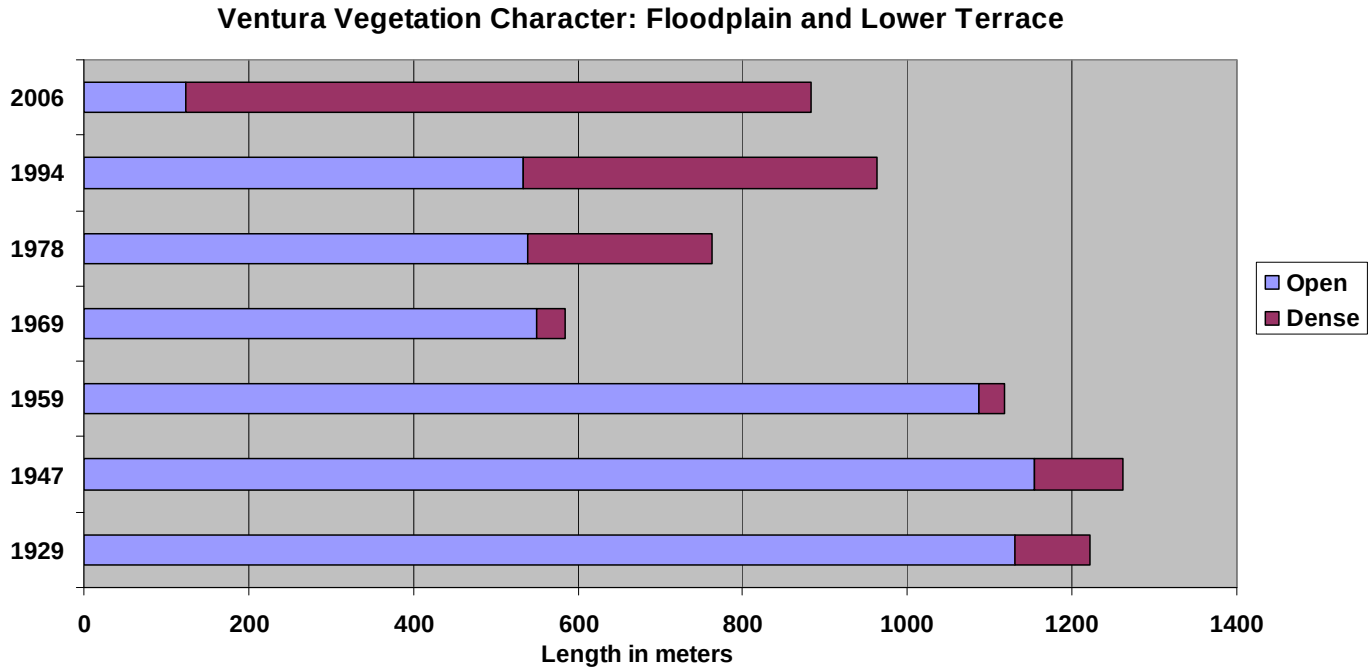


Figure 5-2.24. Ventura open and dense vegetation classification on floodplain and lower terrace areas from 1929 to 2006.

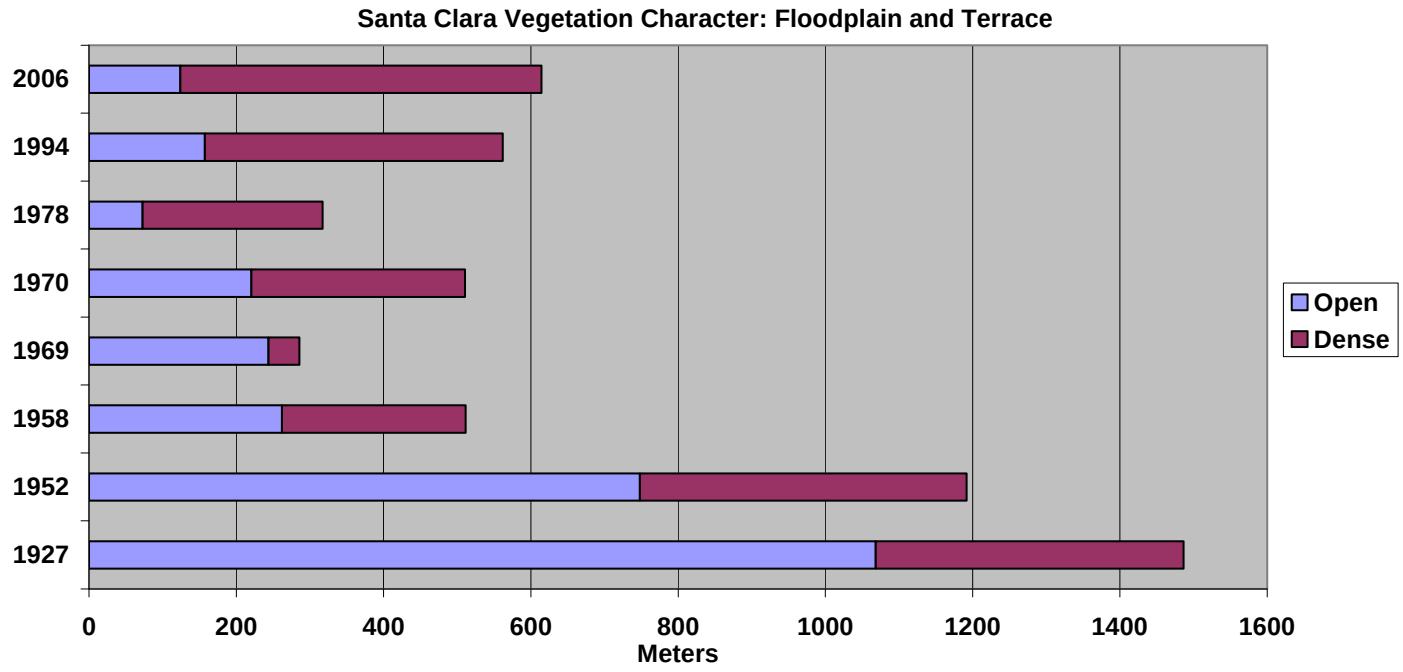


Figure 5-2.25. Santa Clara open and dense vegetation classification on floodplain and lower terrace areas from 1927 to 2006.

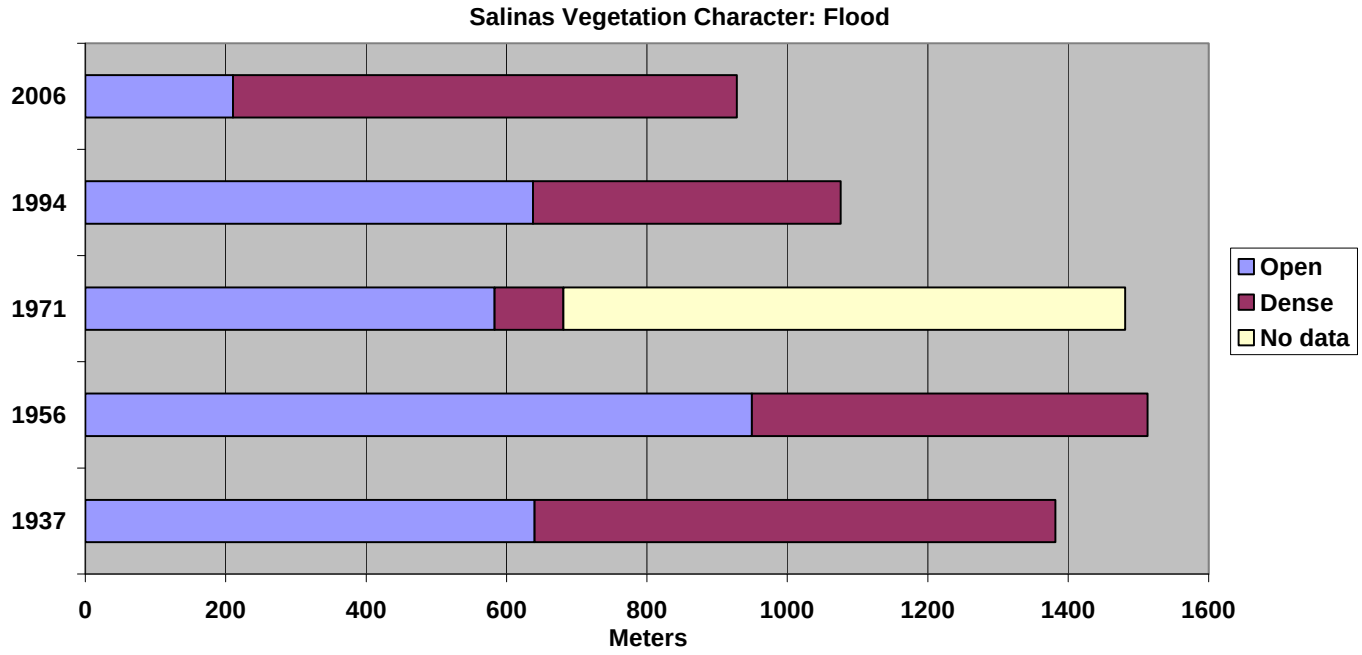


Figure 5-2.26. Salinas open and dense vegetation classification on floodplain and lower terrace areas from 1937 to 2006.

Table 5-2.5. Open and dense vegetation by year for four watersheds.

Watershed	Year	Total length (m)	Open length (m)	Dense Length (m)	% Open	% Dense
San Luis Rey	1938	2112	1688	424	80%	20%
San Luis Rey	1946	2461	1899	561	77%	23%
San Luis Rey	1953	1332	1265	67	95%	5%
San Luis Rey	1964	949	867	81	91%	9%
San Luis Rey	1980	1354	292	1062	22%	78%
San Luis Rey	1990	1451	709	742	49%	51%
San Luis Rey	1997	1502	665	837	44%	56%
San Luis Rey	2010	1605	526	1079	33%	67%
Santa Margarita	1938	1838	745	1093	41%	59%
Santa Margarita	1946	3351	1597	1754	48%	52%
Santa Margarita	1953	3336	2235	1101	67%	33%
Santa Margarita	1980	2724	1266	1458	46%	54%
Santa Margarita	1990	3857	1694	2163	44%	56%
Santa Margarita	1997	4790	2036	2753	43%	57%
Santa Margarita	2010	4978	2225	2753	45%	55%
Santa Ana	1938	2043	1187	856	58%	42%
Santa Ana	1948	1858	755	1103	41%	59%
Santa Ana	1967	1088	389	699	36%	64%
Santa Ana	1980	3292	475	2817	14%	86%
Santa Ana	1993	4169	584	3585	14%	86%
Santa Ana	2006	3530	362	3168	10%	90%
Ventura	1929	1222	1131	91	93%	7%
Ventura	1947	1262	1153	108	91%	9%
Ventura	1959	1117	1087	30	97%	3%
Ventura	1969	584	550	34	94%	6%
Ventura	1978	762	538	224	71%	29%
Ventura	1994	963	534	429	55%	45%
Ventura	2006	883	125	758	14%	86%

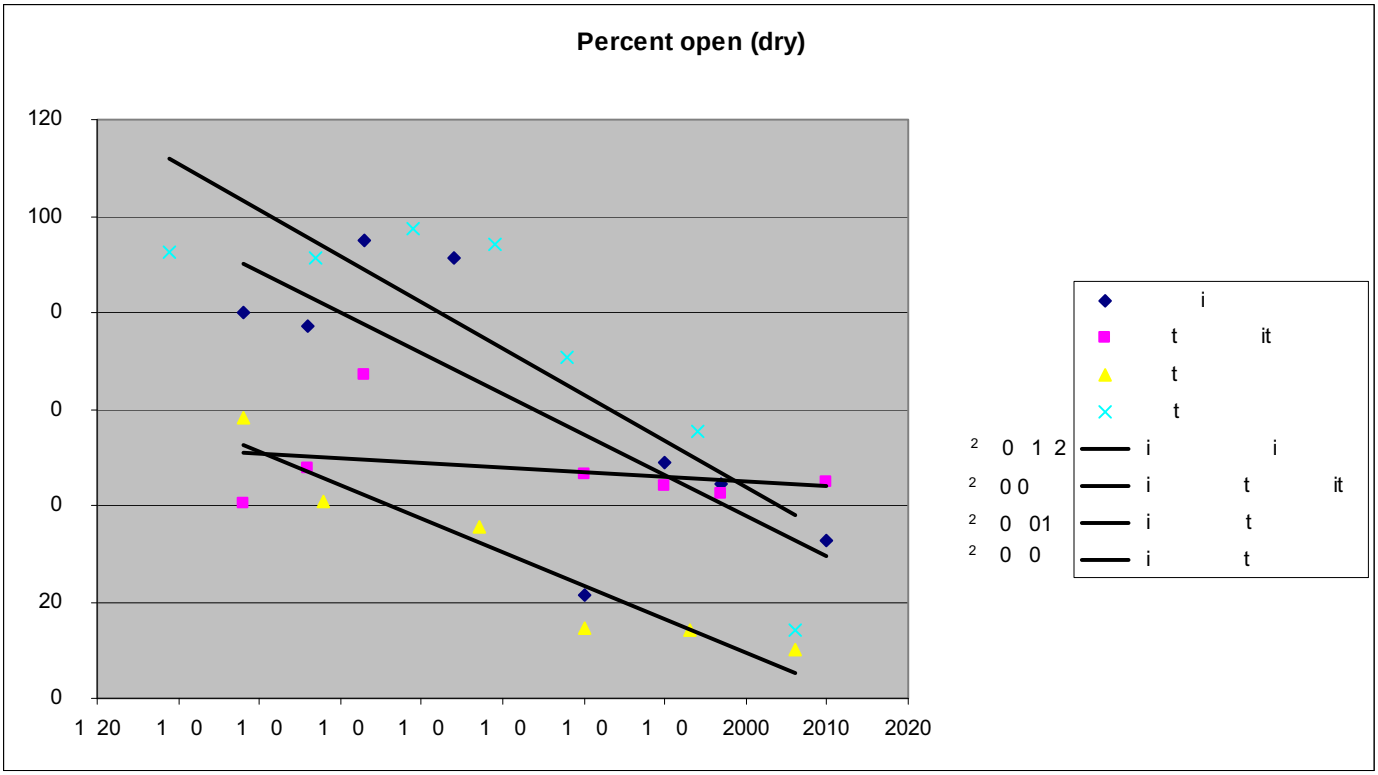


Figure 5-2.27. Trend graph of percent of the open vegetation category from 1927 to 2010 for four watersheds with the AOI.

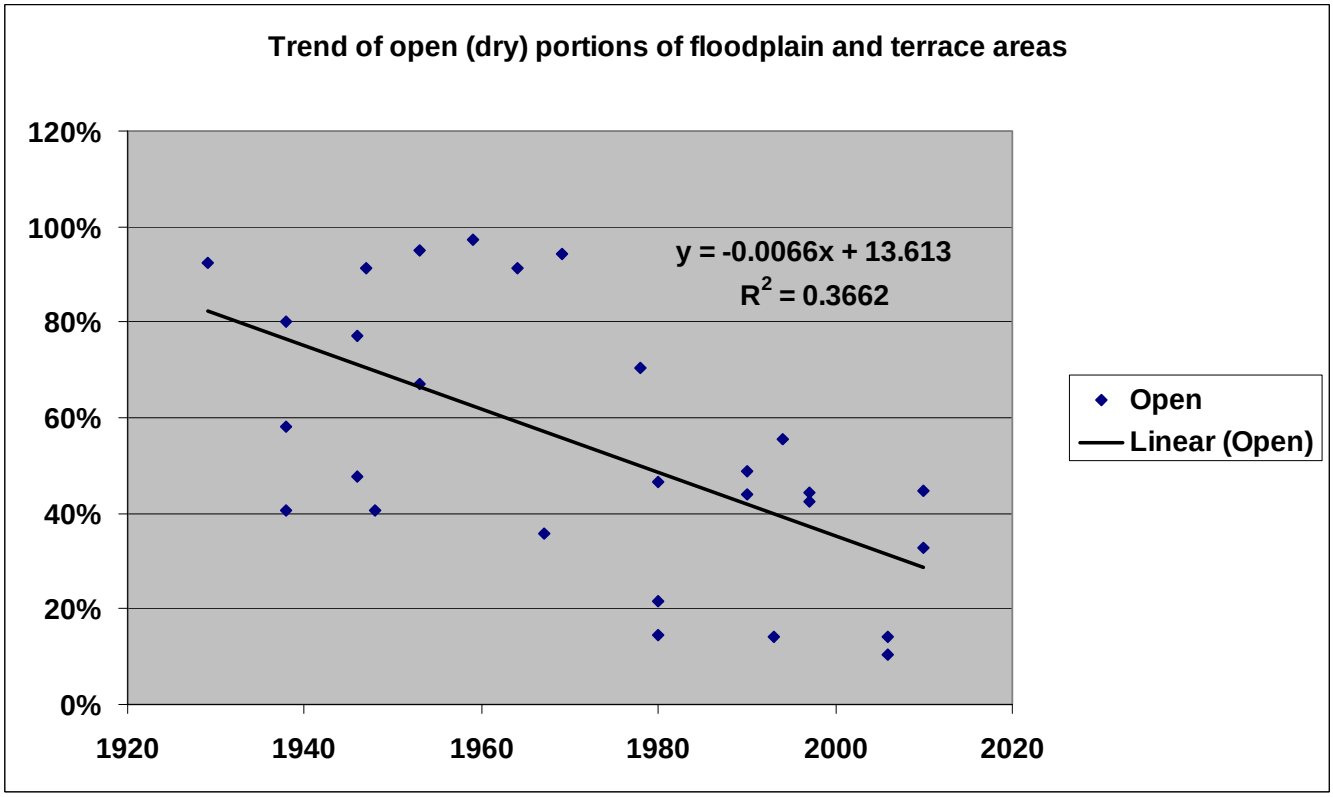


Figure 5-2.28. Trend graph of percent of the open vegetation category from 1927 to 2010 for all watersheds with the AOI.

5.2.4 Geomorphology and Hydrologic Modification by Arundo

What role does *Arundo* play in modifying geomorphic processes? This topic was examined in Sections 5.1 and 5.2 in the context of mapping geomorphic forms and investigating how *Arundo* interacts with river flows and sediment movement. What happens when *Arundo* is removed from a river system? *Arundo* was controlled over a large portion of the Santa Margarita watershed by 2000, so this provides an opportunity to look at one system after *Arundo* has been effectively removed. Large flood events have occurred in the ten years since then, so has the acreage of geomorphic forms changed? Mapping of geomorphic forms at peak *Arundo* cover (1997) and 10-year post *Arundo* removal (2010) show some interesting changes (Figure 5-2.15, Table 5-2.6). Low flow channel area decreased, but bar/channel area increased. Combined together they increased 38% from 118 acres to 163 acres. This is a sizeable change, especially given the linear decline of that class that had been occurring (Figure 5-2.15). A major shift in classification from floodplain to low terrace also occurred. These two classes are close in elevation, and the shift shows a movement to more stable native vegetation on terraces and more active zone area (but vegetated) on floodplains. The floodplain is no longer a dense wall of vegetation (*Arundo* with natives) that restricts flows, rather water now passes through the area. This change in functional flow area has broadened the active flow zone to 362 acres in 2010, a 307% increase over the highly invaded *Arundo* state in 1997 (118 acres). This is a major functional change with implications for groundwater recharge, flood risk, sediment transport and habitat function.

The lower elevation areas in the 2010 classification will likely be more 'dynamic' over time as the vegetation is not able to hold the low flow channel in place. Movement of the low flow channel, braiding, and changing bar/channel structure in the 362.5-acre zone is a significant re-establishment of fluvial forms that was in decline within the study area.

Table 5-2.6. Acreage of geomorphic forms within a portion of the Santa Margarita River in 1997 and 2010.

Geomorphic form	**1997 Acreage:** *Arundo* present	**Flows in a 15 Year event?**	**2010 Acreage:** *Arundo* removed	**Flows in a 15 Year event?**	**Percent change**
Low flow channel	74	Yes	49	Yes	-34%
Bar/channel	44	Yes	114	Yes	159%
Floodplain	536	No	199	Yes	-63%
Floodplain/low terrace	557	No	900	No	62%
Upper terrace	297	No	253	No	-15%

5.2.5 Infrastructure Impacts: Roads, Bridges, Levees, Sewer/Water Transfer, Beaches

5.2.5.1 Bridges & Levees

Reduced flow capacity (elevation of 5'), outlined in Section 5.1, is of great consequence for both bridges and levees. Bridges, particularly older structures, may not have been designed to account for this altered flow capacity during large flow events. The loss of 5 feet of profile over the width of a structure is a significant flow conveyance loss. Many older bridges have multiple, tightly spaced buttresses that tend to collect biomass during flows. *Arundo* mixed with large-sized tree trunks is a particularly problematic combination as it forms a block that catches what might otherwise have flowed through the structure. *Arundo* lodged against a Santa Ana River bridge that failed in 2004 (Figure 5-2.29). A bridge on the Santa Margarita River on Stuart Mesa Road was nearly lost in 1998, but crews pulled *Arundo* off pylons during the flow event, likely saving the structure. In 1993 the Basilone Bridge on the same river was lost and a levee protecting the Air Station was breached with severe flooding of the Air Station occurring. Although these losses cannot be fully ascribed to *Arundo* stands that were dense in the area, it was clearly a factor in these structural failures due to flow conveyance loss. An additional levee failure in the same area in 1998, resulting in damage to Air Station fuel pad, led to the baseline work of documenting *Arundo* impacts on flows (see Section 5.1). It was this study that demonstrated the 5' flow conveyance loss over *Arundo* stands. These higher flows overtopped the levee in 1998, an event size that should not have achieved this outcome. *Arundo* was specifically pinpointed as the reason why flows were higher than expected. Given *Arundo*'s demonstrated effect in 1998, it is certain that levee breaches and flooding in 1992 was of greater magnitude due to the presence of extensive *Arundo* stands. This realization was one of the impetuses for *Arundo* eradication on the Santa Margarita River.

A similar series of events has occurred on the San Luis Rey River. Two bridges were lost following 1992 flooding events at College Avenue and at Camino del Ray Ave. The College Bridge was located below large *Arundo* stands, but the Camino del Ray Bridge was not. An extensive levee system was constructed in the early 1990s on the lower San Luis Rey River. By 2005 significant flow capacity had been lost due to vegetation growth (*Arundo* and natives combined). This led to vegetation reduction and *Arundo* control activities initiated in 2008.

These events on three heavily invaded *Arundo* invaded river systems suggest there will likely be future impacts from *Arundo* on other watersheds in the study area. Impacts and cost valuation for bridge damage or loss is included in the Cost Benefit study in Chapter 8.

Figure 5-2.29. Floods stacked *Arundo* biomass against the River Road Bridge on the Santa Ana River, resulting in the bridge being pushed off its foundation in 2004.
Photo by Richard Zembal.

5.2.5.2 Biomass on Beaches

Arundo biomass on beaches following flow events is a recurring impact (Figure 5-2.30 & 5-2.31). In many areas, particularly from Santa Monica to San Diego, biomass is cleared by Municipal, County and State workers using tractors, loaders and sweepers. Estimating the magnitude and cost of these efforts is complicated due to their periodic nature, in addition to a large range in the amount of material. *Arundo* biomass is not the only material discharged by river flow events. There are also other non-native plants, native plants and refuse. It is not unusual for more than 80% of the material to be *Arundo* biomass near heavily invaded watersheds (San Luis Rey, Santa Margarita, Santa Clara, Ventura). Two of these systems will have lower *Arundo* biomass yields in the future as most *Arundo* has been removed (San Luis Rey, Santa Margarita). Santa Ana has lower *Arundo* discharge than other systems because most *Arundo* is present above the Prado Dam. Small and mid-sized watersheds may discharge large amounts of *Arundo* material, particularly watersheds in the Los Angeles basin (Douce 1993).

Figure 5-2.30. In Santa Barbara County, *Arundo* washes down the Santa Clara River and accumulates on Rincon Beach, blocking access for beachgoers and increasing the cost of beach maintenance.
Photo by David Chang.

Figure 5-2.31. *Arundo* and other biomass washed onto the beach in Long Beach after a large flow event on the Los Angeles/San Gabriel River.
Photo by Drew Ready.

Many beach areas are not maintained for public use. Some of these areas are of significant value to wildlife, particularly areas near estuaries and river mouths. These are also where *Arundo* biomass load is highest. Impact to fauna and threatened and endangered species are outlined in Chapter 7.

Approximately 21 miles of beach are likely to have routine removal of *Arundo* biomass. These areas are north San Diego, Los Angeles/Long Beach, and Ventura/Ojai. Estimates for *Arundo* biomass are based on data from Long Beach following large flood events in 2004/05 (Lopez, pers. comm. 2009, Douce 1993). The city estimates *Arundo* at 40% of total biomass/debris on their beaches. Note that the Los Angeles and San Gabriel Rivers (source of *Arundo* for Long Beach) have significantly less *Arundo*

acreage compared to many other systems. Tons of *Arundo* cleared and the cost of collection are presented in Table 5-2.7. Additional flood event sizes are added to reflect a ten-year period. This data is then extrapolated to the two other regions that have higher levels of *Arundo* biomass on their beaches. Discharge of *Arundo* biomass for a single region is estimated at 875 tons/year or 8,750 tons over ten years. For the region, it would be 2,625 tons of *Arundo* biomass annually or 26,250 tons over ten years (Table 5-2.8).

5.2.5.3 Conclusions: Impacts to Infrastructure

Arundo appears to be having significant impacts to structures that cross rivers as well as structures that contain flows (levees). *Arundo* biomass combined with the loss of flow capacity are the two primary factors contributing to these impacts.

- Loss of flow capacity and presence of *Arundo* biomass is likely contributing to overbank flows and bridge loss and damage. (Section 5.2.5.1)
- Flow events mobilize large amounts of *Arundo* biomass. Part of this biomass load ends up on coastal beaches where it is frequently removed by public agencies that required an estimated annual cost of $197,000. This does not include impacts on habitat quality. (Section 5.2.5.2)

Table 5-2.7. Amount of *Arundo* biomass on beaches of Long Beach and clean-up costs for a ten-year period.

Flood Events in 10 Year Period for Long Beach (LA & San Gabriel Rivers)	Percent cost	Tons *Arundo* biomass	Cost of disposal	Cost of collection	Total cost
Large event (1 in 10)	100	5,000	$175,000	$200,000	$375,000
Medium event (2 in 10)	50	2,500	$87,500	$100,000	$187,500
Small events (2 in 10)	25	1,250	$43,750	$50,000	$93,750
No event (5 in 10)	0	0	0	0	-
10 year Total:		**8,750**	**$306,250**	**$350,000**	**$656,250**

Table 5-2.8. Estimate of the amount of *Arundo* biomass on beaches in North San Diego County, Long Beach and Ventura, and the clean-up costs for a ten-year period.

Major regions	10 yr cost	*Arundo* 10 yr biomass (tons)
Long Beach: L.A. and San Gabriel Rivers	$656,250	8,750
North San Diego: San Luis Rey, Santa Margarita	$656,250	8,750
Ventura: Ventura and Santa Clara	$656,250	8,750
10 years:	**$1,968,750**	**26,250**
Annual cost:	**$196,875**	**2,625**

6.0 IMPACTS OF *ARUNDO: Fire*

Fire is one of the most discussed impacts related to *Arundo* invasion, yet there is little documentation of its occurrence in the literature. A few studies have looked at post-fire recovery of vegetation, but no studies have examined fuel loads, fuel characteristics and ignition sources, explicitly attempted to quantify fire events that start in *Arundo*, or quantified wildfire events that burn riparian areas with *Arundo* in them. All of these subjects will be explored in this chapter.

6.1 Fuel Load

Arundo stands have greatly increased the fuel load of riparian habitat. As outlined in section 2.3, *Arundo* stands in the study area had an average dry biomass of 69 tons/acre or 155 tons/hectare (Table 2-5). This is within the range of other studies on *Arundo* biomass. Studies have shown that *Arundo* produces biomass containing large amounts of energy per unit (17 to 19.8 MJ/Kg; Table 6-1). The high productivity of *Arundo* is why biofuel generation has focused on *Arundo* as a potential fuel source. It is significantly more productive than other species used for fuel generation. One study specifically growing willows for biofuel in riparian strips with high planted density of 15,300 trees/ha (6,200 trees/ac) generated 16.8GJ/ha (for 36.8t/ha biomass, Turhollow 1999). Compare this to *Arundo*: 810 GJ/ha (for 45 t/ha annual biomass, Williams et al. 2008) or 2,790GJ/ha for a mature *Arundo* stand (for 155t/ha biomass, this study). Based on annual yield, *Arundo*'s productivity is 400% higher than riparian vegetation (Turhollow 1999). This is in excess of estimates made by Scott (1993) who proposed that *Arundo* has doubled or tripled the fuel available for fires in the Santa Ana River Basin. Examination of mature stands during collection of *Arundo* biomass for this study also indicated that *Arundo* stands retain a significantly higher amount of dry, dead biomass compared to native woody and herbaceous vegetation, and it is held higher in the canopy. The *Arundo* stand has optimal, well-ventilated structure with both wet and dry fuel present throughout the stand profile. This introduction of a unique stand structure of *Arundo*, a clonal tall grass, into an ecosystem naturally dominated by woody trees and shrubs, herbaceous vegetation and open spaces, has altered fuel types, layers, and loads (Scott 1993, DiTomaso 1998, Brooks et al. 2004). The documentation of biomass loads in Spencer et al. (2006) and this study demonstrate the high levels of *Arundo* fuel. Later portions of this chapter focus on documentation of ignition sources and fire events in *Arundo*, which demonstrates how *Arundo* can be a direct or indirect factor contributing to an increase of fire occurrences.

Table 6-1. *Arundo* energy levels per unit of dry biomass.

Energy MJ/kg	Source
19.0	Williams et al. 2008
18.3	FAIR 2000
17.0	Angelini 2004
19.8	Dahl & Obernberger 2004
18.5	**Average**

Decreased moisture content and increased surface to volume ratio of *Arundo* versus native vegetation may lead to an altered or increased length of fire susceptibility and probability of ignition in these systems, although no data currently exists to document this assertion. Addition of this novel fuel

characteristic to the riparian ecosystem has increased vertical continuity (structure of fuel allows fire to spread from surface to crowns of shrubs and trees), which can in turn increase the frequency and extent of fires (Brooks et al. 2004).

Research still needs to investigate comparative moisture and surface to volume ratios, but current studies definitely indicate that *Arundo* has exceptionally high biomass levels. This directly translates into higher energy per acre.

6.2 Fire Intensity

Arundo stands contain a significant amount of energy and aboveground plant biomass, in addition to a well-ventilated, tall structure. *Arundo* stands always have large amounts of dry leaves, primary and secondary leaves that drop off canes as they grow. As it was discussed in sections 2.2 and 2.3, when a cane matures from the first year of growth to the second year, with the emergence of secondary branches, more than half of the leaves on the cane senesce (Figures 2-18 &6-1). Senescence of leaves on secondary branches also occurs periodically as the canes age. In addition to leaf senescence, both primary and secondary leaves frequently have portions of the leaf that are dry and non-photosynthetic (Figures 2-3 & 4). There is also a highly variable amount of dead cane material, in addition to the large amount of dry leaf material found both at the base of the stand and throughout the canopy. Within a stand, 0 -30% of the biomass is dead cane and leaf material (Spencer et al. 2006, Figure 6-1). This study did not directly measure dead cane biomass, but we observed a low density of dead canes within the plots sampled, averaging less than one cane per m^2 (n = 16, Table 2-4). However, sites can certainly be found with high amounts of dead cane biomass. Often these are areas where material has collected within the stand during flow events (photos in Chapter 5). Stands growing in dry areas will also have significant dead biomass, but these stands also have shorter stature and lower cane density (i.e. lower overall biomass). *Arundo* stand structure (tall height and high cane density per square meter) is an important factor in conveying fires high into the riparian canopy.

Movement and intensity of the fire are also related to weather, but conditions do not need to be favorable for a fire to occur in *Arundo*. *Arundo* can burn any time of the year under varying conditions. *Arundo* stands contain enough dead dry fuel that they can be ignited and carry a fire even under poor fire conditions, such as low wind speed, cool weather, and even when humidity is high or during light rains. This was demonstrated by the fire event on October 2006, which started at night during a light rain and low temperatures (Figure 6-2). Fires have also been observed during light rains and cool temperatures on the San Luis Rey River. Successive heavy rains will reduce *Arundo* stand flammability, but for many areas in the study region heavy rainfall only occurs for 6-10 weeks of the year. High fire threat weather conditions (low humidity and high winds) are not required to start or carry *Arundo* fires. The greatest risk of fire is still in the late summer/fall when stand moisture is low and Santa Ana conditions can exacerbate fire events.

The large amount of biomass per unit area along with a favorable structure for burning generates fires that burn intensively. This is illustrated by fire behavior and an examination of post-fire site conditions. Low intensity fires leave unburned material. Ash levels and color can also be used to gauge fire intensity. *Arundo* fires usually leave little unburned biomass and ash is usually white (Figures 6-3 & 4, also section 6.4 photos).

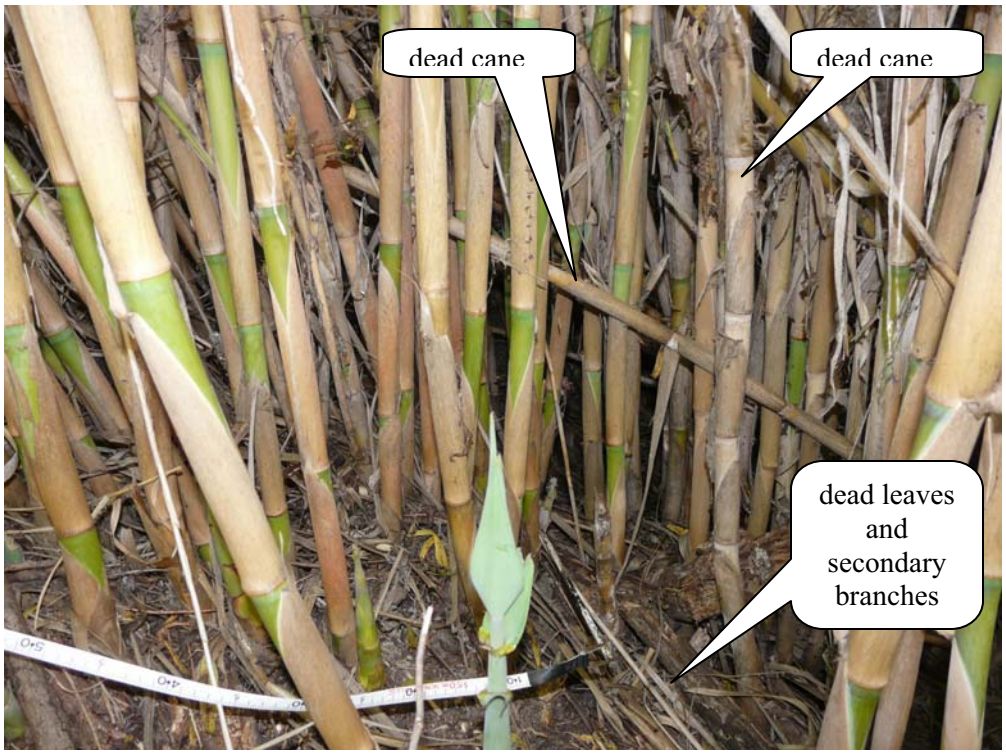


Figure 6-1. Large amount of dead/dry *Arundo* fuel.
While only a small percent of the overall stand biomass is dead and dry, it is enough to start and maintain fires.

Figure 6-2. This fire started in *Arundo* at night during a light rain in October 2006.
Photos from San Diego News outlets (Fires SLR#1-3).

Figure 6-3. Burned *Arundo* stands on the San Luis Rey River (Fire SLR #6).

Figure 6-4. Burned *Arundo* stands on the San Luis Rey River (Fire SLR #6).

6.3 Ignition Sources

Fires must have an ignition source in order to burn. Two main groups of ignition sources have been observed for fires that burn *Arundo* stands: local ignition sources (people in or around *Arundo* stands) and wildland fires. Wildland fires may be started by humans, or may start from lightning, although this is an increasingly infrequent occurrence (Keeley & Fotheringham 2005). Most wildfires start from arson, campfires, vehicle fires, power lines, and other human activities (CalFire and Ventura incident reports, Keeley & Fotheringham 2001).

6.3.1 Human Ignition Sources:

This report documents that *Arundo* directly increases the probability of fire ignition due to *Arundo* stands supporting human activities that lead to fires. *Arundo* stands offer concealment and shelter, which results in encampments and use by transients (Figure 6-5). Activities by transients within *Arundo* stands directly start fires. The following examples are from the San Luis Rey watershed, which has had documented camps and fires within *Arundo* stands for the past 10 years. Camps often have open fires for cooking and heat (Figures 6-6 & 7). Some camps even have portable heaters and ovens (Figure 6-8). Humans frequently smoke and use substances that must be ignited or heated for use, or may process these materials in camps (Figure 6-9). Humans have also intentionally set fires to *Arundo* stands (NLF 2006/7). Fireworks and firearm discharge may also lead to fires. Concealment, availability of water, and remoteness in some areas has also led to the cultivating of cannabis on several watersheds (documented on the San Luis Rey and Santa Ana). These operations have resulted in at least one fire event from an area where the workers had an open campfire (Figure 6-10). Transient activities and encampments are the primary ignition source for fires that start in *Arundo* stands. Direct evidence of the ignition source is usually present at the fire site.

Figure 6-5. Camp on San Luis Rey River with *Arundo* folded over to make an enclosure.

Figure 6-6. Camp on San Luis Rey River in *Arundo* stands showing tent, tarp and fire ring. *Arundo* surrounds the camp.

Figure 6-7. Camp on San Luis Rey River within *Arundo*, showing multiple lighters, cooking area and burned *Arundo* canes.

Figure 6-8. Camp on San Luis Rey River in *Arundo* showing tent and cooking area with a portable oven connected to propane.

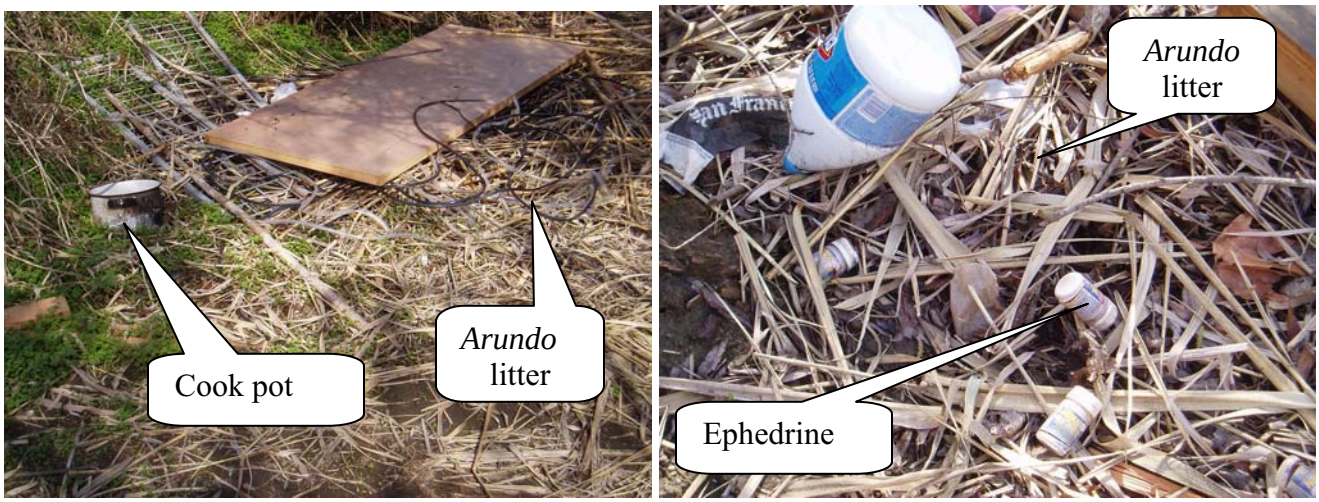


Figure 6-9. Small methamphetamine lab on the San Luis Rey River within *Arundo* stands.

Figure 6-10. Open fire associated with workers of a cannabis plantation.
This was the ignition source of a wildfire that started within *Arundo* on the San Luis Rey River (Fire SLR #6).

An excerpt from the North County Times on January 23, 2007, referred to the fires on the San Luis Rey River:

> "The fires all started in areas widely known as hideouts for transients that set up camps among the brush and 'bamboo' that clogs the riverbed," authorities said. "We've always had fires occur in the river bottom due to the homeless population," Lawrence said. "But transients normally go through great effort to keep fires from spreading, so we're surprised to find uncontained vegetation fires when we arrive. Normally they're small cooking fires." Patricia Clutter, who lives near the river, said that she has witnessed five fires in the last four years and many neighbors are concerned.

Between 2000 and 2009, 34 encampments in *Arundo* stands were documented on the San Luis Rey River (Figure 6-11, Table 6-2). San Luis Rey data indicate that approximately one camp occurs for every 2 miles of invaded river. Encampments in *Arundo* on other rivers were recorded as encountered through reports or during the mapping phase of this project. While this is an incomplete data set, it indicates that encampment use of *Arundo* stands occurs on all large watersheds (Figure 6-11): San Diego (6 recorded), Santa Ana (3), Los Angeles (3), and Ventura (5 recorded with very high density). More focused surveying over a longer time period would likely reveal similar levels of encampment use as seen on the San Luis Rey River. This study's data, coupled with the San Luis Rey long-term monitoring data, clearly show a fairly high density of encampments in *Arundo* stands occurring in urbanized areas (homeless transients) as well as agricultural areas (agricultural workers).

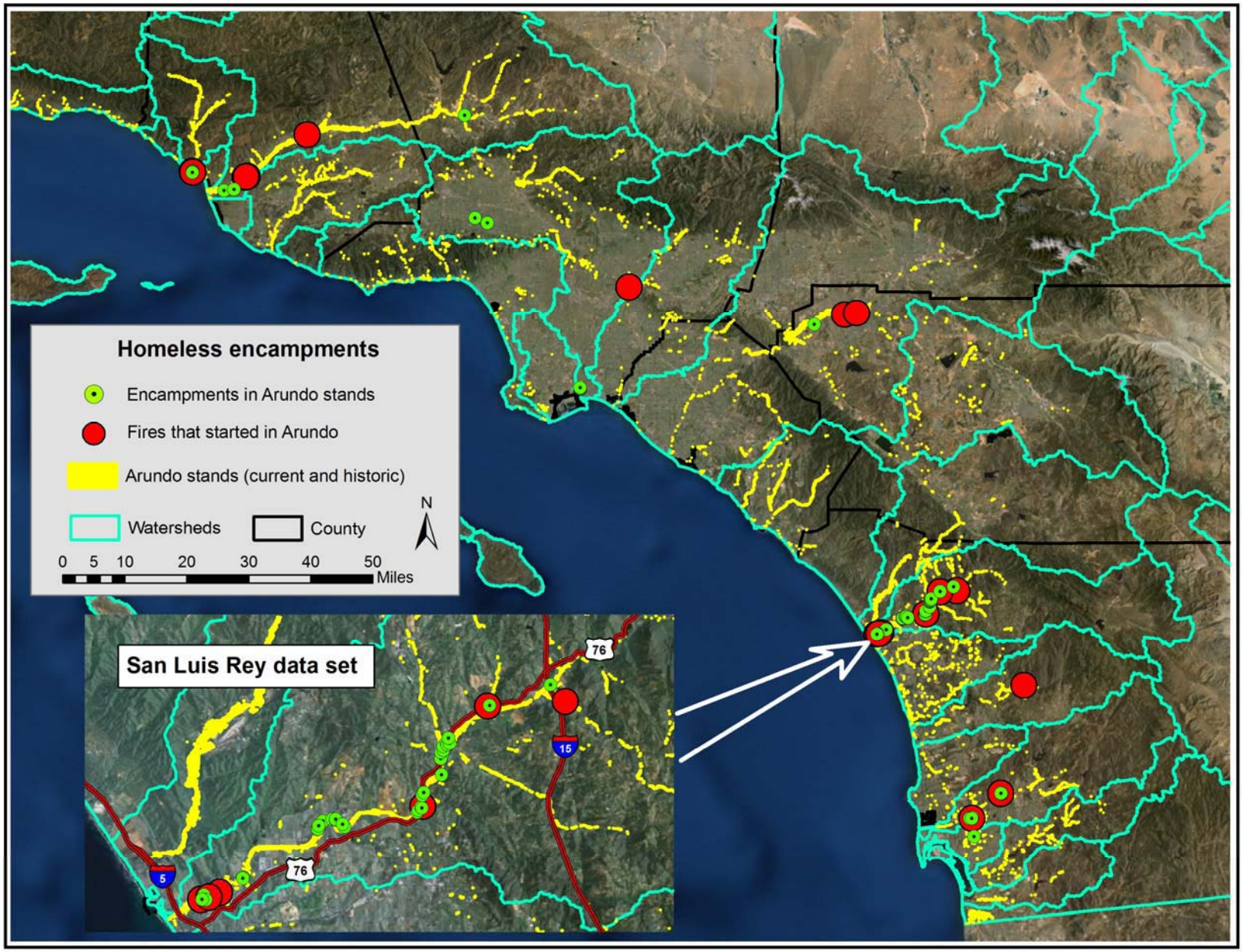


Figure 6-11. Location of *Arundo* fires for some southern California watersheds.

Table 6-2. Encampments found within *Arundo* stands on the San Luis Rey River.

Camps	People	Time Frame	Completeness
34	84	2000-2009	Very complete, but likely an underestimate

The second most common ignition source is likely from cigarettes being thrown out of vehicles on bridges above *Arundo* stands. This has resulted in frequent fires in the San Diego, San Luis Rey, and Santa Ana Rivers. Areas under bridges and overpasses are also high use areas for transients, so differentiating ignition sources can be difficult, but some fire events occurred in areas that have little use by transients.

Arundo fires started by human activities are usually suppressed quickly. The fires can occur at any time during the year. They frequently occur during conditions that are not optimal for fire events, helping fire suppression/response teams. These fires usually have smaller footprints than wildland fires. There is no recorded example of a fire that started in *Arundo* developing into a large wildland fire, but the number of *Arundo* fires that have already been documented increases the potential for this to occur.

6.3.2 Wildland Fire As An Ignition Source:

Wildfires that pass through an area where *Arundo* is present will ignite and burn *Arundo* stands. The presence of *Arundo* changes how the fire behaves within the riparian zone. *Arundo* can have three important impacts on wildfires: 1) *Arundo* causes the fire to burn hotter and more completely within the riparian area, 2) *Arundo* causes the wildfire to burn larger areas within the riparian zone, and 3) *Arundo* conveys the wildfire through the riparian area into adjacent landscapes, causing more area to burn (urban, rural, or wildland areas). These impacts will be explained in the next section.

6.4 Spatial Distribution and Frequency of *Arundo* Fires

Two types of fire events that burn *Arundo* were mentioned in the previous section: 1) fires that start in *Arundo* and 2) wildland fires that burn *Arundo* stands. The frequency and spatial distribution of these events within the study area will be discussed in this section.

6.4.1 Fires Starting in Arundo

Due to the difficulty of detecting fires on aerial imagery (unless they happen to be taken right after a fire event), only the San Luis Rey River watershed can be used as a comprehensive estimate of *Arundo* fire events over time. Boundaries of fires were captured by examining aerial imagery and ground-based photography, and digitizing the footprint of the fire. In some instances the fire line had been walked with a GPS immediately after the fire events to document the extent of the fire. The San Luis Rey River watershed is a good system to examine as it had abundant *Arundo* acreage and is fairly characteristic of coastal watersheds with various land uses (urban, rural, and open space). Additionally, as outlined in the previous section, data on ignition and encampments has been collected for the San Luis Rey. The number of fires, acreage of fires, and impacts associated with fire suppression were recorded.

6.4.1.1 San Luis Rey Watershed Case Study

A total of six separate fire events initiated in *Arundo* stands were recorded between 2000 and 2007 (Figure 6-12, Table 6-3). Fire events occurred within all reaches of the watershed where *Arundo* was abundant, from the coast to inland areas.

Three fires (SLR #1 to 3) occurred near the river mouth between October 2006 and March 2007 (Figures 6-2, 6-12 to14). These fires were reported in local newspapers and observed by Jason Giessow (this study). Fire suppression clear zones as well as fuel break strips were created to contain the fire (Figures 6-13&14). The ignition source for at least one fire was believed to be an arsonist. Transient use of the area was also high. The fires burned a total of 27.7 acres, and 5.6 acres of habitat were cleared during fire suppression activities (Table 6-3).

Proceeding upstream, the next fire (SLR #4) occurred at the Highway 76 bridge over the San Luis Rey River near East Vista Way in June 2005. This fire burned 1.40 acres (Figures 6-12 & 15). No specific ignition source was identified, but it was likely either a discarded cigarette from the highway overpass or a transient camp. Both uses occur in that specific area. No fire lines were cut around the fire because the river channel and a road surrounded it.

A large fire occurred on June 17, 2007 near Gird Road and Highway 76 (SLR #5; Figures 6-3 & 4, 6-12 & 16). This struck during high fire season and burned a larger area than the other fires on the river. The fire was 64.31 acres in size and fire suppression activities disturbed an additional 0.90 acres. This fire had active suppression, but would likely have been much larger were it not for a vertical 30-foot river bank that served as a natural fuel break on the southern edge of the fire line. The ignition source was likely a campfire related to cannabis cultivation within the central portion of the *Arundo* stand (Figure 6-10). Irrigation tubing was observed leading into the stand area from the river.

The most upstream fire within the study area occurred on a tributary near the confluence of the San Luis Rey River and Keys Creek (SLR #6; Figures 6-12 & 17). This fire occurred in 2001 and was 10.37 acres in size. Local residents speculated that it was kids playing with fire/fireworks/guns. The area has no use by transients and it is not close enough to the highway for cigarettes to have caused the fire. No fire suppression disturbance was recorded, but impacts could have occurred.

Table 6-3. San Luis Rey Watershed: Data on fire events fires that started in *Arundo* between 2000 and 2007.

Fire Name	Date	Fire acreage	Acreage of Impacts from suppression	Total
SLR Fire #1-3	Oct 2006-Mar 2007	27.7	5.6	33.3
SLR Fire #4	June 2005	1.4	0	1.4
SLR Fire #5	June 17, 2007	64.3	0.9	65.2
SLR Fire #6	May 2004	10.4	?	10.4
	Total:	**103.8**	**6.5**	**110.3**

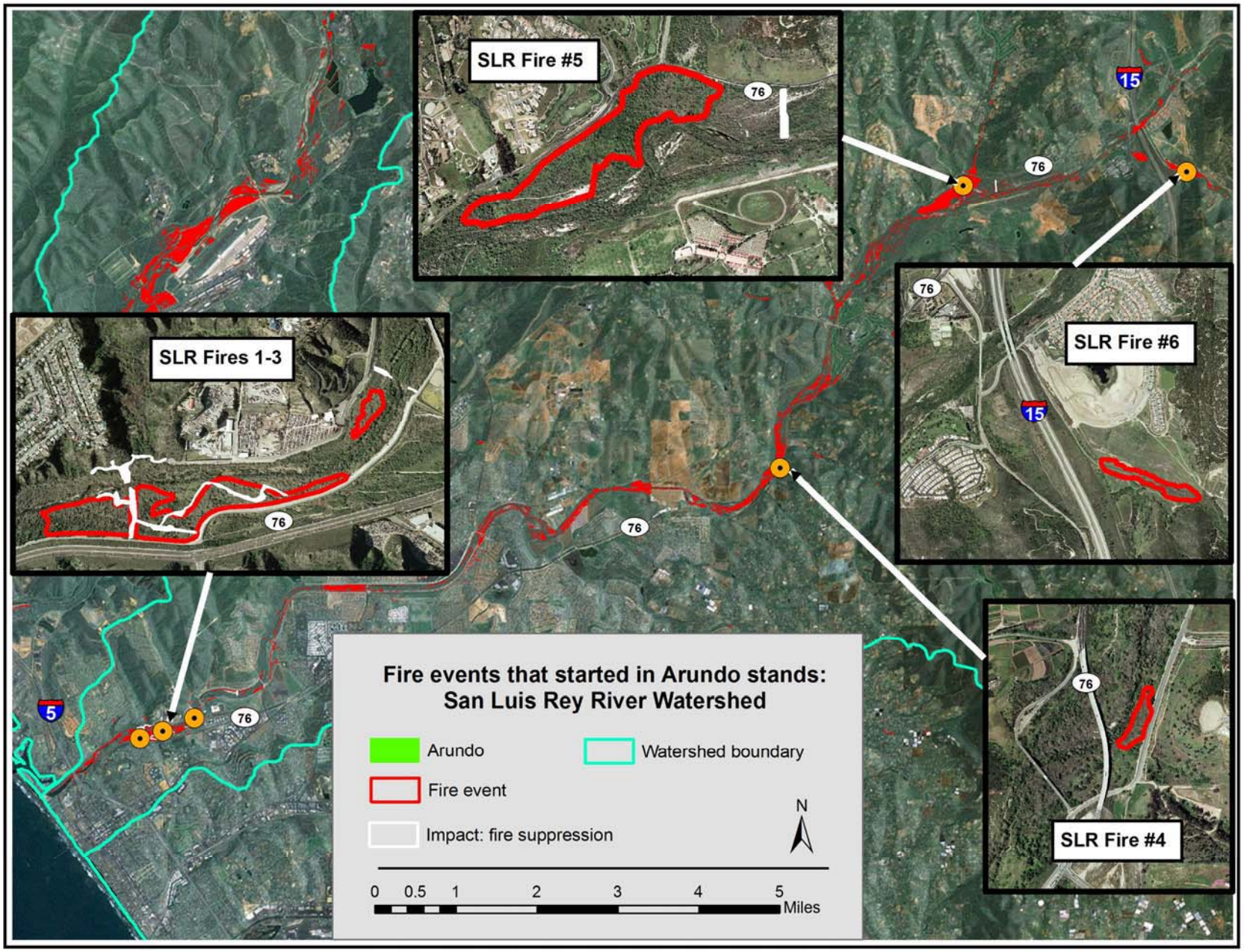


Figure 6-12. Fire events that started in *Arundo* stands on the San Luis Rey River from 2000 to 2007.

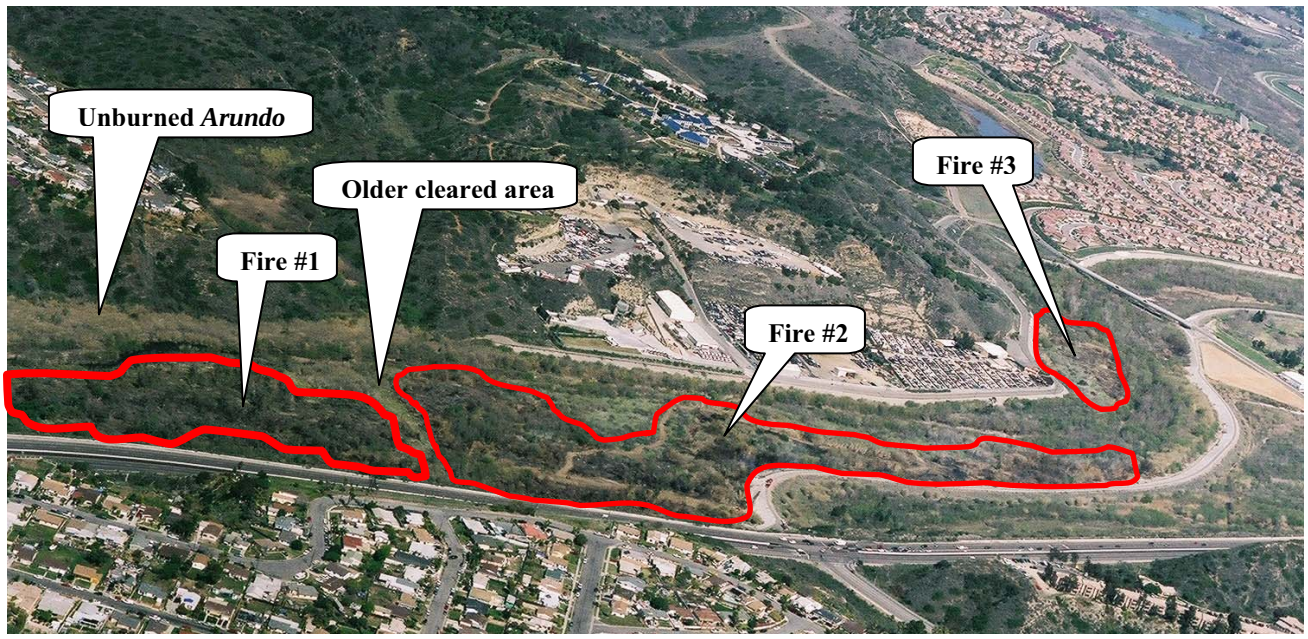


Figure 6-13. Footprint of fires # SLR 1-3 on the San Luis Rey River.

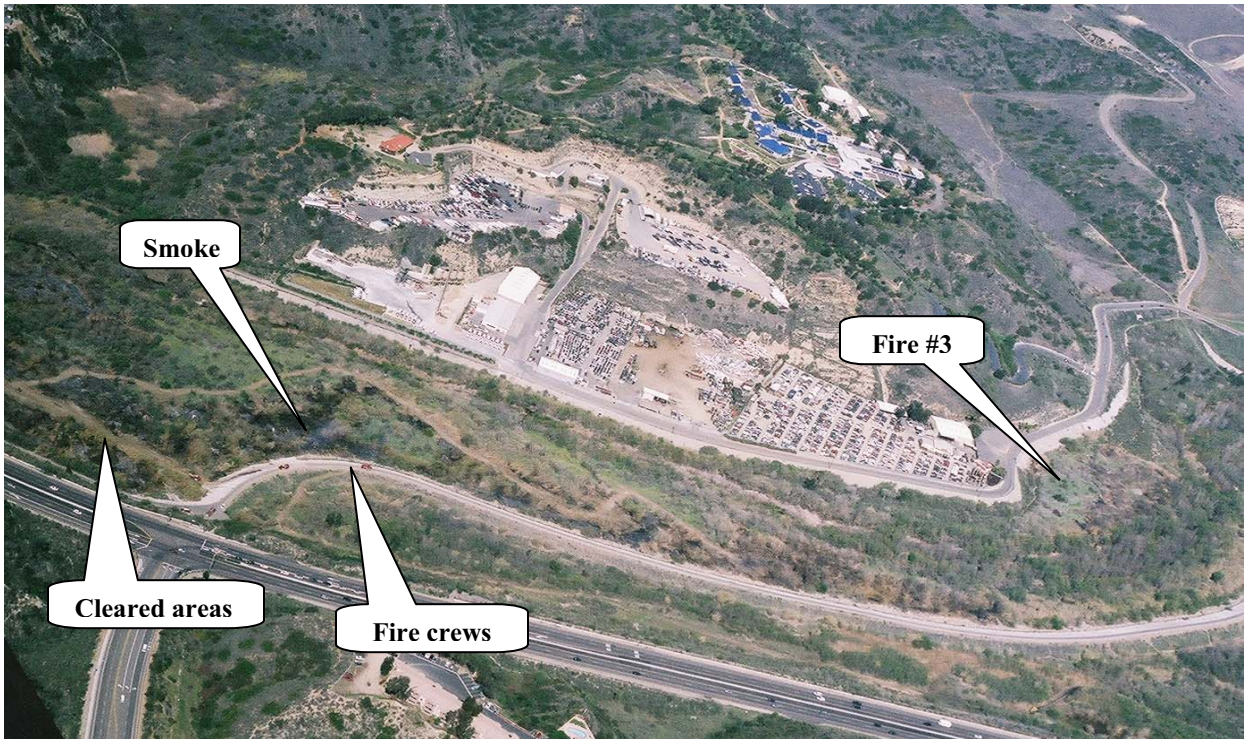


Figure 6-14. Location of fires # SLR 1-3 and fire containment cleared areas on the San Luis Rey River.

Figure 6-15. *Arundo* resprouting after a fire on the San Luis Rey River. Native trees are either dead, or still dormant (Fire SLR #5).

Figure 6-16. Immediately after a fire that burned an *Arundo* stand on the San Luis Rey River, leaving only ash and very little unburned material (Fire SLR #6).

Figure 6-17. Shortly after a fire through *Arundo*-infested riparian habitat on the San Luis Rey River. This demonstrates the quick and dense resprouting of *Arundo* before any native vegetation (Fire SLR #7).

6.4.1.2 Summary of Fire Impacts: Fires Initiated in *Arundo* Stands

For the eight-year period between 2000 and 2007, a total of 103.8 acres of riparian habitat burned during six recorded events (Table 6-4). *Arundo* dominated stands were 43.28 acres of the burned area and native dominated vegetation was 60.54 acres. *Arundo* stands on the San Luis Rey totaled 684.2 acres. During the eight-year period, 6.3% of the *Arundo* stands burned in fires that started in *Arundo* (Table 6-5). A total of 6.9% of *Arundo* stands either burned or were impacted during fire suppression for these events. The average acreage burned each year was 13.0 acres with an additional 0.8 acres impacted during fire suppression. These relationships will be used to extrapolate the fire and fire suppression impacts to other watersheds.

Table 6-4. San Luis Rey Watershed: Acreage summary of impacted vegetation for fires started within *Arundo* stands over an eight-year period (2000 to 2007).

Interval	**Acreage Burned: Fires Started in *Arundo***			**Acreage impacted during fire suppression**			**Total riparian acreage**
	Arundo	*Native*	*Riparian*	*Arundo*	*Native*	*Riparian*	*Total*
8 yr	43.3	60.5	103.8	3.7	2.8	6.5	110.3
Annual	5.4	7.6	13.0	0.5	0.4	0.8	13.9

Table 6-5. San Luis Rey Watershed: Acreage of *Arundo* that burned in fires started within *Arundo* stands over an eight-year period (2000-2007).

Fires started in *Arundo* (documented)	Gross *Arundo* Acres	*Arundo* burned acres over 8yrs	% *Arundo* burned in 8 yrs	Annual % *Arundo* burned in 8 yrs
San Luis Rey	683.9	43.28	6.3%	0.8%

A key finding in this San Luis Rey River fire history is that *all recorded fires that started in the river were initiated in Arundo.* This does not mean that riparian habitat lacking *Arundo* cannot burn. The fires that started in *Arundo* burned large sections of riparian habitat (60.54 acres) that had little or no *Arundo*. What this shows is that un-invaded riparian habitat is not typically ignitable and usually only burns if a hot, well-developed fire is actively burning. This happens when *Arundo*-initiated fires start or when wildland fires occur.

6.4.1.3 Fires That Started Within *Arundo* Stands: Other Watersheds

A second data set was also prepared on behalf of the San Diego River Watershed for known fires that began within *Arundo* stands. The data set is most likely incomplete as less background information was found for the system. Two fires were mapped: 1) a 1990 8.4-acre fire that occurred on the lower watershed and 2) a January 2008 0.9-acre fire on the upper watershed. Over this 19 year time there were 9.3 acres of *Arundo* fires. This represents 6.2% of the *Arundo* stands on the San Diego River (150.5 acres), but over a longer time frame then the San Luis Rey fire documentation. There are more reports of fire events on the lower and upper San Diego River, but it was not possible to quantify them. Operators of a golf course along 1.5 miles of the heavily invaded upper river report frequent fire events over the past 15 years. Ignition source was likely a mix of transient use (which is high in that area) and discarded cigarettes from the highway that runs over the river. The lower San Diego River also has had additional fire events that are tied to homeless activity, but these could not be tied to specific locations and/or *Arundo* stands. The San Diego River *Arundo* fires show the same general pattern of ignition and fire pattern as the San Luis Rey River.

To help illustrate those fires that originate in *Arundo* stands are not isolated occurrences, we prepared a data set of all fires reported/encountered within *Arundo* for the project area (Figure 6-11). We mapped 12 fires that started in *Arundo* stands on other watersheds. This data set grossly underestimates the number of fires starting in *Arundo*, as it is limited to citations in reports, media coverage, fire response reporting, and discussion with program proponents on other watersheds. Even as a conservative representation of *Arundo* fire events, it shows that fires initiated within *Arundo* are indeed common events that have been observed on most watersheds with dense stands of *Arundo*. A brief qualitative overview demonstrates that each affected watershed has similar fire patterns - fires tend to occur where there are dense *Arundo* stands and ignition sources (encampments, bridges). Level of urbanization and transient use is highest along the coast for select watersheds (Ventura, San Luis Rey, San Diego), although interior cities and towns are found along rivers on others (Santa Ana, Santa Clara, Salinas). Agricultural use and migrant worker camps are found in the centralized portions of the watersheds (San Luis Rey, Santa Clara, Salinas). Remoteness, allowing cannabis cultivation and its associated fire impacts, has been observed in San Luis Rey and Santa Ana. These operations usually are not discovered until *Arundo* control is initiated. Highway and road overpasses occur at numerous points along each

watershed creating conditions where stands can burn from discarded cigarettes. Highway bridges in dense and moderate urban/agricultural areas are particular attractants for transients and homeless use.

Since the pattern and frequency of fires appears to be similar across watersheds, applying the relationships outlined on the San Luis Rey Watershed seems reasonable. This holds true as an approximation of acreage burned on an annual and decade basis for each watershed and the overall study area, with two exceptions (Table 6-7). The Salinas Watershed was adjusted downward as humans report fewer fires there, likely due to a combination of different climatic conditions and lower use of the river. Also, the Santa Margarita River is mostly owned and managed by the Department of Defense, so there is limited use by transients in riparian areas. The lack of fires initiated within *Arundo* on the Santa Margarita River, where there are no encampments, supports that this is a primary ignition source.

6.4.2 Wildland Fires That Burn Arundo Stands

Arundo stands have two main effects on wildfires: 1) when a wildfire burns riparian habitat containing *Arundo*, it burns hotter than the habitat would have without the presence of *Arundo* and 2) *Arundo*-infested riparian habitat can act as a fire conveyor across the landscape. This can increase the size of riparian fires and may spread fires to upland areas that would normally have been separated by less flammable native riparian vegetation.

Wildland fires that burned riparian habitat containing *Arundo* stands are noted in Figure 6-18 and Table 6-6. Events that burned large riparian areas on San Dieguito, Santa Margarita, Santa Ana, and Santa Clara watersheds, as well as smaller events on San Luis Rey, San Diego and Otay watersheds, are noted. These are events that started in upland areas, and then developed into large wildland fires. These large wildfire events will often burn riparian vegetation regardless of how much *Arundo* is present. However, when an area infested with *Arundo* does burn, there is significantly more biomass present than would occur in comparison to uninvaded habitat (see section 6.1 on biomass). *Arundo* fuel loads are more vertical and well ventilated than native vegetation. Wildland fire events frequently have unburned patches within them, and vegetation with higher water content does not burn as well. For this reason, riparian zones often have more unburned or lightly burned areas. Presence of *Arundo* within the riparian zone increases the completeness of the burn, as well as the intensity. Wildland fire events that burn *Arundo* stands also lead to type conversion of those sites to *Arundo* dominated habitat (section 6.5.1).

The increased fuel load within *Arundo*-infested riparian habitat, and the resulting hotter and more complete fire, likely leads to riparian areas acting as fire corridors or areas of connectivity. This was documented for a fire on the Santa Clara River in June 2006 (Figure 6-19). This fire started on the north side of the river, burning 8,474 acres of uplands (A). The fire then moved into a riparian area with dense *Arundo*, crossed the 0.43 mile wide river, and then set the southern upland mountain range on fire (B). This fire burned an additional 107,560 acres, including setting the river on fire again 40 miles downstream (C). The fire crossed the river again, but did not set the north range uplands on fire. Agriculture and development blocked the fire's path (D). *Arundo*-infested riverine areas acting as fire corridors could be occurring in other areas, but it is difficult to prove because the effect of the *Arundo* is not always known. For the 2007 San Dieguito Watershed fire that burned 197,990 acres, there could have been areas that would not have conveyed the fire if *Arundo* had not been present, or there may have been larger central portions within the fire boundary that would not have burned (Figure 6-18). Similar patterns occurred in the 'freeway complex fire' that burned upland, riparian, and urban areas on the Santa Ana (Figure 6-18). The fire moved through *Arundo*-infested riparian habitat areas during early stages of the fire.

Table 6-6. Acreage of *Arundo* by watershed that burned during documented wildfires over a ten-year period.

Watershed	Gross *Arundo* Acres	*Arundo* acreage burned over 10 yrs (gross)	% *Arundo* burned over 10 yrs	Annual % *Arundo* burned over 10 yrs
Calleguas	231.5	71.5	30.9%	3.1%
Otay	18.6	0.5	2.5%	0.3%
San Dieguito	175.0	134.9	77.1%	7.7%
San Luis Rey	683.9	15.6	2.3%	0.2%
Santa Ana	2,723.9	95.7	3.5%	0.4%
Santa Clara	1,081.3	220.5	20.4%	2.0%
Sweetwater	42.3	6.0	14.2%	1.4%
Total:	**4,956.5**	**544.6**	**11.0%**	**1.1%**

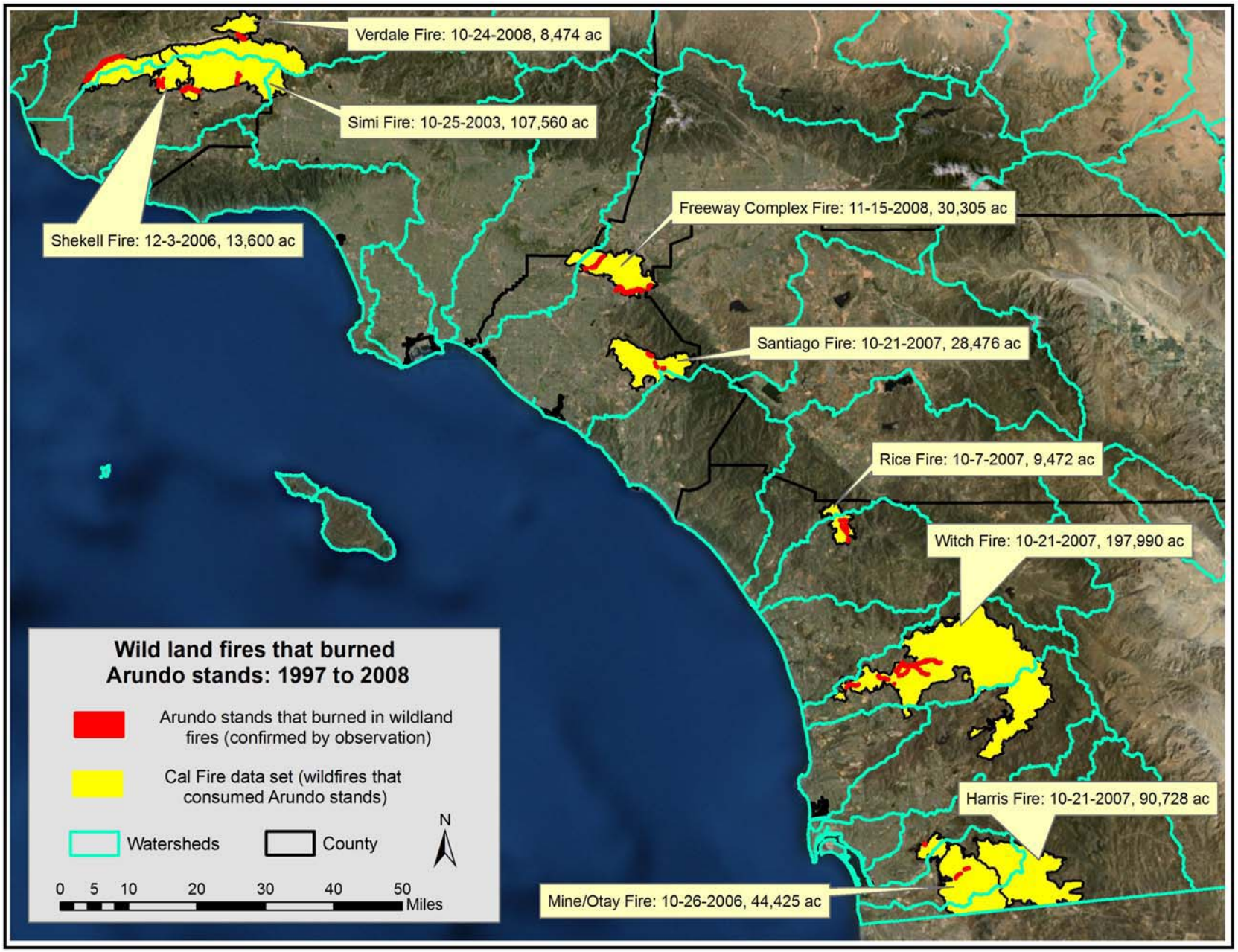


Figure 6-18. Location of wildland fires that burned *Arundo* stands within the project area from 1997 to 2008.

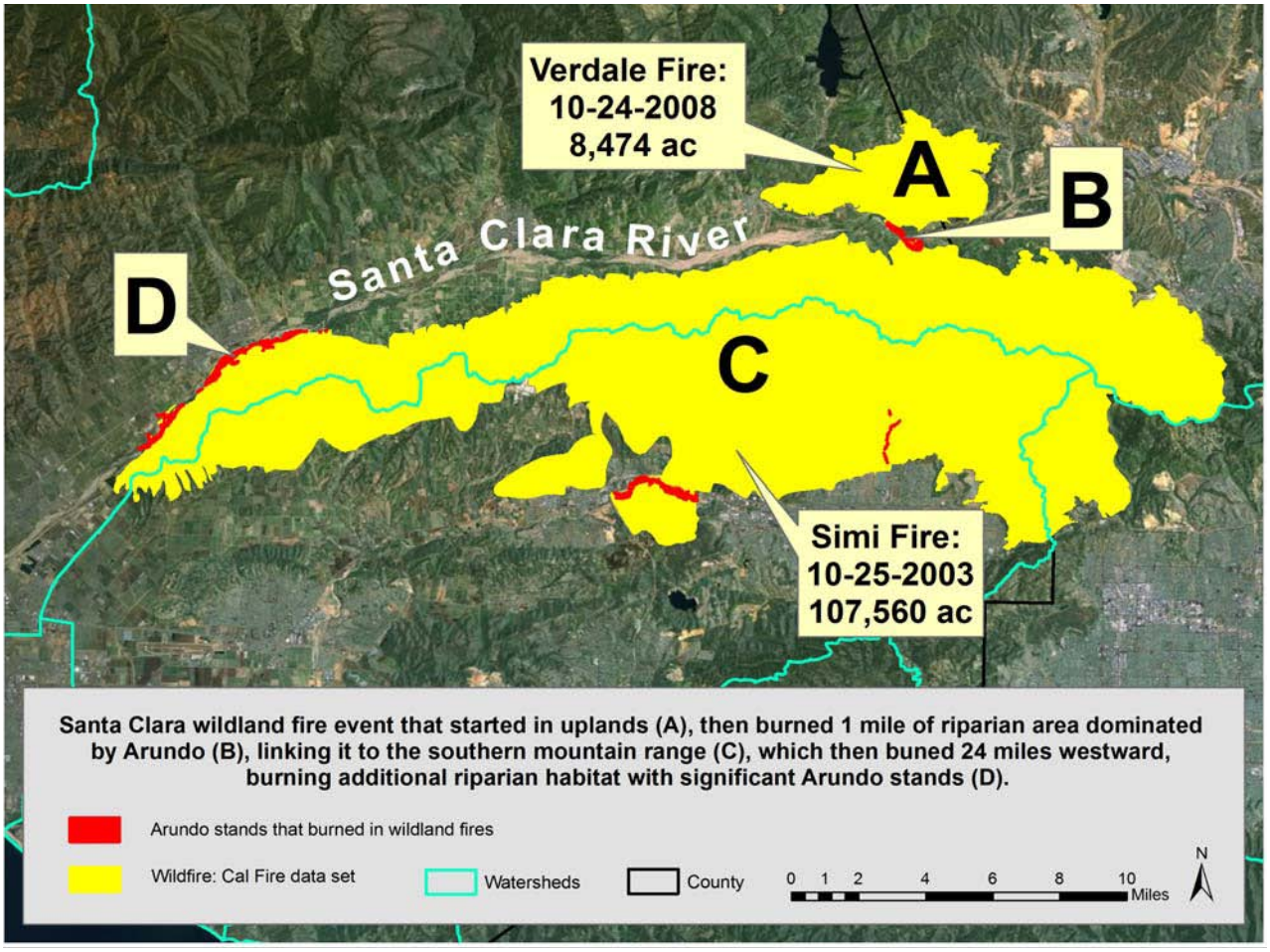


Figure 6-19. Wildfire on the Santa Clara with points A, B, C and D marked.

Conclusions:

- Watersheds with significant *Arundo* stands experience fire events that are due to the presence of *Arundo* (this study). The occurrence of these *Arundo*-initiated fires is quantifiable, both as percent of stands burned and acreage burned (this study).
- *Arundo* is a significant fire threat due to high fuel levels (Spencer et al. 2006, this study) in combination with harboring ignition sources. Fires that start in *Arundo* stands are observed on nearly all watersheds in the project area (this study).
- Wildland fires that burn riparian areas containing *Arundo* burn hotter and more completely due to higher fuel levels associated with the presence of *Arundo* (based on higher fuel loads – Spencer et al. 2006, this study).

Although fire was once a natural part of shrubland ecosystems that characterize the coastal southern California landscape, large riparian ecosystems provided natural firebreaks because native vegetation retains foliar water that resists ignition (Hanes 1971, Naveh 1975, Bell 1997, Rundel 1998, Keeley and Fotheringham 2001). This 'firebreak' function is lost if *Arundo* is present, and is even reversed, whereby riparian areas become 1) a fire source, or 2) a corridor of fire conveyance. Riparian ecosystems infested by *A. donax* adjacent to fire-prone shrublands in southern California appear to be on

a trajectory to an invasive plant-fire regime cycle (Brooks et al. 2004). Clearly wildland fires are burning *Arundo* stands in riparian areas. While it was not documented in this study, it is also likely that *Arundo*-initiated fires will lead to wildland fires given the frequency and intensity of *Arundo* fire events.

Fire Districts/Departments are keenly aware of the fire risks associated with *Arundo* stands. This led the City of Oceanside (San Luis Rey) to enact an ordinance under its code enforcement allowing action to be taken if private property has *Arundo* stands that are a fire risk. This action was driven by two factors: fires occurring in *Arundo* and the identification of wildland fire risk due to fires moving down *Arundo*-infested riparian corridors into urban areas.

6.5 Fire Impacts

In the previous section, it was established that *Arundo* impacts fire events in two general situations: fires that originate in *Arundo* stands (resulting from high fuel load combined with ignition sources) and wildland fires that burn *Arundo*-infested riparian habitat. This chapter will examine and quantify, based on the *Arundo* spatial data set, the impacts that these *Arundo*-driven fires cause.

6.5.1 Type Conversion to Arundo-Dominated Habitat

Arundo stands have high fuel loads and a tall growth form. Infestations of *Arundo* mixed with native species spread fire vertically into the canopy of riparian trees, as well as burning trunks (Figures 6-15 to 17 & 6-20; Ambrose and Rundel 2007). After a fire, *Arundo* immediately (1-2 weeks) begins regrowth from its rhizomes, whereas native riparian plants can remain dormant for several months. High mortality of native trees and shrubs is frequent in comparison to *Arundo*. Furthermore, *Arundo* grows much faster than native plants, up to 3-4 times faster than native riparian plants after fire on the Santa Clara River (Ambrose and Rundel 2007). A year after the fire, *Arundo* dominated the area, comprising 99% relative cover and a 24% increase in relative cover compared to pre-fire conditions (Ambrose and Rundel 2007).

Figure 6-20. *Arundo* one year after a fire, already 2-3 feet high, at the site of fire SLR #6.

A positive-feedback cycle is created whereby the high growth rate of *Arundo*, the fire adapted phenology of *Arundo*, and increased nutrient levels after fire contribute to type conversion. This domination by *Arundo*, in turn leads to more fires, creating an invasive plant-fire regime cycle (Ambrose and Rundel 2007, this study). Results from the mapping data also show that areas with mixed-*Arundo*/native vegetation prior to fire events are dominated by *Arundo* after the fires. This type conversion is important because it is a significant reduction in habitat value (section 7.1, Table 6-5). Fires started within *Arundo* combined with wildfires burned 12% (1,058 ac) of the *Arundo* acreage on all watersheds over a ten-year period (Table 6-7). Type conversion feeds the positive feedback loop. *Arundo*-dominated sites have higher biomass than mixed or patchy stands, increasing the likelihood of fire.

It should be noted that fire only affects within site spread/invasion. It does not allow or cause invasion to the broader system. Invasion outside the site still only occurs through movement of live plant material (flood action and/or human movement of rhizomes). However, the larger the *Arundo* sites, the more material there is for flood-based dispersal.

Table 6-7. Burned *Arundo* acreage from fires that start in *Arundo* and wildfires that burn *Arundo* (for one year and ten-year periods).
Acreages are calculated based on San Luis Rey watershed documented fire events, which is 0.8% of the gross *Arundo* acreage burned annually.

Watershed	Gross *Arundo* Acres	Fires that start in *Arundo*		Wildfires that burn *Arundo*		Combined *Arundo* fire totals	
		Burned *Arundo* acreage* (1 yr)	Burned *Arundo* acreage (10 yrs)	Burned *Arundo* acreage (1 yr)	Burned *Arundo* acreage (10 yrs)	Burned *Arundo* acreage (1 yr)	Burned *Arundo* acreage (10 yrs)
Calleguas	231.5	1.9	18.5	7.2	71.5	9.00	90.0
Carlsbad	147.9	1.2	11.8	-	-	1.18	11.8
Los Angeles River	132.8	1.1	10.6	-	-	1.06	10.6
Otay	18.6	0.1	1.5	0.1	0.5	0.20	2.0
Penasquitos	23.6	0.2	1.9	-	-	0.19	1.9
Salinas[1]	2,006.1	1.6	16.0	-	-	1.60	16.0
San Diego	150.2	1.2	12.0	-	-	1.20	12.0
San Dieguito	175.0	1.4	14.0	13.5	134.9	14.89	148.9
San Gabriel	44.6	0.4	3.6	-	-	0.36	3.6
San Juan	175.2	1.4	14.0	-	-	1.40	14.0
San Luis Rey	683.9	5.5	54.7	1.6	15.6	7.03	70.3
Santa Ana	2,723.9	21.8	217.9	9.6	95.7	31.36	313.6
Santa Clara	1,081.3	8.7	86.5	22.1	220.5	30.70	307.0
Santa Margarita [2,3]	688.9	0.6	5.5	-	-	0.55	5.5
Santa Monica	18.6	0.1	1.5	-	-	0.15	1.5
South Coast	29.8	0.2	2.4	-	-	0.24	2.4
Sweetwater	42.3	0.3	3.4	0.6	6.0	0.94	9.4
Tijuana	135.6	1.1	10.8	-	-	1.08	10.8
Ventura	332.0	2.7	26.6	-	-	2.66	26.6
Total:	**8,841.7**	**51.3**	**513.3**	**54.5**	**544.7**	**105.8**	**1,058.0**
% of Gross Ac:			**5.8%**		**6.1%**		**12%**

[1]Annual fire rate lowered to 10% of that for southern California due to weather conditions and lack of fire reports.
[2]Fires starting in *Arundo* are less common on Camp Pendleton (DoD facility), lowered to 10% for the watershed.
[3]Most *Arundo* had been removed in areas where wildfires burned riverine areas, so no acreage was counted.

6.5.2 Impacts to Fauna,

Fires that are started within *Arundo* stands and wildfires made worse by *Arundo* stands can result in direct mortality of fauna, especially species that cannot escape rapidly. Mortality will vary depending on the season in which the fire occurs. During nesting season, fires may result in direct loss of eggs and young birds. Arroyo toads remain buried during portions of the non-breeding season, and may not survive a fire, depending on the intensity. The addition of ash and other mobilized material (erosion) into breeding pools/ponds may impact fish and amphibians, and the loss of vegetation along waterways may impact shading and water temperature regulation.

After a fire, the habitat is degraded to a condition that does not support species for an amount of time that depends on the fire's intensity and season. One year of functional loss and a degraded condition for 2-5 years are evident on most sites. When the habitat does come back, it may not return to pre-fire conditions and may not be able to support the same abundance and diversity of fauna and flora. Areas that burned may be more open and have more weedy species. If *Arundo* was present before the fire, this is especially a concern, as it re-grows faster than the native species (see Sec 6.5.1).

The degradation of riparian habitat from *Arundo*-initiated fires is estimated for all watersheds based on data from San Luis Rey (Table 6-8). Riparian areas that burn during *Arundo*-initiated fires exceed the *Arundo* acreage that burns (705.8 ac vs. 513.3 ac). Suppression activities impact 32.1 acres of riparian habitat and 43.6 acres of *Arundo* habitat. Cumulatively this covers 1,200 acres of riparian habitat over a ten-year period. This is a significant amount of acreage and it does not include wildfire impacts.

Estimation of the *Arundo* acreage that burns is presented in Table 6-5. Wildfires can burn riparian vegetation during certain conditions, so the entire event cannot be ascribed as an *Arundo* fire impact. The presence of *Arundo* does increase the intensity, and *Arundo* may convey wildfires. These impacts are difficult to quantify and to identify spatially, complicating exploration of their impacts on flora and fauna. No specific accounting of these impacts is presented.

However, fires initiated *within Arundo* stands that result in mortality of fauna and flora are fully ascribed as impacts caused by the *Arundo*. Quantifying this presents challenges, but detailed mapping of fires on the San Luis Rey watershed (Section 6.4.1) present an opportunity to explore this. Very detailed survey data (aggregated from USGS, CalTrans, and ACOE) for least Bell's vireos, Southwestern willow flycatchers, and Arroyo toads indicate that *Arundo* fires that burn riparian habitat have directly impacted occupied habitat for endangered wildlife species (Figure 6-21, Table 6-9). These *Arundo*-dominated areas are of moderate habitat quality to begin with, but flora and fauna utilize pockets of native vegetation. *Arundo* fires can also spread into adjacent higher quality native riparian habitat. Fire suppression activities impact both *Arundo* and native habitat. The area of fires SLR#1, #2 and #3 is very near the mouth of the river, which is at the edge of least Bell's vireo habitat range. Least Bell's vireos were present on the edges of all the fire areas. Fire SLR#4 had least Bell's vireo use on the upstream edge of the fire area. Fire SLR#5 was a fire that occurred during breeding season in a high-use least Bell's vireo area. Mortality likely occurred. Arroyo toads could also have occurred on-site in low numbers. Site SLR#6 is in core, high density Arroyo toad habitat, and mortality likely occurred. Least Bell's vireo use could also occur in this area (only limited surveying was completed for this site, but they are abundant nearby).

In addition to direct take of fauna, habitat that was burned in all of the areas has a significantly reduced habitat value and function. Areas with *Arundo* present would have nearly 100% *Arundo* cover post-fire, while burned native vegetation takes over five years to recover structure and productivity.

Table 6-8. Summary of acreage impacted by burning and fire suppression from fires that start in *Arundo*.
Burned acreage and suppression acreage for watersheds is calculated based on San Luis Rey watershed-documented fire events (multiplying percentage from San Luis Rey by gross *Arundo* acreage for each watershed).

Fires that start in *Arundo*		**Fire: *Arundo***		**Fire: Riparian**		**Suppression: *Arundo***		**Suppression: Riparian**		**All Riparian Impacts**	
Watershed	**Gross *Arundo* Acres**	**Annual burn ac (0.8%)**	**10 year total**	**Annual burn ac (1.1%)**	**10 year total**	**Annual impacted ac (0.068%)**	**10 year total**	**Annual impacted ac (0.051%)**	**10 year total**	**Annual ac**	**10 year total**
Calleguas	231.5	1.9	18.5	2.5	25.5	0.2	1.6	0.1	1.2	4.7	46.7
Carlsbad	147.9	1.2	11.8	1.6	16.3	0.1	1.0	0.1	0.7	3.0	29.8
Los Angeles River	132.8	1.1	10.6	1.5	14.6	0.1	0.9	0.1	0.7	2.7	26.8
Otay	18.6	0.1	1.5	0.2	2.1	0.0	0.1	0.0	0.1	0.4	3.8
Penasquitos	23.6	0.2	1.9	0.3	2.6	0.0	0.2	0.0	0.1	0.5	4.8
Salinas[1]	2006.1	1.6	16.0	2.2	22.1	0.1	1.4	0.1	1.0	4.0	40.5
San Diego	150.2	1.2	12.0	1.7	16.5	0.1	1.0	0.1	0.8	3.0	30.3
San Dieguito	175.0	1.4	14.0	1.9	19.2	0.1	1.2	0.1	0.9	3.5	35.3
San Gabriel	44.6	0.4	3.6	0.5	4.9	0.0	0.3	0.0	0.2	0.9	9.0
San Juan	175.2	1.4	14.0	1.9	19.3	0.1	1.2	0.1	0.9	3.5	35.3
San Luis Rey	683.9	5.5	54.7	7.5	75.2	0.5	4.7	0.3	3.4	13.8	138.0
Santa Ana	2723.9	21.8	217.9	30.0	299.6	1.9	18.5	1.4	13.6	55.0	549.7
Santa Clara	1081.3	8.7	86.5	11.9	118.9	0.7	7.4	0.5	5.4	21.8	218.2
Santa Margarita [2]	688.9	0.6	5.5	0.8	7.6	0.0	0.5	0.0	0.3	1.4	13.9
Santa Monica	18.6	0.1	1.5	0.2	2.0	0.0	0.1	0.0	0.1	0.4	3.8
South Coast	29.8	0.2	2.4	0.3	3.3	0.0	0.2	0.0	0.1	0.6	6.0
Sweetwater	42.3	0.3	3.4	0.5	4.7	0.0	0.3	0.0	0.2	0.9	8.5
Tijuana	135.6	1.1	10.8	1.5	14.9	0.1	0.9	0.1	0.7	2.7	27.4
Ventura	332.0	2.7	26.6	3.7	36.5	0.2	2.3	0.2	1.7	6.7	67.0
Totals:	**8,841.7**	**51.3**	**513.3**	**70.6**	**705.8**	**4.4**	**43.6**	**3.2**	**32.1**	**129.5**	**1,294.8**

[1]Annual fire rate lowered to 10% of that for southern CA due to weather conditions and lack of fire reports.
[2]Fires starting in *Arundo* are less common on Camp Pendleton (DoD facility), lowered to 10% for the watershed.

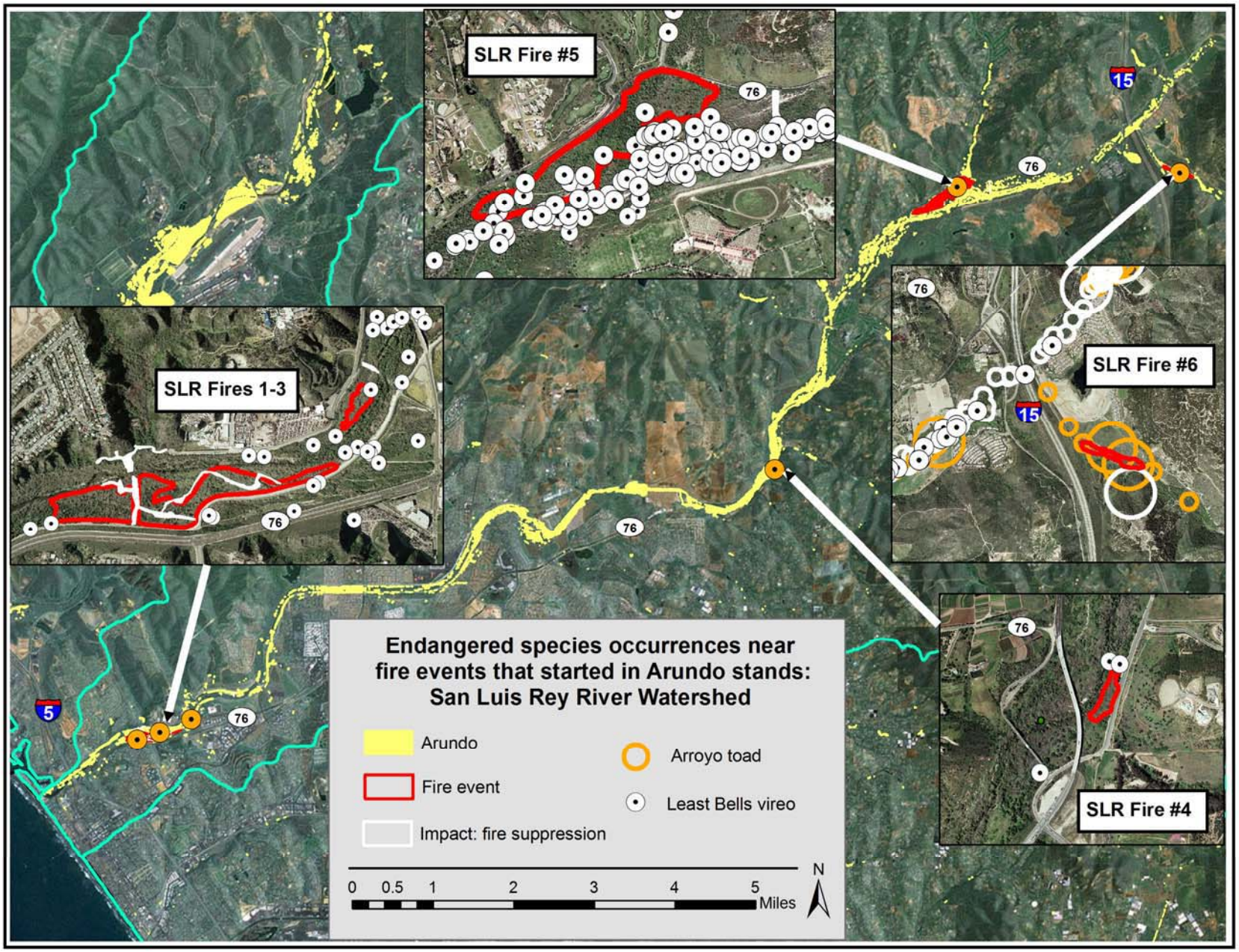


Figure 6-21. Fire events that started in *Arundo* stands on the San Luis Rey River showing sensitive species locations.

Table 6-9. Summary of San Luis Rey River *Arundo* fire impacts on federally endangered species.

Fire Event	Least Bell's vireo	Arroyo toad	Tidewater goby	Southwestern willow flycatcher
SLR#1,2&3	Low	None	Low	Possible
SLR#4	Medium	None	None	Possible
SLR#5	High	Low	None	Possible
SLR#6	Low	High	None	Possible

6.5.3 Impacts from Emergency Acts

Prior to or during fire events, actions are sometimes carried out to reduce the spread of a fire. These actions generally involve clearing vegetated areas to form fire breaks. These cleared areas tend to become weedy due to the disturbance of the soil and removal of established vegetation. If cleared areas are within or near *Arundo* stands, their creation may spread *Arundo* fragments throughout the area and establish new *Arundo* populations. Disturbed areas retain modified topography and poor quality habitat until there is a flow event that resets the geomorphology and allows native recruitment to occur. Depending on the location of the cleared area within the profile, this may occur quickly or after a prolonged period of time.

Emergency actions may also directly impact flora and fauna, as seen in Figure 6-21, where cleared areas were within least Bell's vireo (SLR#1,2,3 & 5) and arroyo toad habitat (SLR#5). The federally endangered plant *Ambrosia pumila* (San Diego ambrosia) also occurred near the disturbance on fire SLR#5.

Although acreage impacted seems minor at first, fire suppression impacts of 43.6 acres of *Arundo* and 32.1 acres of native riparian habitat (Table 6-8) are generated for the study area over 10 years. Many of these impacts are severe modifications (e.g. grading) of occupied threatened and endangered species' habitat.

6.6 Conclusions: Fire Impacts

Arundo significantly changes the intensity, frequency and behavior of fires. It has transformed heavily invaded riparian habitat, which includes many coastal river systems in southern California, from a vegetation type that is normally resistant to fire to a source of fire events. Areas invaded with *Arundo* are flammable, harbor ignition sources, and spread fires both within riparian habitat as well as across the landscape.

- *Arundo* stands are highly flammable throughout the year with large amounts of fuel (15.5 kg/m^2 of biomass), a large amount of energy (287.1 MJ/m^2), and a tall well-ventilated structure with dry fuels distributed throughout the height profile. (Section 6.1)
- Fires frequently start in *Arundo* stands. The primary ignition sources are transient encampments and discarded cigarettes from highway overpasses. (Section 6.1)

- *Arundo* stands strongly attract transient use (dense cover and shelter). This was documented throughout the study area with numerous high use locations noted in both urban and agricultural areas. (Section 6.3.1)
- Fires initiated in *Arundo* stands occur due to fuel and ignition source occurring at the same location. This is a newly defined class of fire events. (Section 6.4.1)
- Fires that are initiated in *Arundo* burn both *Arundo* stands and native riparian areas. In addition, suppression of fires also impacts riparian habitat. Impacts were calculated for all watersheds using San Luis Rey as a case study. Over a ten-year period for the study area, *Arundo*-initiated fire events are estimated to have burned 513 acres of *Arundo* and 706 acres of native riparian habitat. Fire suppression over a ten-year period has impacted 44 acres of *Arundo* and 32 acres of native riparian vegetation. (Section 6.5)
- Wildfires burn a significant acreage of *Arundo* stands. Over ten years, 11% of *Arundo* stands (544 acres) burned within the study area. (Section 6.4.2)
- Due to high fuel load and stand structure, areas with *Arundo* burn hotter and more completely then native vegetation during wildfire events. (Section 6.4.2)
- *Arundo* stands appear to be conveying fires across riparian zones- linking upland vegetation areas that would have been separated by less flammable riparian vegetation. This can have catastrophic impacts like those observed in the 2008 Simi fire. The 8,474-acre fire crossed the Santa Clara River and then burned an additional 107,560 acres. (Section 6.4.2)
- *Arundo* fires accelerate the dominance of *Arundo* in invaded areas due to rapid re-growth and low mortality of *Arundo*. (Section 6.5.1)
- *Arundo* fire events lead to both direct mortality of wildlife and plants (some of which are sensitive) as well as a longer-term quality reduction of burned riparian areas (post-fire recovery of vegetation and structure). (Section 6.5.2)
- Emergency actions tied to *Arundo* fire suppression also result in impacts (disturbance of both *Arundo* and riparian vegetation) that degrade riparian habitat and/or may result in mortality of species. (Section 6.5.4)

7.0 IMPACTS OF *ARUNDO*: Federally Endangered and Threatened Species

7.1 Examination and Characterization of *Arundo* Impacts on Flora and Fauna

Arundo's impacts on federally listed species will be evaluated and described. These species have been intensively studied with: documentation of distribution, assessment of stresses on their habitat, and identification of ecological constraints to their ability to persist in the habitats that they occupy. This allows a thorough exploration of impacts caused by *Arundo,* as well as the subjective ranking of the impact level. The determination of critical habitat areas and extensive survey data collected for the species also allows for a spatial assessment of their interaction with *Arundo* distribution at the watershed level (using the *Arundo* spatial data collected for this study). A total of 22 federally listed species will be examined representing five taxonomic groups: amphibians (4), birds (8), fish (4), mammals (1), and plants (5).

To determine the impacts of *Arundo* on federally listed species, we reviewed documents prepared by the U.S. Fish and Wildlife Service during their evaluations for listing and recovery. We restricted the focal species to federally listed species in order to 'standardize' the individual species descriptions and treatment (biology, reproduction, distribution, review of impacts and stresses). The documents used include: Critical Habitat Designations, Recovery Plans, Incremental Reviews (5 year, 10 year, etc.), and Biological Opinions (Section 7 and 10) issued for projects that may adversely impact listed species. A significant amount of the data presented in this chapter is taken directly from numerous Biological Opinions issued by the USFWS. Many of these Biological Opinions are for *Arundo* control programs on the watersheds within the study area, including: Salinas, Ventura, Santa Clara, Santa Ana, San Juan, Santa Margarita, San Luis Rey, Carlsbad CHU, and San Diego River. Additional Biological Opinions and documents prepared by NOAA/NMFS for programs carrying out activities (channel maintenance, sand extraction, etc.) in the project watersheds were also reviewed. These documents are a significant resource as they specifically examine: population status (distribution and abundance, sometimes trends), general biology (reproduction, foraging, movement/migration, predation, habitat needs), and stressors for the species (abiotic, biotic, and anthropogenic). Impacts caused by *Arundo* invasion are evaluated for each of these areas.

7.1.1 Determine Arundo Impact Score

Information from USFWS documents, this report, and other data, literature, and expert opinions was used to determine an 'Impact Score' for each species on a 10-point scale (Table 7-1). Impacts of *Arundo* on each sensitive species are described in Section 7.2, with evaluation of general ecological and habitat needs, reproduction, movement, range and other impacts/threats. Higher scores reflect significant *Arundo* impacts to both abiotic and biotic modification of riparian systems. A general discussion of *Arundo* impacts (both biotic and abiotic) is presented in section 2.7.

Table 7-1. *Arundo* Impact Score for each sensitive species.

Score	Impact Level	Impacts
10	Very severe	Very significant alteration of abiotic structure and biological function, and direct take of individuals
9	Severe	Significant alteration of abiotic structure and biological function and direct take of individuals
8	Very high	Alteration of abiotic structure and biological function, direct take possible
7	High	Alteration of abiotic structure and biological function: impacts on mobility
6	Moderate/High	Moderate alteration of abiotic structure and/or biological function
5	Moderate	Minor alteration of abiotic structure and/or biological function
4	Low/Moderate	Low abiotic or biotic impacts
3	Low	Slight changes in food resources, harboring pathogen/predator OR Minor changes to estuary systems
2	Very low	Minor interaction: mobility
1	Very low/Improbable	Difficult to describe any interaction with *Arundo*
0	None	No interaction

7.1.2 Determine Arundo and Federally Listed Species 'Overlap Score'

To characterize the level of interaction between each sensitive species and *Arundo*, a watershed specific 'Overlap Score' was created (Table 7-2). This metric measures the abundance and distribution of *Arundo* and the sensitive species, with a specific focus on overlap in spatial distribution. The score for the metric captures the level of interaction between *Arundo* and the listed species. The *Arundo* spatial data set was examined with GIS data for each listed species (Maps 1-30, Appendix B).

A listed species with large populations high on the watershed where *Arundo* does not occur would be ranked with a low score, even if the watershed has high *Arundo* abundance overall. A high metric score (10) requires frequent occurrence of the sensitive species within portions of the watershed that have high *Arundo* abundance. Low scores are given for species that have low occurrences within areas of low *Arundo* cover. Intermediate scores are given for co-occurrence, where there are moderate levels of abundance for *Arundo* and/or sensitive species. Species that occur at or near the end of the watershed may not have significant co-occurrence with *Arundo* stands, but they may have significant *Arundo* upstream of them that is modifying abiotic processes or generating *Arundo* biomass into the sensitive species habitat (*Arundo* debris, or modified hydrology). These interactions, which are often for estuarine or river mouth species, have a full range of overlap/interaction scores from low to high.

Table 7-2. Definition of overlap scores that are assigned to federally listed species.

Overlap Score	***Arundo* abundance** (nearby or upstream of sensitive species)	**Listed species *relative* abundance & distribution**	**Interaction Level**
10	Very High	Very high (core area)	High interaction
9	High	High	
8	High	Moderate	
7	Moderate	High	
6	Moderate	Moderate	Moderate interaction
5	Low	High	
4	High/Moderate	Low	
3	Low	Moderate	
2	Low	Low	Low interaction
1	Any	Historic range* or a few records of more 'abundant species	Possible or potential interaction
0	Any	Not recorded	No interaction

* Sensitive species not currently known to occur in the area, but has confirmed historic distribution.

7.1.3 Calculate 'Cumulative Arundo Impact Scores'

The 'Impact Score' for each species is then multiplied by the 'Overlap Score' on each watershed to generate a 'Cumulative *Arundo* Impact Score' for each sensitive species. This data can be examined for each species, taxonomic group, and watershed. Scores highlight species and those watersheds that are most impacted by *Arundo*.

7.2 Species Descriptions and *Arundo* Impacts Elucidated

Each federally listed species is evaluated below for potential impacts caused by *Arundo*. These impacts may be either indirect (modification of habitat) or direct (loss of life- such as fire or emergency response to fire or flood). All types of impacts are explored and relative importance/magnitude of the impact is described for each species. A general discussion of *Arundo* impacts (both biotic and abiotic) is presented in section 2.7.

Interaction of *Arundo* distribution and species occurrences is presented by watershed in Table 7-3 and Appendix B. Information on the biology and distribution of each species is taken from USFWS documents and other reports, which are listed at the end of each species' summary. Citations to particular studies within these documents are not listed here.

7.2.1 California Tiger Salamander (*Ambystoma californiense*)

Federal status: Endangered for the Santa Barbara Distinct Population Segment (September 2000). Critical habitat was designated in August 2005, but may change as it is under review.
State status: Threatened (May 2010).
Arundo impact score: 1

General Ecological Needs/Habitat Affinities:
The California tiger salamander is a stocky, terrestrial amphibian. Adult males are about 20 cm (8 in) long, and females a little less than 18 cm (7 in). It is restricted to grasslands and low foothill regions (typically below 2000 feet/610 meters) where lowland aquatic sites are available for breeding. They prefer natural ephemeral pools, or ponds that mimic them (e.g. stock ponds that are allowed to go dry). While on land they are generally underground in burrows. They are poor burrowers, therefore require refuges provided by ground squirrels and other burrowing mammals in which to enter a dormant state called *estivation* during the dry months.

Arundo impacts: *Arundo is not typically abundant on the low order streams and steeper hilly terrain that are favored by the tiger salamander. No significant alteration of abiotic process would occur.*

Breeding/Life History:
California tiger salamanders require lowland aquatic sites for breeding. They prefer natural ephemeral pools, or ponds that mimic them. Around November, salamanders come out of their burrows, usually on a wet, stormy night. They may travel as much as a mile to a pond to breed. They prefer natural ephemeral pools, or ponds that mimic them. Females lay eggs singly or in small groups. They may lay as many as 1,300 eggs. These are usually attached to vegetation. Eggs hatch in about 10 to 14 days. Larvae require significantly more time to transform into juvenile adults than other amphibians such as the western spadefoot toad and Pacific tree frog. Around late spring, salamanders leave the ponds to find burrows. Adults reach sexual maturity in 4 or 5 years. Although they may live as long as 10 years, they may reproduce only once, or not at all. Some salamanders die before they reach sexual maturity, and others may not find a suitable pond for mating in very dry years. The main predators of the California tiger salamander are birds such as egrets and herons, fish, and bullfrogs.

Arundo impacts: *Little impact as Arundo not abundant enough to impact hydrology of pools.*

Diet:
Adults mostly eat insects. Larvae eat algae, mosquito larvae, tadpoles and insects.

Arundo impacts: *Little impact as Arundo not abundant enough to impact food resources or habitat that food resources depend on.*

Movement:
A California tiger salamander spends most of its life on land underground. It uses burrows made by squirrels and other animals. Around November, usually on a wet night, salamanders come out of their burrows and may go as much as a mile to a pond to breed. In late spring, salamanders leave the ponds to find burrows.

Arundo impacts: *Little impact as Arundo not abundant enough to impact movement of salamanders or change distribution of mammals that create micro habitat needed by the species.*

Status/Distribution or Historic and Current Range:
This species is restricted to California and does not overlap with any other species of tiger salamander. They are found in grassland and oak savannah plant communities with vernal pools and/or seasonal ponds (including constructed stock ponds). They predominantly occur from sea level to 2,000 feet in central California. In the Coastal region, populations are scattered from Sonoma County in the northern San Francisco Bay Area to Santa Barbara County (up to elevations of 3,500 ft/1,067 m), and in the Central Valley and Sierra Nevada foothills from Yolo to Kern counties (up to 2,000 ft/610 m).

Arundo impacts: *There is very low interaction between Arundo distribution and salamanders. Critical areas have almost no overlap and occurrence data has a few points of interaction (Appendix B). Pajaro River in San Benito would be the greatest interaction and Salinas is very low (based on current Salinas survey data). If salamanders were found to occur in the Salinas River itself significant revision of impact scores would be needed.*

Decline and Threats:
The primary cause of the decline of California tiger salamander populations is the loss and fragmentation of habitat from human activities and the encroachment of non-native predators. All of the estimated seven genetic populations of this species have been significantly reduced because of urban and agricultural development, land conversion, and other human-caused factors. A typical salamander breeding population in a pond can drop to less than twenty breeding adults and/or recruiting juveniles in some years, making these local populations prone to extinction. California tiger salamanders therefore require large contiguous areas of vernal pools (vernal pool complexes or comparable aquatic breeding habitat) containing multiple breeding ponds to ensure re-colonization of individual ponds.

Arundo impacts*: No additional Arundo interaction with decline and threats.*

Overall impact metric for *Arundo* on CA tiger salamander: Very low/improbable impact, score of 1

Interaction of *Arundo* distribution and CA tiger salamander occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Species Account, California Tiger Salamander (*Ambystoma californiense)*, U.S. Fish & Wildlife Service Sacramento Fish & Wildlife Office.

7.2.2 Arroyo Toad (*Bufo californicus*)

Federal status:	Endangered, December 16, 1994. Critical habitat designated April 13, 2005. Recovery plan completed in 1999.
State status:	Not listed?
Arundo impact score:	10

General Ecological Needs/Habitat Affinities:
Arroyo toads breed and deposit egg masses in shallow sandy pools, which are usually bordered by sand-gravel flood-terraces. Optimal breeding habitat consists of low-gradient sections of slow-moving streams with shallow pools, nearby sandbars, and adjacent stream terraces. Stream order, elevation, and floodplain width appear to be important factors in determining habitat capacity. High stream order (i.e., 3rd to 6th order), low elevation (particularly below 3,000 ft/914 m) and wide floodplains seem to be positively correlated with arroyo toad population size. However, small populations are also found in 1st and 2nd order streams up to 4,600 ft (1,402 m). Outside the breeding season, arroyo toads are

essentially terrestrial and use a variety of upland habitats including (but not limited to): sycamore-cottonwood woodlands, oak woodlands, coastal sage scrub, chaparral, and grasslands.

Arundo impacts: *Changing geomorphic processes- rivers and streams move away from complex multi-channel structure with elevational complexity to a single narrow channel. The single channel is also deeper, typically transporting sediment out of the system under low flow events. Larger events also may not be generating as much sediment deposition in open areas. Because there are fewer open areas sediment is being trapped within Arundo stands which themselves have low arroyo toad use (Camp Pendleton management reports). Arundo has a very strong affinity for the same areas favored by arroyo toads: low elevation, broad floodplains and especially high stream order systems. Direct take of the species can occur during Arundo fire events and fire suppression efforts.*

Breeding/Life History:
Breeding is typically from February to July on streams with persistent water. Eggs are deposited and develop in shallow pools with minimal current and little to no emergent vegetation. Substrate is generally sand or fine gravel overlain with silt. Eggs hatch in 4-5 days, and hatchlings are immobile for 5-6 days. They then disperse from the pool margin into surrounding shallow water and develop for 10 weeks. After metamorphosis (typically June/July) the juvenile toads remain on the bordering gravel bars until the pool dries out (8-12 weeks, depending on site and rainfall/conditions).

Arundo impacts: *Arundo does not typically occur within pools/stream channel, but it may overhang pools/stream channel. Arundo does use large amounts of water, which could alter hydrology of the stream, potentially accelerating the dropping of the water table and the drying of pools. Arundo biomass in pools would likely be a negative impact. The greatest impact is that the system has fewer areas for pools to form. The areas that would be open/bar habitat are filled in with Arundo (Sections 5.1 & 2). This restricts pools to the narrow channel zone where pools are less likely to form. Pools that do form are also at greater risk of late season flow events that purge pools of egg masses and possibly even breeding adults.*

Diet:
Arroyo toad tadpoles feed on loose organic material such as algae, bacteria, and diatoms. They do not forage on macroscopic vegetation. Juvenile toads feed almost exclusively on ants. By the time they are 0.7 to 0.9 inch length they forage on beetles and ants. Adults consume a wide range of insects and arthropods.

Arundo impacts: *Arundo litter provides limited food for aquatic insects (Going & Dudley 2008) in comparison to native litter. This would reduce forage for aquatic insects which could be a food source for tadpoles. Decaying Arundo litter would be little nutritional value for insects. Arundo does support ants (particularly non-native argentine ants), but diversity and abundance is low for other arthropods (Herrera & Dudley 2003, Lovich et al. 2009). Arundo stands also are a barrier to toad movement and studies looking at toad use of Arundo showed little use, presumably indicating a low function for foraging.*

Movement: Arroyo toads have been observed moving one mile within the stream reach and 0.6 miles away from the stream into upland native habitat and agricultural areas. Movement may be regulated by topography and channel morphology. Toads are critically dependent on upland terraces and the marginal zone between stream channels and upland terraces during the non-breeding season, especially during periods of inactivity (generally late fall and winter). Toads generally burrow within sandy or loamy substrate with no associated canopy cover, within mulefat scrub, or within arroyo willow patches. The majority of individuals tracked in one study were located immediately adjacent to the active channel or within the bench habitats within the flood prone areas.

Arundo impacts: *Movement of toads both within and through the system is significantly restricted in highly invaded systems. Arundo can also be abundant in the area between the channel and terraces, filling open spaces in the habitat. This area is specifically noted as being a critical portion of the habitat for the first year toads. Chapter 5 demonstrates that this is where Arundo is most abundant and dense.*

Status/Distribution or Historic and Current Range:
Current estimated distribution is shown in Appendix B. Critical habitat areas have been designated. Survey data is of high quality in San Diego and Orange Counties and lower quality as one moves north. Santa Clara and Salinas in particular have not had substantial uniform survey work, but these areas do not have large populations (according to Biological Opinions). Distribution and abundance levels have been assessed from FWS data, CNDDB data, critical habitat areas, and verbal descriptions in USFWS Biological Opinions (all watersheds). Arroyo toads have disappeared from 75% of occupied habitat in California. Arroyo toads once occurred on 22 river basins from Monterey County (upper Salinas) to San Diego County southward to San Quintin, Baja CA, Mexico. In Orange and San Diego Counties the species occurred from estuaries to the headwaters of many drainages. Populations now are restricted to headwaters and small isolated populations along streams/rivers. The arroyo toad is principally along coastal drainages, although it has also been found on the desert facing slopes of San Gabriel and San Bernardino Mountains. Core populations occur on: Santa Margarita, San Luis Rey and San Juan Watersheds. Secondary watersheds are San Dieguito and Sweetwater. Additional smaller populations occur on San Diego, Los Angeles, Santa Clara and Salinas Watersheds.

Arundo impacts: *Arundo is abundant within core population areas as well as satellite populations. Arundo is less abundant in some of the more mountainous areas where toad populations occur. Significant overlap in Arundo and toad distribution exists (Table 7-3).*

Decline and Threats: Dam building and operation (modification of hydrologic regime and flushing events). Urban and agriculture development, sand and gravel mining. Impacts from vehicle and recreation activities. Non-native predators (bull frogs, fish, crayfish, etc.). Non-native plants (*Arundo* and tamarisk). Loss of habitat, modification of hydrology, and non-native predation have caused arroyo toads to disappear from a large portion of previously occupied habitat. Currently the greatest threats to arroyo toads are continued stream modification, development, and pressure from non-native organisms. Most systems have already had significant hydromodification.

Arundo impacts: *Arundo does interact with human hydromodification and flood management. Clearing of areas for reduced flood risk increases dispersal and spread of the plant. Reduced flow capacity and higher flood risk, exacerbated by Arundo stands, can lead to engineered solutions that contain and restrict flows.*

Overall impact metric for *Arundo* on Arroyo toad: Very severe impacts (10)

Interaction of *Arundo* distribution and occurrence of arroyo toads is presented by watershed in Table 7-3 and Appendix B.

Sources:
Arroyo toad (*Bufo californicus*) Five Year Review: Summary and Evaluation, U.S. Fish and Wildlife Service, Ventura, CA. August 2009. http://ecos.fws.gov/docs/five_year_review/doc2592.pdf

Stillwater Sciences. 2007. Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study.
Formal Section 7 Consultation for Invasive Plant Removal in the San Juan Hydrologic Unit, Orange County, CA, U.S. F&WS, Carlsbad Fish and Wildlife Office, Carlsbad, CA.

7.2.3 California Red-Legged Frog *(Rana aurora draytonii)*

Federal status: Threatened, May 23 1996. Critical habitat was first designated in 2001, but has been changed several times, with the most recent designation occurring in 2010.
State status: None
Arundo impact score: 3

General Ecological Needs/Habitat Affinities:

California red-legged frogs live from sea level to about 5,000 ft/1,524 m in California and Baja California, Mexico, and may be found in a variety of habitats. The frogs breed in aquatic habitats such as streams, ponds, marshes and stock ponds. Larvae, juveniles and adults have been collected from streams, marshes, plunge pools and backwaters of streams, dune ponds, lagoons, and estuaries. They frequently breed in artificial impoundments such as stock ponds, if conditions are appropriate. If riparian vegetation is present, red-legged frogs spend considerable time resting and feeding in it. The moisture and camouflage provided by the riparian plant community apparently provides good foraging habitat and may facilitate dispersal in addition to providing pools and backwater aquatic areas for breeding. Frogs may move through upland habitats, primarily in wet weather. For the California red-legged frog, suitable habitat is potentially all aquatic and riparian areas within the range of the species and includes any landscape features that provide cover and moisture.

The riparian and upland habitats adjacent to aquatic areas used by the California red-legged frog are essential in maintaining frog populations, and for protecting the appropriate hydrological, physical, and water quality conditions of the aquatic areas. The frog uses both riparian and upland habitats for foraging, shelter, cover, and non-dispersal movement. One researcher who studied California red-legged frog's terrestrial activity in coastal forest and grassland habitats recommends at least a 328 ft (100m) buffer zone for protection of adjacent aquatic and upland habitat, as well as seasonal restrictions for activities within this zone. In a recent study also specific to the California red-legged frog, the recommendation was for establishing zones around breeding habitat, non-breeding habitat, and migration corridors that are sufficient to protect function of the amphibian habitat. However, the study authors discourage setting specific distances for these zones due to differences in biological or site-specific requirements; they further state that any distances set for avoidance of upland habitat should be made on a case-by-case basis, taking into account the need to protect breeding and non-breeding habitat as well as any migration corridors. Without protecting and maintaining the upland areas surrounding breeding and non-breeding habitats the quality of the water feature may deteriorate to such an extent as to not support the California red-legged frog.

Arundo impacts: *Red legged frogs have very wide distribution among habitat types but tend to occur in steeper terrain than Arundo. Arundo is typically not abundant enough to alter abiotic factors that would severely degrade frog habitat.*

Breeding/Life History:
Red-legged frogs breed from November through March, though earlier breeding has been recorded in southern localities. Males appear at breeding sites 2-4 weeks prior to females. Females deposit egg

masses on emergent vegetation so that the masses float on the surface of the water. Eggs hatch in 6 to 14 days, and larvae undergo metamorphosis 3.5 to 7 months after hatching. Sexual maturity is attained at 2 years by males and 3 years by females. Adults may live 8 to 10 years, although the average life span is considered much lower.

Arundo impacts : *Impacts would be minor as breeding pools are not usually in close proximity to Arundo stands. Arundo is not abundant enough to alter hydrology and pool duration.*

Diet:
The diet of the red-legged frog is highly variable. Tadpoles probably eat algae, and invertebrates seem to be the most common food of adults. Larger frogs can eat vertebrates such as Pacific chorus frogs and California mice. Feeding activity probably occurs along the shoreline and on the surface of the water. Juveniles have been found to be active diurnally and nocturnally, but adults are largely nocturnal.

Arundo impacts: *Minor impacts, if any, as Arundo is not abundant enough to typically affect abundance of food resources.*

Movement:
Juvenile and adult California red-legged frogs may disperse long distances from breeding sites throughout the year. They can be encountered living within streams at distances exceeding 1.8 miles from the breeding site, and have been found up to 400 feet from water in adjacent dense riparian vegetation. During period of wet weather, some individuals may make overland excursions through upland habitats, mostly at night. In Santa Cruz County, red-legged frogs made overland movements of up to 2 miles over the course of a wet season. Most of these long-distance movements were over variable upland terrain. Adult California red-legged frogs may disperse from breeding sites at any time of year depending on habitat availability and the environmental conditions of the aquatic habitat. In addition, a few frogs may disperse long distances in search of additional breeding or non-breeding habitat.

Arundo impacts: *Low likely hood of impact except on Ventura River watershed where dense Arundo stands could impede movement (as seen with arroyo toads).*

Status/Distribution or Historic and Current Range:
The current distribution of the red-legged frog is primarily in the coastal drainages of central California. Today, only 28 counties have known populations. Monterey, San Luis Obispo and Santa Barbara counties have the greatest amount of currently occupied habitat. Only four areas within the entire historic range of this species may currently harbor more than 350 adults.

Arundo impacts: *Arundo does have some overlap in distribution (Appendix B). Arundo is not usually abundant in these areas- particularly on smaller size watersheds, but localized high Arundo cover can exist and could lead to impacts (fire, limited movement, impacts to breeding pools). A significant noted exception occurs on Ventura River watershed where dense Arundo overlaps with core population areas.*

Decline and Threats:
The frog and its habitat are threatened by a multitude of factors including but not limited to:
1) Degradation and loss of habitat through urbanization, mining, improper management of grazing, recreation, invasion of nonnative plants, impoundments, water diversions and degraded water quality, 2) Introduced predators, such as bullfrogs, and 3) Previous overexploitation.

Historically, the California red-legged frog was found in 46 counties. The range was thought to extend coastally from Sonoma County (but recently has been confirmed further north in Mendocino County)

and inland from the vicinity of Redding, Shasta County, south to northwestern Baja California, Mexico. The frog has sustained a 70 percent reduction in its geographic range in California as a result of habitat loss and alteration, overexploitation, and introduction of exotic predators.

Arundo impacts: *Little interaction between Arundo and these factors.*

Overall impact metric for *Arundo* on California red-legged frog: Low impact, score of 3.

Interaction of *Arundo* distribution and CA red-legged frog occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

Biological and Conference Opinions for Annual Removal of Giant Reed and Tamarisk in Upper Santa Clara River Watershed, Los Angeles county, CA (File No. 2004-01540-AOA)(1-8-06-F-5).

Endangered and Threatened Wildlife and Plants; Revised Designation of Critical Habitat for the California Red-Legged Frog: Final Rule. 50 CFR Part 17 [FWS-R8-ES-2009-0089], U.S. Fish and Wildlife Service.

7.2.4 Mountain Yellow-Legged Frog (*Rana muscosa*)

Federal status:	Endangered (Southern California DPS July 2 2002), Endangered Candidate List (frogs occurring north of the Tehachapi Mountains). Critical habitat for the southern California DPS designated on September 14 2006.
State status:	Candidate species
Arundo impact score:	4

General Ecological Needs/Habitat Affinities:

Mountain yellow-legged frogs live in glaciated alpine lakes, ponds, tarns, springs, and streams. Lakes used usually have grassy or muddy margins, and adults are typically found sitting on wet rocks along the shoreline, usually where there is little or no vegetation. Field research conducted by USGS and the San Diego Zoo within the current and historic range of the mountain yellow-legged frog in the San Jacinto, San Bernardino, and San Gabriel mountains has been carried out to improve understanding of habitat preferences of this species. Results indicate that adult frogs prefer deep, long, pools with little understory and ample leaf litter. Tadpoles also were more likely to be found in pools with less understory and more leaf litter, but showed no preference for pool depth or length. They did, however, demonstrate a preference for pools with rock substrate. Mountain yellow-legged frogs have been observed in the field basking in direct sunlight, sometimes in aggregations of more than 20. It is hypothesized that frogs aggregate to reduce the surface area exposed to the air and thus reduce water loss. Suitable habitat for mountain yellow-legged frogs presumably must include appropriate basking structures

Arundo impacts: *Low level of Arundo impacts due to little overlap in range. Frogs are restricted to higher elevations in general. But overlap in occurrence in two areas create the potential for interaction (Los Angeles River, in the San Gabriel Mountains and Santa Ana River in San Bernardino Mountains). Frogs appear to prefer little vegetative cover- Arundo would therefore be negatively associated with prime habitat.*

Breeding/Life History:

Breeding sites are generally located in, or connected to, lakes and ponds that do not dry up in the summer, and that are sufficiently deep not to freeze through in winter. The frogs breed in June or July.

Eggs hatch within several weeks and larvae usually transform during July or August. Larvae at high elevations, or subject to severe winters, may not metamorphose until the end of their fourth summer. Adults hibernate in water during the coldest months, under ice or near shore under ledges and in underwater crevasses.

Arundo impacts: *Arundo may add to water stress in foothill washes shortening pool duration.*

Diet:
Adults feed on terrestrial insects and adult aquatic insects: beetles, flies, wasps, bees, ants, true bugs, and spiders. They also consume large quantities of Yosemite toad and Pacific treefrog tadpoles and can be cannibalistic. Tadpoles graze on algae and diatoms along rocky bottoms of streams, lakes, and ponds.

Arundo impacts: *Limited impacts to food resources.*

Movement:
This species has no distinct breeding migration, as adults are almost always found within two to three feet of water. In some areas, there is a seasonal movement of frogs from deeper lakes to nearby breeding areas after overwintering. Frogs typically move less than a few hundred meters.

Arundo impacts: *Limited impacts to movement- very localized at stream/pool edges.*

Status/Distribution or Historic and Current Range:
Once common throughout much of southern California, the mountain yellow-legged frog has been decreasing in numbers since the 1970s. The frog lives in the Sierra Nevada Mountains of California and Nevada from southern Plumas County to southern Tulare County, at elevations mostly above 6,000 feet. A genetic study published in 2007 revealed that there are two distinct mountain yellow-legged frog species that do not overlap in range or interbreed: a northern and central Sierra Nevada species and a southern Sierra Nevada and southern California species. In southern California, only a small wild population of less than 200 individuals can be found in the San Gabriel, San Bernardino, and San Jacinto Mountains. For the first time in April 2010, scientists reintroduced its eggs to its former habitat at University of California Riverside's James San Jacinto Mountains Reserve.

Arundo impacts: *The frogs have isolated small populations (Appendix B). The fact that several of the San Gabriel Mountain populations co-occur with Arundo is of concern. Impacts related to water use, shading, and the frogs' preference for less vegetated pools indicates that Arundo is likely a minor to moderate stressor on habitat fitness. Arundo could become a more pronounced impact if it continued to increase in abundance at sites where overlap in ranges occurs.*

Decline and Threats:
These frogs are threatened by predation by introduced trout, pesticides, environmental changes from drought and global warming, disease, and habitat degradation due to livestock grazing. More than 93 percent of northern and central Sierra Nevada populations, and more than 95 percent of southern Sierra Nevada and southern California populations, are already extinct.

Arundo impacts: *Little interaction with other stressors- but the species very tenuous persistence makes low to moderate levels of impacts already outlined potentially significant for the species especially for isolated southern CA populations.*

Overall impact metric for *Arundo* on mountain yellow-legged frog: Low/Moderate impact (4)

Interaction of *Arundo* distribution and mountain yellow-legged frog occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
USGS, Mountain yellow-legged frogs reintroduced to wild 4/16/2010.
Mountain Yellow-legged Frog Update, Mountain Yellow-legged Frog Captive Breeding 2009 Annual Report, San Diego Zoo.
Species Profile for the Mountain Yellow-Legged Frog, U.S. Fish & Wildlife Service.

7.2.5 Western Snowy Plover (*Charadrius alexandrinus nivosus*)

Federal status: Threatened, March 1993. Critical habitat designated September 2005. Recovery Plan published in 2007.
State status: Species of special concern
Arundo impact score: 5

General Ecological Needs/Habitat Affinities:
The Pacific coast population of the western snowy plover breeds primarily above the high tide line on coastal beaches, sand spits, dune-backed beaches, sparsely-vegetated dunes, beaches at creek and river mouths, and salt pans at lagoons and estuaries. This habitat is unstable because of unconsolidated soils, high winds, storms, wave action, and colonization by plants. Less common nesting habitats include bluff-backed beaches, dredged material disposal sites, salt pond levees, dry salt ponds, and river bars. In winter, western snowy plovers are found on many of the beaches used for nesting as well as on beaches where they do not nest, in man-made salt ponds, and on estuarine sand and mud flats.

Arundo impacts: *Arundo is typically not abundant in beach and estuary habitats (although it can develop into large stands if left to persist there). The major impacts from Arundo are related to biomass accumulating in these areas. Additionally there may be impacts to sediment transport (Chapter 5) which could be effecting beach and estuaries. These impacts are speculative but possible given Arundo strong effect of fluvial and processes. Plovers have strong preference for river mouths and estuaries in comparison to beach areas along bluffs (Appendix B).*

Breeding/Life History:
The Pacific coast population of the western snowy plover breeds primarily on coastal beaches from southern Washington to southern Baja California, Mexico. Nesting western snowy plovers at coastal locations consist of both year-round residents and migrants. Migrants begin arriving at breeding areas in central California as early as January, although the main arrival is from early March to late April. Since some individuals nest at multiple locations during the same year, birds may continue arriving through June. In California, pre-nesting bonds and courtship activities are observed as early as mid-February. Eggs are laid in scrapes (depression in the sand or other substrate created by the male). The earliest nests on the California coast occur during the first week of March in some years and by the third week of March in most years. Peak initiation of nesting is from mid-April to mid-June. Nests typically occur in flat, open areas with sandy or saline substrates; vegetation and driftwood are usually sparse or absent. In southern California, western snowy plovers nest in areas with 6 to 18 percent vegetative cover and 1 - 14 % inorganic cover; vegetation height is usually less than six centimeters (2.3 inches).
Nests consist of a shallow scrape or depression, sometimes lined with beach debris (*e.g.*, small pebbles, shell fragments, plant debris, and mud chips); nest lining increases as incubation progresses. Driftwood, kelp, and dune plants provide cover for chicks that crouch near objects to hide from predators. Although driftwood is an important component of western snowy plover habitat, too much driftwood on a beach, which may occur after frequent and prolonged storm events, can be detrimental if there is not sufficient open habitat to induce the birds to nest. In southern California nests are usually located within 328 ft

(100 m) of water, which could be either ocean, lagoon, or river mouth. Invertebrates are often found near debris, so driftwood and kelp are also important for harboring western snowy plover food sources. Hatching lasts from early April through mid-August, with chicks reaching fledging age approximately one month after hatching. Fledging of late-season broods may extend into the third week of September throughout the breeding range.

Arundo impacts: *Arundo biomass significantly degrades nesting habitat by covering open sandy substrate. Additional impacts are outlined in FWS BO's: In some areas of California, such as the Santa Margarita River in San Diego County, and the Santa Clara and Ventura Rivers in Ventura County, giant reed has become a problem along riparian zones. During winter storms, giant reed is washed downstream and deposited at the river mouths where western snowy plovers nest. Large piles of dead and sprouting giant reed eliminate nesting sites and increase the presence of predators, which use it as perches and prey on rodents in the piles of vegetation.*

Diet:
Western snowy plovers are primarily visual foragers, using the run-stop-peck method of feeding. They forage on invertebrates in the wet sand and amongst surf-cast kelp within the intertidal zone, in dry sand areas above the high tide, on salt pans, on spoil sites, and along the edges of salt marshes, salt ponds, and lagoons. They sometimes probe for prey in the sand and pick insects from low-growing plants. Western snowy plover food consists of immature and adult forms of aquatic and terrestrial invertebrates.

Arundo impacts: *Arundo debris and stands reduce habitat quality for food (invertebrates); impacts feeding as well as foraging for prey.*

Movement:
While some western snowy plovers remain in their coastal breeding areas year-round, others migrate south or north for winter. In Monterey Bay, California, 41 % of nesting males and 24 % of the females were consistent year-round residents. At Marine Corps Base Camp Pendleton in San Diego County, California, about 30 % of nesting birds stayed during winter. The migrants vacate California coastal nesting areas primarily from late June to late October.

Arundo impacts: *Arundo debris piles limit movement of young.*

Status/Distribution or Historic and Current Range:
The Pacific coast population is defined as those individuals that nest within 50 miles of the Pacific Ocean on the mainland coast, peninsulas, offshore islands, bays, estuaries, or rivers of the United States and Baja California, Mexico. By the late 1970s, nesting western snowy plovers were absent from 33 of 53 locations with breeding records prior to 1970. By 2000 populations had declined further to 71 % of the 1977-1980 levels along the California coast and 27 % of the 1977-1980 levels in San Francisco Bay. However, since then populations have grown substantially, roughly doubling along the coast while fluctuating irregularly in San Francisco Bay. Recent population increases along the coast have been associated with implementation of management actions for the benefit of western snowy plovers and California least terns, including predator management and protection and restoration of habitat.

Arundo impacts: *Arundo is abundant on several key watersheds that support plover populations (Appendix B).*

Decline and Threats:
Habitat degradation caused by human disturbance, urban development, introduced beachgrass (*Ammophila* spp.), and expanding predator populations have resulted in a decline in active nesting areas and in the size of the breeding and wintering populations.

Arundo impacts: *As indicated Arundo stands are correlated with predation as predators use stands for perching in nesting areas.*

Overall impact metric for *Arundo* on the Western snowy plover: Moderate, score of 5.

Interaction of *Arundo* distribution and the Western snowy plover's occurrence is presented by watershed in Table 7-3.

Sources:

Recovery Plan for Pacific Coast Population of the Western Snowy Plover, USFWS, 2001 http://www.fws.gov/arcata/es/birds/WSP/documents/RecoveryPlanWebRelease_09242007/WSP%20Final%20RP%2010-1-07.pdf

Powell, A.N., J.M. Terp, C.L. Collier, and B.L. Peterson. 1997. The status of western snowy plovers (*Charadrius alexandrinus nivosus*) in San Diego County, 1997. Report to the California Department of Fish and Game, Sacramento, CA, and U.S. Fish and Wildlife Service, Carlsbad CA, & Portland OR.

7.2.6 Western Yellow-Billed Cuckoo (*Coccyzus americanus*)

Federal status: Species of Concern
State status: Endangered
Arundo impact score: 7

General Ecological Needs/Habitat Affinities:
Western yellow-billed cuckoos typically inhabit densely foliated, stands of deciduous trees and shrubs, particularly willows, with a dense understory formed by blackberry, nettles, and/or wild grapes, adjacent to slow-moving watercourses, backwaters, or seeps. River bottoms and other mesic habitats, including valley-foothill and desert riparian habitats, are necessary for breeding. Dense low-level or understory foliage with high humidity is preferred. Field studies and habitat suitability modeling have concluded that vegetation type (*e.g.*, willow scrub and cottonwood-willow forest), patch size, patch width, and distance to water are important factors determining the suitability of habitat for yellow-billed cuckoo breeding. Patch size is an important variable determining presence of cuckoos in California, with a trend toward increasing occupancy with increased patch size. Few cuckoos have been found in forested habitat of less than 25 acres. Willow-cottonwood habitat patches greater than 1,970 ft (600 m) in width were found to be optimal, and typically anything less than 328 ft (100 m) is unsuitable.

Arundo impacts: *Arundo and cuckoos both prefer broad river bottoms creating a significant interaction between the species. Cuckoos prefer well-developed riparian habitat that is dense with large gallery trees. Arundo displaces native vegetation and fires generate create younger serial stages that cuckoos do not prefer or utilize as habitat.*

Breeding/Life History:
Western cuckoos breed in large blocks of riparian habitats, particularly woodlands with cottonwoods (*Populus fremontii*) and willows (*Salix* spp.). Dense understory foliage appears to be an important factor in nest site selection, while cottonwood trees are an important foraging habitat in areas where the species has been studied in California. Clutch size is usually two or three eggs, and development of the young is very rapid, with a breeding cycle of 17 days from egg-laying to fledging of young. Although yellow-billed cuckoos usually raise their own young, they are facultative brood parasites, occasionally laying eggs in the nests of other yellow-billed cuckoos or of other bird species. Males and females reach

sexual maturity the first year after hatching. Chicks are able to fly between 17 and 21 days after hatching and within a few weeks will migrate to South America.

Arundo impacts: *Arundo significantly degrades habitat by impacting lager mature trees (fire) and displacing the dense native understory vegetation. Arundo fragments and degrades riparian habitat through fire and swaths of low value habitat isolating higher quality patches.*

Diet:
More than 75 % of the yellow-billed cuckoo's diet is comprised of grasshoppers and caterpillars, though the species has been known to eat other insects such as beetles, cicadas, wasps, flies, katydids, dragonflies, and praying mantids.

Arundo impacts: *Arundo provides none of the preferred food sources and displaces native vegetation- particularly native willows and cottonwoods that are habitat for mourning cloak butterfly and caterpillars.*

Movement:
Cuckoos leave North America in August and head to their wintering grounds in northwestern Costa Rica, Panama, and west of the Andes in Columbia, Ecuador, and Peru. It is believed that western cuckoos migrate primarily to southern Central America, remaining along the Pacific, and down into northwestern South America, remaining west of the Andes.

Arundo impacts: *No impact to migration. Movement within habitat is impacted.*

Status/Distribution or Historic and Current Range:
Yellow-billed cuckoos occur in the western United States as a distinct population segment (DPS). The area for this DPS is west of the crest of the Rocky Mountains. In California prior to the 1930s, the species was widely distributed in suitable river bottom habitats, and was locally common. It is estimated that in California the species' range is now about 30 % of its historical extent. Studies since the 1970s indicate that there are fewer than 50 breeding pairs in all of California. Given that only Santa Ana and Santa Clara have had reported sightings since 1989, it is possible that the species may become or is already functionally extirpated from Southern California. Sightings may be individuals migrating to the South Fork of the Kern River or the Sacramento River.

Arundo impacts: *Arundo* is abundant on the two watersheds with cuckoo occurrence data collected since 1989; all other occurrence data is from the 1970s or late 1800s/early 1900s (Los Angeles region- Appendix B).

Decline and Threats:
Adequate patch size and loss of habitat are the primary threats to western yellow-billed cuckoo populations. Principal causes of riparian habitat losses are conversion to agricultural and other uses, dams and river flow management, stream channelization and stabilization, and livestock grazing. Available breeding habitats for cuckoos have also been substantially reduced in area and quality by groundwater pumping and the replacement of native riparian habitats by invasive non-native plants, particularly tamarisk and *Arundo*. Fragmentation effects include the loss of patches large enough to sustain local populations, leading to local extinctions, and the potential loss of migratory corridors, affecting the ability to recolonize habitat patches. Much of the catastrophic decline of the cuckoo in California has been directly attributed to breeding habitat loss from clearing and removal of huge areas of riparian forest for agriculture, urban development and flood control (see chapter 5.3- historic trends of geomorphology, particularly the loss of terraces, where mature gallery forest would occur). Another likely factor in the loss and modification of the yellow-billed cuckoo is the invasion by exotic tamarisk

(*Tamarisk* spp.) and *Arundo*. The spread and persistence of tamarisk and *Arundo* has resulted in significant changes in riparian plant communities. In monotypic tamarisk and *Arundo* stands, the most striking change is the loss of community structure. The multi-layered community of herbaceous understory, small shrubs, middle-layer willows, and over-story deciduous trees is often replaced by one monotonous layer. Plant species diversity has declined in many areas and relative species abundance has shifted in others. Other effects include changes in percent cover, total biomass, fire cycles, thermal regimes, and perhaps insect fauna. Conversion to tamarisk or *Arundo* typically coincides with reduction or complete loss of bird species strongly associated with cottonwood-willow habitat including the yellow-billed cuckoo

Overall impact metric for *Arundo* on the Western yellow-billed cuckoo: High impact, score of 7.

Interaction of *Arundo* distribution and the Western yellow-billed cuckoo's occurrence is presented by watershed in Table 7-3 and Appendix B. Note that although there is high impact to habitat function for the species- the species is only present as 'historic occurrences' on most watersheds. Santa Ana and Santa Clara still have periodic sightings. These watersheds score high in relative abundance: there are not many sightings but these are a large proportion of sightings for the species. It is not locally abundant anywhere.

Sources:

U.S. Fish and Wildlife Service Species Assessment and Listing Priority Assignment Form for: *Coccyzus americanus* (Yellow-billed Cuckoo), Western United States Distinct Population Segment. http://ecos.fws.gov/docs/candforms_pdf/r8/B06R_V01.pdf

Stillwater Sciences. 2007. Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study.

7.2.7 Southwestern Willow Flycatcher (*Empidonax trailii extimus*)

Federally status: Endangered, February 1995. Critical habitat designated October 2005. Final recovery plan completed August 2002.
State status: Endangered, January 1991.
Arundo impact score: 8

General Ecological Needs/Habitat Affinities:
The southwestern willow flycatcher occurs in riparian woodlands along streams and rivers with mature, dense stands of willows (*Salix* spp.), cottonwoods (*Populus* spp.), or smaller spring fed areas with willows or alders (*Alnus* spp.). Riparian habitat is used for both foraging and breeding.

Suitable habitat typically consists of the following habitat features: 1) Nesting habitat with trees and shrubs that include, but are not limited to, willow (*Salix* spp.) species and boxelder (*Acer negundo*), 2) Nesting habitat with a dense (*i.e.*, 50- 100 %) tree and/or shrub canopy, 3) Dense riparian vegetation with thickets of trees and shrubs, 4) Dense patches of riparian forest interspersed with small areas of open water or marsh, creating a mosaic; patch size may be as small as 0.25 ac or as large as 175 ac.

Arundo impacts: *Arundo displaces native vegetation forming monotypic stands or co-occurring with native woody vegetation. Both of these situations degrade habitat value. Abiotic system changes caused by Arundo related to fire and more frequent flooding degrade habitat value by creating more areas with early serial stages.*

Breeding/Life History:
Nests are typically placed in even-aged, structurally homogeneous and dense plant communities. They usually nest in the upright fork of a shrub, but occasionally nest on horizontal limbs within trees and shrubs. Historically the flycatcher nested primarily in willows and mulefat (*Baccharis salicifolia*) with a scattered overstory of cottonwood. With changes to riparian plant communities, they still nest in willows where available, but are also known to nest in thickets dominated by the non-native shrub tamarisk (*Tamarix* species) and Russian olive (*Elaeagnus angustifolia*). Males typically arrive in California at the end of April and females arrive approximately one week later. They have a home range that is larger than the defended territory. Territorial defense usually begins in late May. Territory size varies from 0.25 to 5.7 acres, with most in the range between 0.5 and 1.2 aces. They typically raise one brood per year, with a clutch size usually 3-4. The fledglings leave the nest at age 12-15 days in early July, and usually disperse from the natal territory at age 26-30 days. In southern California flycatchers usually leave the breeding grounds by the end of August, and it is exceeding scarce in the United States after mid-October.

Arundo impacts: *Arundo degrades habitat quality as it displaces vegetation with suitable nesting structure.*

Diet:
The southwestern willow flycatcher is an insectivore that forages within and above dense riparian vegetation, taking insects on the wing or gleaning them from foliage. They may also forage in areas adjacent to nest sites which may be more open. They are active diurnally.

Arundo impacts: *Arundo appears to have little foraging value for the southwestern willow flycatcher as it supports a reduced diversity and abundance of aerial insects compared to native vegetation (Herrera & Dudley 2003). Arundo displaces vegetation that supports food species.*

Movement:
Males usually arrive in California at the end of April, and females about a week later. They generally leave in August. The migration routes and destination of the willow flycatcher are not well known. The flycatcher most likely winters in Mexico, Central America and perhaps northern South America, however, the habitat is uses as wintering grounds are unknown.

Arundo impacts: *No impact to migration- but Arundo interferes with movement within the territory- obstructing access to lower canopy and impeding foraging.*

Status/Distribution or Historic and Current Range:
Current estimated distribution of the southwestern willow flycatcher in California is shown in Figure 7-16/19. The current breeding range includes southern California, southern Nevada, Arizona, New Mexico and western Texas. The historic range in California apparently included all lowland riparian areas of the southern third of the state. In the 1930 it was considered a common breeder in coastal southern California, but it declined precipitously over the last 50 years or so.

Arundo impacts: *Arundo is abundant on two specific watersheds with large numbers of flycatchers (Table 7-3, Appendix B). One watershed has moderate interaction/overlap in distribution and eight watersheds have slight interaction. The species has a wide distribution but low populations on most watersheds.*

Decline and Threats:
The major threats to the flycatcher are the destruction, modification, or curtailments of habitat, and nest parasitism by cowbirds. Loss and modification of riparian habitat has occurred due to urban and agricultural development, water diversion and impoundments, channelization, livestock grazing, off-road vehicle and other recreational uses, and hydrological changes resulting from these and other land uses.

Overall impact metric for *Arundo* on southwestern willow flycatcher: Very high impact, score of 8.

Interaction of *Arundo* distribution and southwestern willow flycatcher occurrence is presented by watershed in Table 7-3 and illustrated in Appendix B.

Sources:
U.S. Fish and Wildlife Service. 2002. Southwestern Willow Flycatcher Recovery Plan. Albuquerque, New Mexico. http://ecos.fws.gov/docs/recovery_plans/2002/020830c.pdf
Stillwater Sciences. 2007. Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study.

7.2.8 Belding's Savannah Sparrow (*Passerculus sandwichensis beldingi*)

Federal status: Species of Concern
State status: Endangered, 1974.
Arundo impact score: 2

General Ecological Needs/Habitat Affinities:
Belding's are ecologically associated with dense pickleweed, particularly *Sarcocornia pacifica (formerly Salicornia virginica)*, within which most nests are found.

Arundo impacts: *Arundo is not typically abundant in estuaries although it can occur there. Of more concern is biomass from upstream sources that accumulates in estuaries. Most of the estuaries where the sparrows occur are connected to smaller stream order riverine systems. Less Arundo is found on these size systems. Arundo impacts to system hydrology and geomorphic processes could be of concern in certain situations- sediment loads, biomass blocking flows. But these impacts are probably less on the size river systems that support sparrow habitat in estuaries.*

Breeding/Life History:
Breeding territories can be very small and they nest semi-colonially or locally concentrated within a larger block of habitat, all of which may appear generally suitable.

Arundo impacts: *Minimal impact.*

Diet:
Feeds mostly on the ground (seeds), generally alone or, during the non-breeding season, in small flocks.

Arundo impacts: *Minimal impact.*

Movement:
They remain within the salt marsh year round.

Arundo impacts*: Minimal impact.*

Status/Distribution or Historic and Current Range:
Based upon the 2010 surveys, Belding's sparrows are doing well within their range in California but particularly at Point Mugu, Seal Beach National Wildlife Refuge (NWR), Bolsa Chica, Upper Newport Bay, Sweetwater Marsh NWR, and Tijuana Slough NWR. This is associated in part with the levels and quality of hands-on efforts at these wetlands. For example, Point Mugu has one of the most active and successful Natural Resources Management programs of any of the coastal wetlands in the southern California Bight. At San Elijo and Los Peñasquitos Lagoons the ocean inlets are being monitored and kept open as much as possible. This often minimizes flooding and hyper-saline conditions that greatly reduce Belding's sparrows nesting success.

Arundo impacts: *There is interaction between sparrow and Arundo distributions. Arundo occurs within occupied habitat in a few areas, but as noted it is not abundant in estuaries. Arundo debris is not mapped, but is predicted based on abundance of Arundo upstream of occupied sites. Many of the occupied estuaries are on smaller lower energy systems so significant Arundo biomass inputs are not likely. Calleguas Watershed is a noted potential exception but much of the estuary complex is not well connected to the river mouth. This partly protects it from Arundo debris being pulled back into the estuary complex after it has been dispersed into the ocean or from deposition as debris racks during flow events.*

Decline and Threats:
Over 75% of the coastal wetland habitats within this range have been lost or highly degraded and the remainder suffer from the effects of increasing human populations.

Overall impact metric for *Arundo* on the Belding's savannah sparrow: Very low impact, score of 2.

Interaction of *Arundo* distribution and the Belding's savannah sparrow's occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
A Survey of the Belding's Savannah Sparrow in California 2010, State of California, The Resources Agency, Department of Fish and Game Wildlife Branch. Prepared by Richard Zembal and Susan M. Hoffman, Clapper Rail Recovery Fund, Huntington Beach Wetlands Conservancy, September 2010.

7.2.9 Coastal California Gnatcatcher (*Polioptila californica californica*)

Federal status: Threatened, March 1993. Critical habitat (Revised) designated December 2007.
State status: None?
Arundo impact score: 2

General Ecological Needs/Habitat Affinities:
The range and distribution of the gnatcatcher is closely aligned with coastal scrub vegetation. This vegetation is typified by low (<1m), shrub and sub-shrub species that are often drought deciduous. The coastal scrub plant communities that overlap the range of the gnatcatcher include Venturan, Diegan, and Riversidean coastal sage scrub (CSS) communities, and Martirian and Vizcainan coastal succulent scrub communities. Gnatcatchers may also occur in other nearby plant communities, especially during the non-breeding season, but gnatcatchers are closely tied to coastal scrub for reproduction.

Arundo impacts: *Arundo is not typically found in coastal sage scrub, but CSS habitat and riparian zones are closely aligned in most areas along the coast. Impacts related to fire, both fires starting in*

Arundo and Arundo contributions to wildland fires, can have impacts to adjacent habitat. Fire impacts to CSS can result in both direct take of the species as well as degradation of habitat (short term functional loss, and potentially long term degradation- dependent on fire history and recovery of site). Gnatcatchers are also year round residents and riparian vegetation offers refuge and food resources in late summer/fall/winter when coastal sage scrub is less productive.

Breeding/Life History:
The gnatcatcher is non-migratory and defends breeding territories ranging in size from 1 - 6 hectares (2 - 14 acres). The home range size of the gnatcatcher varies seasonally and geographically, with winter season home ranges being larger than breeding season ranges and inland populations having larger home ranges than coastal. The breeding season of the gnatcatcher generally extends from late February through July (sometimes later), with the peak of nest initiations occurring from mid-March through mid-May. Nests are composed of grasses, bark strips, small leaves, spider webs, down, and other materials and are often located in California sagebrush (*Artemisia californica*) plants about 1 m above the ground. The incubation and nestling periods encompass about 14 and 16 days, respectively.

Arundo impacts: *No impact except those related to fire.*

Diet:
California gnatcatchers are ground and shrub-foraging insectivores. They feed on arthropods, beetles, spiders, leafhoppers, and other small insects. Most of their water intake is obtained through their diet.

Arundo impacts: *Little impact-although riparian areas can be used for foraging during times of low productivity in CSS, and high Arundo cover degrades this function.*

Movement:
The gnatcatcher is non-migratory. Dispersal of juveniles generally requires a corridor of native vegetation that provides certain foraging and sheltering requisites and that connects to larger patches of appropriate sage scrub vegetation. These dispersal corridors facilitate the exchange of genetic material and provide a path for re-colonization of extirpated areas. The gnatcatcher generally disperses short distances through contiguous, undisturbed habitat, but juvenile gnatcatchers are capable of dispersing long distances (up to 22km/14 mi) across fragmented and highly disturbed sage scrub habitat, such as that found along highway and utility corridors or remnant mosaics of habitat adjacent to developed lands.

Arundo impacts: *No impact.*

Status/Distribution or Historic and Current Range:
The range of the gnatcatcher is coastal southern California and northwestern Baja California, Mexico, from southern Ventura and San Bernardino Counties, California, south to approximately El Rosario, Mexico, at about 30 degrees north latitude.

Arundo impacts: *See Appendix B.*

Decline and Threats:
The main threat to the coastal California gnatcatcher is habitat loss, fragmentation, and degradation. Urban and agricultural development, livestock grazing, invasion of exotic grasses, off-road vehicles, pesticides, and military training activities all contribute to the destruction of gnatcatcher habitat.

Overall impact metric for *Arundo* on the coastal California gnatcatcher: Very low impact, score of 2. If wildland fires were documented to have greater extent due to presence of *Arundo* stands in core gnatcatcher upland areas this score should be elevated. Significant take and/or long term degradation would occur to upland habitat.

Interaction of *Arundo* distribution and the coastal California gnatcatcher's occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Coastal California Gnatcatcher Five Year Review, U.S. Fish and Wildlife Service, Carlsbad, CA. September 2010. http://ecos.fws.gov/docs/five_year_review/doc3571.pdf

7.2.10 Light Footed Clapper Rail (*Rallus longirostris levipes*)

Federal status: Endangered, October 1970. No critical habitat designated.
State status: Endangered, June 1971
Arundo impact score: 3

General Ecological Needs/Habitat Affinities:
The light-footed clapper rail uses coastal salt marshes, lagoons, and their maritime environs. Nesting habitat includes tall, dense cordgrass (*Spartina foliosa*) and occasionally pickleweed (*Sarcocornia pacifica* – formerly *Salicornia virginica*) in the low littoral zone, wrack deposits in the low marsh zone, and hummocks of high marsh within the low marsh zone. Fringing areas of high marsh serve as refugia during high tides. Although less common, light-footed clapper rails have also been observed to reside and nest in freshwater marshes.

Activities of the light-footed clapper rail are tide-dependent. They require shallow water and mudflats for foraging, with adjacent higher vegetation for cover during high water. They forage in all parts of the salt marsh, concentrating their efforts in the lower marsh when the tide is out, and moving into the higher marsh as the tide advances.

Arundo impacts: *Arundo does not occur in the lower estuary habitat that rails use. However, biomass of Arundo from upstream stands can be deposited in estuaries (relevance is tied to abundance of Arundo on a given system). Also, larger order systems that are significantly invaded may have significant modification of flow dynamics, sediment transport, and hydrology which may affect quality of estuary habitat at the river mouth (if estuaries are still connected to the river system).*

Breeding/Life History:
Nesting usually begins in March and late nests hatch by August. Nests are placed to avoid flooding by tides, yet in dense enough cover to be hidden from predators and to support the relatively large nest. Potential predators on eggs, nestlings, or adults include California ground squirrels, old world rats, striped skunk, feral house cats, dogs, gray fox, red fox, Virginia opossum, and raptors.

Arundo impacts: *Arundo harbors a range of mammals and predators that use the physical structure.*

Diet:
Light-footed clapper rails are omnivorous and opportunistic foragers, which rely mostly on salt marsh invertebrates such as beetles, garden snails, California horn snails, salt marsh snails, fiddler and hermit crabs, crayfish, isopods, and decapods.

***Arundo impacts**: No impact.*

Movement:
The light-footed clapper rail is resident in its home marsh except under unusual circumstances. Within-marsh movements are also generally confined and usually of no greater spread than 1,312 feet (400m). However, a banded captive-bred female rail which was released at Point Mugu in August of 2004 was found in December of 2004 at Upper Newport Bay, a distance of 145 km (90 mi) along the coast. Minimum home range sizes for nine clapper rails that were radio-harnessed for telemetry at Upper Newport Bay varied from approximately 0.8 - 4.1 acres. The larger areas and daily movements were by first year birds attempting to claim their first breeding territories.

***Arundo impacts:** No impact.*

Status/Distribution or Historic and Current Range:
The historical range of the light-footed clapper rail was originally described as extending from Santa Barbara County, California to San Quintin Bay, Baja California, Mexico. In the early 1900s, ornithologists noted a decrease in the abundance of rails and observed that they were no longer found in areas, which were formerly occupied. Since 1900, 75 %of the coastal estuaries and wetlands in southern California have been destroyed or adversely modified. Light-footed clapper rails have not been detected in Santa Barbara County since 2004 or in Los Angeles County since 1983. The range in California now extends from Ventura County in the north to the Mexican border in the south.

***Arundo impacts:** Rails occur in estuaries of both large and small watershed systems- particularly in San Diego County (Appendix B). Rails can extend fairly far into the watershed (where pickleweed occurs), but some of these are historic records. Arundo is abundant on some of these watersheds.*

Decline and Threats:
Continued loss and degradation of salt marsh habitat.

Overall impact metric for *Arundo* on the light-footed clapper rail: Low impact, score of 3.

Interaction of *Arundo* distribution and the light footed clapper rail's occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Light-footed Clapper Rail Five Year Review, U.S. Fish and Wildlife Service, Carlsbad, CA. August 2009. http://ecos.fws.gov/docs/five_year_review/doc2573.pdf

7.2.11 California Least Tern (*Sterna antillarum browni*)

Federal status: Endangered June 2, 1970. Final Recovery Plan 1980, revised 1985.
State status: Endangered, June 27, 1971.
Arundo impact score: 4

General Ecological Needs/Habitat Affinities:
California least terns nest on beaches, usually choosing locations in an open expanse of light-colored sand, dirt or dried mud close to a lagoon or estuary with a dependable food supply. Formerly, sandy open beaches were used, but human activity on beaches has forced terns to nest on mud and sand flats back from the ocean, and on man-made habitats. In addition to nesting areas, California least terns also require secure roosting and foraging areas. Roosting areas are of two kinds: pre-season nocturnal roosts and post-season dispersal sites where adults and fledglings congregate. Terns forage primarily in nearshore ocean waters and in shallow estuaries and lagoons.

Arundo impacts: *Arundo is not abundant in the beach and estuary habitat- but there can be locally occurring stands and occurrences of the plant. Arundo debris and to a lesser degree hydrologic and geomorphic alteration of river systems can have impacts on terns.*

Breeding/Life History:
Most least terns begin breeding in their third year. Mating begins in April or May. The nest is a simple scrape in the sand and may be lined with shell fragments, pebbles, twigs. Typically there are 2 eggs. Both parents incubate and care for the young. They can re-nest up to two times if eggs or chicks are lost early in the breeding season. Nesting season extends from approximately May 15 into early August, with the majority of nests completed by mid June. A second wave of nesting occurs from mid-June to early August. These are mainly re-nests after initial failures, and second year birds nesting for the first time. Predators of the California least tern are larger birds, mammals such as raccoons and foxes, and domestic dogs and cats.

Arundo impacts: *Most tern breeding areas are nearly devoid of vegetation and plant debris (observation of nesting sites in San Diego and Ventura Counties). Arundo debris and live plant structure is a degradation of habitat. Debris reduces useable area. Any structure fosters predation from birds and any concealment encourages predatory mammals.*

Diet:
California least terns eat small fish.

Arundo impacts: *No impact.*

Movement:
The California least tern is migratory, usually arriving in its breeding area by mid April and departing again in August. However, terns have been recorded in the breeding range as early as March 13 and as late as October 31. Adult terns move south along the California coast with their fledglings in the autumn, stopping to rest and feed along the migration route.

Arundo impacts: *No impact.*

Status/Distribution or Historic and Current Range:
Historically California least terns nesting in large colonies spread along undisturbed beaches. However with development of the California coast and fragmentation of large beach areas, birds now nest in the small fragments of habitat remaining in the same general areas. The nesting range in California is discontinuous, with large colonies spread out along beaches at estuaries. The northern limit for nesting is San Francisco Bay, and the southern limit is in Baja California, Mexico. Today the tern is concentrated in three southern California counties: Los Angeles, Orange and San Diego.

Arundo impacts: *Arundo is abundant on several watersheds in Orange and San Diego Counties (Appendix B).*

Decline and Threats:
California least terns were apparently once abundance and well distributed on barrier beaches and beach strand along the southern California coast. The reduction in tern numbers was apparently gradual and associated with human population increases in the area. The species was noted as seriously declining within its range before the 1930s. Today the tern is concentrated in three southern California counties: Los Angeles, Orange and San Diego. Since 1973 there has been on overall increase in least tern in California due to recovery efforts such as site management and protection of known nesting sites (fencing, predator control, monitoring, research). Decline of the California least tern is due to loss and degradation of beach habitat, impacts and disturbance from human and domestic animal use of beaches, and loss and fragmentation of wintering habitat.

Overall impact metric for *Arundo* on the coastal California least tern: Low/Moderate, score of 4.

Interaction of *Arundo* distribution and the coastal California least tern's occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
California Least Tern Five Year Review Summary and Evaluation, U.S. Fish and Wildlife Service, Carlsbad, CA. September 2006. http://ecos.fws.gov/docs/five_year_review/doc775.pdf
Revised California Least Tern Recovery Plan, U.S. Fish and Wildlife Service, Portland, Oregon. April 1980. http://ecos.fws.gov/docs/recovery_plan/850927_w%20signature.pdf

7.2.12 Least Bell's Vireo (*Vireo bellii pusillus*)

Federal status:	Endangered, May 1986. Critical habitat designated February 1994. Draft recovery plan completed in 1998.
State status:	Endangered, October 1980.
Arundo impact score:	9

General Ecological Needs/Habitat Affinities:
Least Bell's vireo is a small, olive-grey migratory songbird that nests and forages almost exclusively in riparian woodland habitats. Primary constituents of critical habitat for the vireo include riverine and floodplain habitat, and adjacent coastal sage scrub, chaparral, or other upland communities. Nesting habitat typically consists of well-developed overstories and understories, and low densities of aquatic and herbaceous cover. The understory frequently contains dense subshrub or shrub thickets. These thickets are often dominated by sandbar willow (*Salix hindsiana*), mulefat (*Baccharis salicifolia*), young individuals of other willow species, such as arroyo willow (*Salix lasiolepis*) or black willow (*Salix gooddingii*), and one or more herbaceous species. Important overstory specie include mature arroyo willow and black willows; occasional cottonwoods (*Populus* spp.) and western sycamores (*Platanus racemosa*) occur in some habitats. Additionally, coast live oak (*Quercus agrifolia*) can be a locally important overstory component, as can mesquite (*Prosopis* spp.).

Arundo impacts: *Arundo and vireos prefer the same broad coastal riparian habitat types. Significant impacts from abiotic modification of the riverine system impact ecosystem to the detriment of the vireo. There changes include fire, geomorphic impacts that interfere with vegetation succession, and outright displacement of vegetation that vireos are dependent on. Direct take and long term degradation of habitat occurs after fires initiating in Arundo stands as well as wildland fires that are larger are more intense when Arundo is present.*

Breeding/Life History:
Following pair formation, it takes approximately 5 - 7 days for them to finish nest construction and egg laying. Young typically fledge within 20 - 24 days after eggs are laid. The egg laying and incubation periods are critical to the nesting success, as disturbance at this point may result in abandonment of the nest.

Arundo impacts: *Arundo displaces native vegetation reducing available habitat for nesting. Arundo does not have suitable structure for vireo nests.*

Diet:
They are almost exclusively insectivorous, and forage in riparian woodland and suitable adjacent upland habitat.

Arundo impacts: *Arundo support a low abundance and diversity of insects, particularly in comparison to native vegetation (Herrera & Dudley 2003, Going & Dudley 2008). Vireos are rarely seen feeding on Arundo as the plants has few insects that directly feed on it. Birds are rarely seen feeding in Arundo.*

Movement:
Least Bell's vireos generally begin to arrive from their wintering range in southern Baja California and establish breeding territories by mid- to late March. Most breeding vireos depart by the third week of September and only a very few individuals are found wintering in California. Most vireos occupy home ranges that are typically from 0.5 - 4.5 acres, but a few may be as large as 7.5 acres. Once the young are fledged they wander widely throughout the parents' territory.

Arundo impacts: *Arundo stands inhibit movement of avian species as the feed, spatially segregating the habitat. Territories frequently include Arundo stands but there is always a native component of the territory. Territories are roughly drawn- it would be interesting to see if territory size is larger when Arundo is present.*

Status/Distribution or Historic and Current Range:
Historically the vireo was described as common to abundant in the appropriate riparian habitat from as far north as Tehama County, CA to northern Baja, Mexico. Habitat loss has fragmented most remaining populations into small, disjunct, widely dispersed subpopulations. Currently the largest population of vireos is on Marine Corps Base Camp Pendleton in San Diego County. This population combined the population in the Prado Basin represent approximately 60 % of all known territories in California.

Arundo impacts: *Arundo is abundant on the three largest population centers for the vireo: Santa Margarita, Santa Ana, and San Luis Rey. Vireos are in greater abundance on larger systems, but they do occur on smaller watersheds if riparian vegetation is well developed (Appendix B). Vireos also occur in greater abundance in urban riparian areas then other federally listed species.*

Decline and Threats:
Decline of vireos is primarily the result of habitat loss and degradation, and cowbird nest-parasitism. The historic loss of wetlands (including riparian woodlands) has been estimated at 91 %. Much of the potential remaining habitat is infested with non-native plants and cowbirds. Ongoing causes of destruction or degradation of habitat include: removal of riparian vegetation; invasion of non-native species (e.g. *Arundo*, cowbird); thinning of riparian growth, especially near ground level; removal or destruction of adjacent upland habitats used for foraging; increases in human-associated or human induced disturbances; and flood control activities, including dams, channelization, water impoundment or extraction, and water diversion. Vireos are also sensitive to many forms of human disturbance, including noise, night lighting, and consistent human presence in an area.

Overall impact metric for *Arundo* on least Bell's vireo: Severe impact, score of 9.

Interaction of *Arundo* distribution and least Bell's vireo occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:

Stillwater Sciences. 2007. Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study.

Programmatic Biological Opinion for the Salinas River Watershed Permit Coordination Program, Monterey County, CA (1-8-02-F-19), US Fish and Wildlife Service, Ventura, CA. 2002.

7.2.13 Tidewater Goby (*Eucyclogobius newberryi*)

Federal status: Endangered, March 7 1994. Critical habitat designated November 20 2000.
State status: none
Arundo impact score: 7

General Ecological Needs/Habitat Affinities:
The tidewater goby, a species endemic to California, is found primarily in waters of coastal lagoons, estuaries, and marshes. The species is benthic in nature, and its habitat is characterized by brackish, shallow lagoons and lower stream reaches where the water is fairly still but not stagnant. Tidewater gobies prefer a sandy substrate for breeding, but they can be found on rocky, mud, and silt substrates as well. The species is typically found in water less than 1 m deep. Tidewater gobies have been documented in waters with salinity levels from 0 - 42 parts per thousand (ppt), temperature levels from 8 - 25 ° C (46 - 77° F), and water depths from 25 200 cm (10 to 79 in). Critical habitat includes the stream channels and their associated wetlands, flood plains, and estuaries.

Arundo impacts : *Alteration of geomorphology and accumulation of excessive dead biomass in habitat areas are the primary impacts. It is possible that abundant Arundo is extremely detrimental to the species as they have not been observed on the Salinas River, Santa Clara, and Santa Margarita, and San Luis Rey Rivers in recent time frames. River channels could be becoming too deep for the species on some systems (such as San Luis Rey) resulting from excessive vegetation on floodplains (see chapter 5). The species now seems to occur on smaller river/creek systems, many of which have no or little Arundo on them (areas of Camp Pendleton and Estero Bay).*

Breeding/Life History:
The tidewater goby is typically an annual species, although some variation has been observed. Reproduction occurs year-round although distinct peaks in spawning, often in early spring and late summer, do occur. Male tidewater gobies begin digging breeding burrows in relatively unconsolidated, clean, coarse sand (averaging 0.5 mm diameter), in April or May after lagoons close to the ocean. Female tidewater gobies can lay 300 - 500 eggs per clutch, and can lay 6 - 12 clutches per year. Male tidewater gobies remain in the burrow to guard the eggs that are attached to sand grains in the burrow ceiling and walls. The male tidewater goby cares for the embryos for approximately 9 - 11 days until they hatch. Tidewater goby larvae are planktonic for 1 - 3 days and then become benthic from that point on. Tidewater goby are preyed upon by native and non-native fish, and by fish eating birds.

Arundo impacts: *Accumulated biomass within the channel near the river mouth would cover substrate needed for reproduction.*

Diet:
Tidewater gobies feed mainly on small animals, usually mysid shrimp, amphipods, ostracods, and aquatic insects. Juvenile tidewater gobies are generally day feeders, although adults mainly feed at night.

Arundo impacts: *Unknown if biomass would impacts aquatic food resources. Excessive channel depth would negatively affect feeding (individuals prefer a water depth of up to 1 m).*

Movement:
The tidewater goby appears to spend all life stages in lagoons, estuaries, and river mouths. Tidewater gobies may enter marine environments only when flushed out of lagoons, estuaries, and river mouths by normal breaching of the sandbars following storm events. Tidewater gobies generally select habitat in the upper estuary, usually within the fresh-saltwater interface. Tidewater gobies range upstream a short distance (up to 1.5 miles/2.41 km) into fresh water, and downstream into water of up to about 75 % sea water (28 ppt).

Arundo impacts this by: *The preferred habitat zone frequently has significant Arundo on the banks (in highly invaded systems) It is possible that Arundo debris in these systems interferes with movement during and after flood events- particularly if there are large rafts vegetation (Arundo canes and native vegetation).*

Status/Distribution or Historic and Current Range:
Tidewater gobies are endemic to California and historically ranged from Tillas Slough near the Oregon border to Agua Hedionda Lagoon in northern San Diego County, and are found today entirely within the original known range of the species. The known localities are discrete lagoons, estuaries, or stream mouths separated by mostly marine conditions. Tidewater gobies are absent from areas where the coastline is steep and streams do not form lagoons or estuaries. Tidewater gobies have recolonized areas where they have been extirpated.

Arundo impacts: *Arundo and goby distributions are shown Appendix B. As noted, the species has not been found in several large and heavily invaded watersheds since 2001. But there are smaller watersheds with populations nearby. Goby populations and distribution may naturally fluctuate in response to large flooding events. It will be informative to see if they return to systems that have had Arundo neatly eradicated (Santa Margarita and San Luis Rey).*

Decline and Threats:
The tidewater goby is threatened by modification and loss of habitat as a result of coastal development, channelization of habitat, diversions of water flows, groundwater overdrafting, and alteration of water flows. Potential threats to the tidewater goby include discharge of agricultural and sewage effluents, increased sedimentation due to cattle grazing and feral pig activity, summer breaching of lagoons, upstream alteration of sediment flows into the lagoon areas, introduction of exotic gobies and rainwater killifish, habitat damage, and watercourse contamination resulting from vehicular activity in the vicinity of lagoons.

Arundo impacts: *Arundo effects several of these parameters (water availability, sediment transport), but it is unclear exactly how these factors interact with goby habitat.*

Overall impact metric for *Arundo* on the tidewater goby: High impact, score of 7.

Interaction of *Arundo* distribution and tidewater goby occurrence is presented by watershed in Table 7-3 and Appendix B. It is important to note that there are many smaller watersheds that have no or very low *Arundo* presence and therefore impacts are non-existent. Goby have occurred on large systems- and they are in significant decline or do not occur on these systems over the time period when *Arundo* has become a significant impact. Other hydrologic factors have also changed significantly over that time frame (water flows, sediment transport, etc.) so several factors may be at play.

Sources:

Programmatic Biological Opinion for the Salinas River Watershed Permit Coordination Program, Monterey County, CA (1-8-02-F-19), US Fish and Wildlife Service, Ventura, CA. 2002.

U.S. Fish and Wildlife Service. 2005. Recovery Plan for the Tidewater Goby (*Eucyclogobius newberryi*). U.S. Fish and Wildlife Service, Portland, Oregon.

7.2.14 Unarmored Three Spine Stickleback (*Gasterosteus aculeatus williamsoni*)

Federal status: Endangered, October 13 1970. Designation of critical habitat remains pending. Recovery Plan completed in 1985.

State status: Endangered, June 27 1971.

Arundo impact score: 8

General Ecological Needs/Habitat Affinities:

The unarmored three-spine stickleback inhabits slow moving reaches or quiet water microhabitats of streams and rivers. Favorable habitats usually are shaded by dense and abundant vegetation, but in more open reaches algal mats or barriers may provide refuge. The best habitat seems to be a small clean pond in the stream with a constant flow of water through it. Adults are found in all areas of the stream and tend to gather in areas of slower moving or standing water. In areas where water is moving rapidly, adults tend to be found behind obstructions, or at the edge of the stream, particularly under the edge of algal mats. No adults have been found to be living permanently in ponds isolated from the main stream.

Arundo impacts: *Arundo occurs within the core stickleback population area of the upper Santa Clara Watershed. There is Arundo present within much of the stickleback's range and significant Arundo in the fish's lower range on the main stem of the river. For more invaded portions of the river changes to sediment transport and high water use of Arundo could be impacting pool persistence and quality. Arundo fires in more invaded habitat would also cause impacts.*

Breeding/Life History:

There is some reproduction during almost every month. A large increase in reproductive activity occurs in the spring in about March, and continues at lower levels throughout summer and fall. Males build nests of aquatic vegetation on the bottom within his territory. Nests are located where there is ample vegetation and a gentle flow of water. After the female lays the eggs, the male fertilizes them, guards them, and fans them. Young sticklebacks hatch in a nest from eggs which have been brooded for several days by the adult male. The exact amount of time the young stay in the nest is unknown. Larger juveniles and sub-adults tend to be found in the protection of vegetation, in slow moving or standing water. Fish apparently only live for one year.

Arundo impacts: *Pool/channel water quality and duration may be impacted.*

Diet:

The stickleback feeds mostly on benthic insects, small crustaceans, and snails, and to a lesser degree flat worms and nematodes. Males may also eat stickleback eggs.

Arundo impacts: *Pool/channel water quality and duration may be impacted- which could effect abundance and diversity of food resources.*

Movement:
The unarmored three-spine stickleback remains within stream channels and ponds within the stream area. No adults have been found to be living permanently in ponds isolated from the main stream.

Arundo impacts: *Minimal impacts.*

Status/Distribution or Historic and Current Range:
Historically they were distributed throughout southern California, but are now restricted to the upper Santa Clara River and its tributaries in northern Los Angeles and Ventura Counties, San Antonio and Canada Honda creeks on Vandenberg Air Force Base in Santa Barbara County, and San Felipe Creek in San Diego County. The Canada Honda and San Felipe Creek populations were transplanted.

Arundo impacts: *Arundo and stickleback overlap in distribution (Appendix B).*

Decline and Threats:
Habitat degradation from flood control and channelization are the primary threats to the unarmored three-spine stickleback. Habitat degradation also occurs from trampling of stream banks by humans and livestock, causing increased soil erosion and sedimentation which reduces availability of plants and insects for habitat and food. Damage to emergent vegetation along stream banks degrades the nursery areas. Stream channelization allows increased water velocity in pools, eliminates shallow backwaters and reduces aquatic vegetation. Channelization also increases peak flows during floods, and large flood events scour the channel and wash stickleback individuals downstream. Urbanization has caused a degradation of water quality due to increased run-off, siltation, nutrients, pesticides and other pollutants. These pollutants affect the health of the sticklebacks and can cause deformities. Introduced predators and competitors negatively affect the stickleback by directly removing individuals or restricting them to habitats that predators cannot enter. Other threats to the stickleback include genetic introgression, agricultural impacts, oxygen reduction, groundwater removal, possibly water loss due to transpiration from increase plant growth, and off-road vehicle use.

Arundo impacts: *Arundo stands on floodplains can create many of the same hydrologic and flow conditions as man-made channelization such as faster flows, high erosion within channels, etc. These factors may contribute to the sticklebacks decline by decreasing the elevation and channel complexity that stickleback may prefer over a simple deeper channel form. These factors are more relevant in the lower portions of the sticklebacks' range on the Santa Clara.*

Overall impact metric for *Arundo* on unarmored three-spine stickleback: Very high, score of 8.

Interaction of *Arundo* distribution and unarmored three-spine stickleback occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Unarmored Threespine Stickleback Recovery Plan (Revised), U.S. Fish and Wildlife Service, Portland, Oregon, 1985.
Biological and Conference Opinions for Annual Removal of Giant Reed and Tamarisk in Upper Santa Clara River Watershed, Los Angeles county, CA (File No. 2004-01540-AOA)(1-8-06-F-5).

7.2.15 Southern Steelhead (*Oncorhynchus mykiss*)

Southern California Distinct Population Segment (DPS)

Federal status: Endangered August 18 1997. Critical habitat was designated on September 2 2005.

South-Central California Coast DPS

Threatened Jan 5 2006, Critical habitat designated September 9 2005.

Arundo impact score: 7

General Ecological Needs/Habitat Affinities:

Southern steelhead can survive a wide range of temperature conditions, but require streams with adequate dissolved oxygen. Adult steelhead migrate from the ocean to freshwater spawning grounds. Spawning habitat consists of gravel substrates free of excessive silt. Adults do not feed during their upstream journey, rather use their energy reserves. Once they are large enough, smolts migrate downstream to the ocean, and to successfully complete this journey they require refuge areas with good cover and water quality.

Riparian vegetation provides cover and protection from predators and areas of refuge from high velocities. Riparian vegetation is also important in maintaining low stream temperature, stabilizing banks, and providing food sources for migrating steelhead. To provide these benefits, riparian vegetation needs high vigor, density, and species diversity, including a mixture of canopy trees, brush and grasses. Areas of lowered velocity or reverse flow areas within the channel allow steelhead to use energy reserves efficiently during migration in order to save energy for spawning. Sediment removal of sandbars reduces flow-field complexity, particularly of edgewater eddies and low velocity zones. This likely results in adult steelhead migrating through higher velocities and consuming higher levels of reserved energy. If too much reserved energy is consumed, and sufficient resting pools are not available, adults could be unable to reach spawning grounds, or have less energy for reproductive development. Furthermore, modification of sandbars and velocities could also simply increase the amount of time it takes for steelhead to reach spawning grounds. Removing and/or altering sandbars also reduces the convergence of flows through pools, thus reducing the processes that maintain pools. Pools provide cover and refuge. During the upstream migration steelhead rest in pools and during downstream migration smolts take refuge in pools during the day. Adults and smolts both require adequate flows for migration; they need enough water flow to travel up and down the river/stream, and to keep the river mouth open to the ocean.

Steelhead metabolism can be impacted by high water temperatures and the associated reduction in dissolved oxygen. Temperatures above 20° C have been known to stop fish migration, and temperatures above 25° C can be lethal to salmon and trout. High levels of suspended sediment (e.g. 3,000-4,000 mg/L), generally the result of large storm events or channel grading activities, can significantly impact fish migration and survival. Fish can suffer from gill abrasion and reduced visibility, and suffer mortality after exposure of two or more days. Fish at the mouth of a river would be delayed 1-2 days until the initial flush of sediment passes after a storm.

Arundo impacts: *Arundo has a significant number of impacts on river systems- some of which are negative and others that may be positive. Arundo typically occurs in areas that steelhead pass through so impacts to migration are important to explore. Arundo is not good at stabilizing eroding banks stands and clumps break off and are undercut by flows. This may increase erosion rates locally. Arundo does form dense stands of vegetation on floodplains. These dense stands create conditions that deepen low flow channels and push systems to single thread form in comparison to more complex braided systems or broader shallow systems. This single deep channel may aid migration of steelhead. However, single thread narrow channels have higher velocity and fewer areas to rest; this could be a detriment. Single thread channels also tend to transport (carry) greater suspended loads under a larger*

range of flow events. This could also be a detriment to steelhead, particularly if there a large number of sediment inputs (such as agricultural inputs or other disturbed sites). Highly invaded systems may have Arundo water use that reduces duration of surface flows- this would be a severe impact to steelhead. Water use may be lower at the time of year when fish migration occurs, partially offsetting transpiration rates. Arundo biomass could be a significant stressor as both a physical hindrance to passage and as a contamination in the water column. Water temperature impacts for portions of the habitat where fish passage is occurring are extremely difficult to quantify. It is not clear that large systems would have significant shading of the channel from mature gallery trees. Arundo shades a narrow band of the bank if the low flow channel is directly adjacent to the bank. More complex, but probably more relevant is water depth which may be strongly affected by Arundo stands (by effecting channel depth- chapter 5). Shading would be more relevant in upper portions of the watersheds where fish develop; these areas do not typically have Arundo in them.

Breeding/Life History:
Adult steelhead migrate from the ocean into freshwater streams to spawn between December and April. Female steelhead dig a nest in a stream area with suitable gravel composition, water depth, and velocity. Females may deposit eggs in four to five nests. Steelhead eggs hatch three to four weeks after being deposited. Juvenile steelhead typically spend one to two years rearing in freshwater before migrating to estuarine areas as smolts and then into the ocean to feed and mature. The majority of smolts enter the ocean at age two in March and April. They migrate at night and seek refuge and feed during the day. Steelhead can then remain at sea for up to three years before returning to fresh water to spawn.

Arundo impacts: *Arundo impacts on migration have been reviewed. Arundo debris in estuaries and Arundo effects on sediment movement could degrade estuarine habitat where smolts reside prior to entering the ocean.*

Diet:
Young steelhead fry feed mostly on zooplankton. Adult steelhead eat aquatic and terrestrial insects, mollusks, crustaceans, fish eggs, minnows, and other small fishes.

Arundo impacts: *Little impact as Arundo is not typically present or abundant in the upper portions of watersheds where juveniles develop. There could be greater impacts on Ventura River, Estero Bay and Santa Ynez, but spawning grounds are not clearly indicated on data sets.*

Status/Distribution or Historic and Current Range:
Steelhead within the Southern California DPS includes all naturally spawned anadromous steelhead populations below natural and manmade impassable barriers in streams from the Santa Maria River, San Luis Obispo County, California, to the U.S.-Mexico Border. South-Central California Coast DPS includes all naturally spawned anadromous steelhead from the Pajaro River (inclusive) to, but not including, the Santa Maria River, California. An estimated 30,000 - 50,000 steelhead once spawned in southern California rivers, but the recent runs in four major river systems were made by fewer than 500 adults total. Steelhead could once be found in 46 watersheds in the region, but only remained in 17 - 20 drainages by 2002. Many of these creeks and rivers now sustain only the resident form of steelhead, rainbow trout. Anadromous steelhead currently occur in only four large river systems in southern California: the Santa Maria, Santa Ynez, Ventura, and Santa Clara rivers. But periodic sightings have occurred on San Mateo (San Juan HU) and the San Luis Rey River.

Arundo impacts: *Arundo occurs in abundance on several critical watersheds and may occur on portions of spawning areas on a subset (Appendix B).*

Decline and Threats:
Decline is due to long-standing human induced factors such as lack of flows due to groundwater pumping, dams and water diversions, blocked access to historic spawning and rearing areas upstream of dams, and channel modification.

Arundo impacts: *Arundo has significant impacts on water use, channel form, and sediment transport. These are complex hydro geomorphic processes explored in chapter 5. Most impacts would appear to be strongly negative, others could facilitate migration.*

Overall impact metric for *Arundo* on the southern steelhead: High impact, score of 7.

Interaction of *Arundo* distribution and southern steelhead occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Programmatic Biological Opinion for the United States Army, San Francisco District Corps of Engineers' permit pursuant to 404 of the Clean Water Act for Monterey County Water Resources Agency regional General Permit for the Salinas River Channel Maintenance Program; National Marine Fisheries Service, Southwest Region, Long Beach CA. July 2003.

7.2.16 Santa Ana Sucker (*Catostomus santaanae*)

Federal status: Endangered, April 12 2000. Critical habitat has not been designated.
State status: Species of special concern.
Arundo impact score: 6

General Ecological Needs/Habitat Affinities:
The sucker is fairly general in its habitat requirements, occupying both low-gradient, lowland reaches, and high-gradient, mountain streams. The sucker seems to do best in small to medium streams with higher gradients, clear water, and coarse substrates, such as the east fork of the San Gabriel River. Flowing water is essential, but can vary from slight to swift. It is typically associated with gravel, cobble, and boulder substrates, although it is also found over sand and mud substrates.

Arundo impacts: *Arundo abiotic impacts are of particular concern for the sucker, particularly high water use and modification of geomorphology and sediment transport on the Santa Ana. Arundo is not abundant in the low channel areas where fish occur. The Los Angeles River is steeper in gradient and Arundo, though present, is not abundant enough to significantly impact water availability and fluvial processes.*

Breeding/Life History:
They live three to four years, but reach sexual maturity in one year and have high fecundity. Spawning generally occurs from late March to early July, with the peak in May and June.

Arundo impacts: *Probably low impact- but water use and drying of pools/stream sections could be a factor in some portions of the Santa Ana.*

Diet:
The sucker feeds mostly on algae, diatoms, and detritus scraped form rocks and other hard substrate. Aquatic insects comprise only a small part of their diet.

Arundo impacts: *Probably low impact- but water use and drying of pools/stream sections could be a factor in some portions of the Santa Ana.*

Movement:
Little is known about sucker movements, however other species in the same family are known to be high vagile and undertake spawning migrations.

Arundo impacts: *Probably low impact- but water use and drying of pools/stream sections could be a factor in some portions of the Santa Ana. Modification of sediment transport and fluvial processes would also affect channel forms and movement.*

Status/Distribution or Historic and Current Range:
Historically the sucker occupied the Los Angeles, San Gabriel, and Santa Ana Rivers from near the Pacific Ocean to their uplands. It was described as common in the 1970s, but has since experienced declines throughout most of its range, and now persists in isolated, remnant populations. Approximately 70-80% of its historic range in the Los Angeles, San Gabriel and Santa Ana Rivers has been destroyed. Currently the sucker is found 1) in portions of Big Tujunga Creek between the Big Tujunga and Hansen dams along the Los Angeles River, 2) in the west, east and north forks of the San Gabriel River above Morris Dam, and 3) reaches of the Santa Ana River between the city of San Bernardino and the vicinity of Anaheim. There is also a population of suckers in the Santa Clara River that is thought to be introduced and that has hybridized with the Owen's sucker, so it is not included within the range of the native sucker.

Arundo impacts: *Arundo significantly overlaps with the Santa Ana population and to a lesser degree the Los Angeles River population (Appendix B). There is also a hybridized population on the Santa Clara that may be introduced. There is significant Arundo within this populations range. The Santa Clara watershed is given a distribution score (Appendix B) but it is lowered to reflect the questionable genetic integrity of the resident population. If revisions to the Santa Clara's population value are made a higher impact interaction score should be given.*

Decline and Threats:
Threats that have contributed to the decrease in the sucker include 1) destruction and degradation of habitat through urbanization, channelization, flood control structures, water diversion, water withdrawal, and water quality reduction, 2) direct loss of suckers due to water diversion, 3) competition and predation from non-native species, and 4) loss of connectivity.

Overall impact metric for *Arundo* on the Santa Ana sucker: Moderate/High, score of 6.

Interaction of *Arundo* distribution and Santa Ana sucker occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Biological Opinion on the Prado Mainstem and Santa Ana River Reach 9 Flood Control Projects and Norco Bluffs Stabilization Project, Orange, Riverside, and San Bernardino Counties, California; U.S> Fish and Wildlife Service, Carlsbad, CA, December 2005.

7.2.17 San Joaquin Kit Fox (*Vulpes macrotis mutica*)

Federal status: Endangered, March 11, 1967. No critical habitat has been designated.
State status: Threatened, June 27, 1971.
Arundo impact score: 1

General Ecological Needs/Habitat Affinities:
This species historically inhabited grassland, scrubland, and wetland communities in the San Joaquin Valley and adjacent habitat. Today kit foxes are found in grassland and scrubland communities, most of which have been extensively modified by humans.

Kit foxes use dens for temperature regulation, shelter from adverse weather and protection from predators. They either dig their own dens, use those constructed by other animals, or use human-made structures (culverts, abandoned pipelines, or banks in sumps or roadbeds). Kit foxes often change dens and many dens may be used throughout the year. The majority of their dens lie in relatively flat terrain or gently sloping hills, in washes, drainages, and roadside berms.

Arundo impacts: *Arundo is not abundant within the habitat occupied by foxes. However, it does degrade the habitat as foxes prefer very open habitat with little or no vegetation structure to avoid predation. Arundo creates structure and may interact with dens that occur on washes.*

Breeding/Life History:
Kit foxes can breed when one year old. Adult pairs stay together all year. During September and October, females begin to clean and enlarge their pupping dens. Mating occurs between December and March. Litters of two to six pups are born in February or March. Pups emerge from the den after about a month.

Arundo impacts: *Very minor impacts related to potentially higher predation and lower denning quality.*

Diet:
Kit fox eat small mammals such as mice, kangaroo rats, squirrels and rabbits. They also eat ground-nesting birds and insects. They are primarily nocturnal hunters.

Arundo impacts: *No impact likely.*

Movement:
The kit fox is mostly nocturnal, but can be active in the daytime during cool weather. Home ranges of approximately one to twelve square miles have been reported. Development has significantly degraded movement and dispersal corridors for young kit foxes. Juvenile survival and successful dispersal has been declining in recent years. Three occurrences of kit fox movement have been documented between the Salinas-Pajaro region and the Carrizo Plain Natural Area. Although the total movement of kit foxes between these areas is unknown, land development along the natural movement corridors between Carrizo Plain and the Salinas Valley, as well as development within Salinas Valley has probably reduced immigration of kit foxes into the Salinas Valley, possibly contributing to their decline.

Arundo impacts: *Dense Arundo stands may inhibit movement to new areas as kit foxes prefer open areas. Riparian corridors are extremely important for movement of wildlife. Foxes may use roads as alternate corridors if riparian zones are overly vegetated (Arundo), leading to increased mortality from vehicles. Arundo is not abundant enough on the upper Salinas to significantly discourage use of riparian habitat as a corridor- but migration and use of riparian habitat downstream (north) in Salinas valley could be reduced by Arundo, particularly below King City where Arundo cover is very high.*

Status/Distribution or Historic and Current Range:
In the San Joaquin Valley before 1930, the range of the San Joaquin kit fox is believed to have extended from southern Kern County north to Contra Costa County on the west side and near La Grange, Stanislaus County, on the east side. Until the 1990s, Tracy was the farthest northwest record, but now there are records from the Antioch area of Contra Costa County. By 1930, the kit fox range had been reduced by more than half, with the largest portion remaining in the southern and western parts of the Valley. By 1958, an estimated 50% of the Valley's original natural communities had been lost, due to extensive land conversions, intensive land uses, and the use of pesticides. In 1979, only about 6.7% of the San Joaquin Valley's original wildlands south of Stanislaus County remained untilled and undeveloped. Today many of these communities are represented only by small, degraded remnants. Kit foxes are, however, found in grassland and scrubland communities, which have been extensively modified by humans with oil exploration, wind turbines, agricultural practices and/or grazing. The kit fox population is fragmented, particularly in the northern part of the range.

Arundo impacts: *Arundo and foxes co-occur in the Salinas watershed (Appendix B).*

Decline and Threats:
Kit foxes are subject to competitive exclusion or predation by other species, such as the nonnative red fox, coyote, domestic dog, bobcat, and large raptors. Loss and degradation of habitat by agricultural, industrial, and urban developments and associated practices continue, decreasing the carrying capacity of remaining habitat and threatening kit fox survival. Such losses contribute to kit fox declines through displacement, direct and indirect mortalities, barriers to movement, and reduction of prey populations.

Overall impact metric for *Arundo* on the San Joaquin kit fox:
Extremely low/improbable, score of 1. If high quality habitat was identified north of Salinas range where Salinas River could serve as a corridor, then Impact score should be increased.

Interaction of *Arundo* distribution and the San Joaquin kit fox occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Programmatic Biological Opinion for the United States Army, San Francisco District Corps of Engineers' permit pursuant to 404 of the Clean Water Act for Monterey County Water Resources Agency regional General Permit for the Salinas River Channel Maintenance Program; National Marine Fisheries Service, Southwest Region, Long Beach CA. July 2003.
Species Account SAN JOAQUIN KIT FOX (*Vulpes macrotis mutica)*, U.S. Fish & Wildlife Service, Sacramento Fish & Wildlife Office.

7.2.18 San Diego Ambrosia (*Ambrosia pumila*)

Federal status: Endangered, July 2 2002. Final critical habitat designated November 30 2010.
State status: None?
Arundo impact score: 7

General Ecological Needs/Habitat Affinities:
Ambrosia pumila is a perennial herb in the sunflower family (Asteraceae). It occurs primarily on upper terraces of rivers and drainages. Within these areas, the species is found in open grassland of native and nonnative plant species, and openings in coastal sage scrub, and primarily on sandy loam or clay soils. The species may also be found in ruderal habitat types (disturbed communities containing a mixture of

native and non-native grasses and forbs) such as fire fuel breaks and edges of dirt roadways. Non-native grassland and ruderal habitat types provide adequate habitat for *A. pumila*; however, non-native plants can out-compete *A. pumila* plants for resources in some situations. *Ambrosia pumila* consistently occurs in areas near waterways such as upper terraces of rivers or other water bodies. These areas do not necessarily provide high levels of soil moisture, and *A. pumila* is adapted to dry conditions. *A. pumila* may require periodic flooding for some segment of its life cycle. Additionally, areas subject to periodic flooding may be less amenable to competing non-native and native plants. *A. pumila* is a clonal herbaceous perennial plant that spreads vegetatively by means of slender, branched, underground root like rhizomes from which new aboveground stems (aerial stems or ramets) arise each year. Aerial stems of *Ambrosia pumila* sprout from their underground rhizomes in early spring after winter rains, and flower between May and October. However, aerial stems have been observed sprouting under dry conditions in late fall. The aerial stems senesce after the growing season, leaving the rhizome system in place from which new aerial stems may sprout when environmental conditions are appropriate. Little is known about its reproductive system, but it is presumed to be wind-pollinated. It is thought to have limited sexual reproductive output due to low production of viable seed. The dispersal strategy of *A. pumila* is unknown and the seeds lack structures that facilitate dispersal by wind or passing animals. It may depend on periodic flooding of nearby waterways for dispersal of seeds and rhizomes that can produce new aerial stems. The longevity of individual plants and of seeds, and the potential for buried seed banks to develop in the soil are unknown.

Arundo impacts: *Arundo and A. pumila overlap in range and in habitat. This creates the potential for direct competition and for impacts related to water use, fire and modification of geomorphic processes. These are slightly mitigated by the fact that ambrosia is present in the higher elevation portions of the riparian zone- higher terraces and transition/eco-tones with scrub and grass lands. Arundo debris may cover plants habitat. Arundo fires may result in take and or type conversion. Modified flood and sediment transport may decrease habitat fitness and interfere with seed dispersal of ambrosia.*

Status/Distribution or Historic and Current Range:

Ambrosia pumila is distributed in southern California from northwestern Riverside County, south through western San Diego County, to northwestern Estado de Baja California, Mexico. It is generally found at or below elevations of 487 m (1,600 ft) in Riverside County, and 183 m (600 ft) in San Diego County. At the time of listing, 15 native occurrences of *A. pumila* were considered extant in the United States: 3 in Riverside County and 12 in San Diego County (native is used here to differentiate these from occurrences derived from plants translocated to another site).

Arundo impacts: *Ambrosia is present on highly invaded watersheds, specifically San Diego and San Luis Rey (Appendix B). The strong overlap in range makes larger scale impacts to ambrosia relevant. On Santa Ana one population near Lake Elsinore appears to above the river and little Arundo is present up stream or nearby. The other Santa Ana population is historic (1940), but is near large Arundo infestations on the main river. If new populations were found there could be greater potential for impacts on Santa Ana.*

Decline and Threats:

Loss and degradation of *Ambrosia pumila* habitat is the result of development, non-native plants, fuel modification, altered hydrology and fragmentation. Development results in direct loss of habitat. Competition from non-native plants, primarily non-native grasses and forbs, pose a significant threat to the species throughout its range. No research has been done to clarify the specific effects of non-native plants on *Ambrosia pumila*, but a recent study by the Center for Natural Lands Management in San Diego County demonstrated that reduction of non-natives increased percent cover of *Ambrosia pumila.* Fuel modification activities that can negatively affect *Ambrosia pumila* include weed abatement, fire

suppression, and landscaping practices (including mowing, discing, and plowing). Altered hydrology has the potential to impact *Ambrosia pumila*. It almost always occurs on the upper terraces of rivers/streams or near the margins of vernal pools, where under natural conditions the plants would likely be subjected to inundation during large-scale flooding events. If *Ambrosia pumila* is dependent on these periodic flooding events for some aspect of its life history (e.g., seed germination, dispersal) or control of competing plants, altering the flooding regimes of associated waterways or vernal pools could have a significant impact on the species. However, it is unknown if and to what degree *Ambrosia pumila* is dependent upon periodic flooding or other aspects of its proximity to waterways.

Overall impact metric for *Arundo* on the San Diego ambrosia: High impact, score of 7.

Interaction of *Arundo* distribution and San Diego ambrosia occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Ambrosia pumila (San Diego ambrosia) 5 Year Review and Summary, US Fish and Wildlife Service, Carlsbad Office, CA, July 15 2010. http://ecos.fws.gov/docs/five_year_review/doc3557.pdf

7.2.19 Marsh Sandwort (*Arenaria paludicola*)

Federal status: Endangered, August 3, 1993. Critical habitat has not been designated.
State status: Endangered, February 1990.
Arundo impact score: 4

General Ecological Needs/Habitat Affinities:
Marsh sandwort is an herbaceous green perennial in the Caryophyllaceae family that is often supported by surrounding vegetation. The trailing stems often root at the nodes and can be up to 1 m long. The opposite leaves are lanceolate and narrowly sharp pointed with a solitary mid-vein. It blooms from May to August. Flowers are small, white and borne singly on long stalks. Marsh sandwort is found in freshwater marshes from elevations to about 1,476 ft (450 m) with saturated soils and acidic bog soils, predominantly sandy with high organic content. Vegetation around the Black Lake Canyon population includes emergent freshwater marsh species and some riparian woodland or wetland tree species, mainly willow and wax myrtle. The two existing populations of marsh sandwort in San Luis Obispo County are found in freshwater marshes located within a system of active to partly-stabilized sand dunes.

Arundo impacts: *Minor impacts on the upper Santa Ana to a very old historic sighting (1899).*

Status/Distribution or Historic and Current Range:
Historically it has been collected by botanists from scattered locations near the Pacific coast in southern and central California and Washington. Only two of California's seven historical populations are known to exist today, near the southern San Luis Obispo County coast at Black Lake Canyon on Nipomo Mesa and at Oso Flaco Lake further south.

Arundo impacts: *Only one historic signing on Santa Ana River (Appendix B).*

Decline and Threats:
Immediate threats to the survival of marsh sandwort include habitat destruction, habitat degradation, and competition with non-native species for light, nutrients and space.

Arundo impacts: *Arundo would be a stressor and competitor if it were re-discovered on the Santa Ana River.*

Overall impact metric for *Arundo* on the marsh sandwort: Low/moderate impact, score of 4.

Interaction of *Arundo* distribution and marsh sandwort occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Recovery Plant for marsh sandwort (*Arenaria paludicola*) and Gambel's watercress (*Rorippa gambelii*). U.S. Fish and Wildlife Service, Portland, Oregon, 1998.

7.2.20 San Jacinto Valley Crownscale (*Atriplex coronata* var. *notatior*)

Federal status: Endangered, October 1998. Critical habitat has not been designated.
State status: none
Arundo impact score: 7

General Ecological Needs/Habitat Affinities:
San Jacinto Valley crownscale is an annual plant in the goosefoot family (Chenopodiaceae). It grows 4 to 12 inches (30.5 cm) tall with grayish colored leaves. The plant generally flowers in April and May. This bushy plant can have one or several gray-green stems, which turn deep yellow as it grows older and dies. San Jacinto Valley crownscale is restricted to highly alkaline and silty-clay soils. These soils are found in certain alkali sink scrub, alkali playa, vernal pool, and annual alkali grassland habitats. Habitat for San Jacinto Valley crownscale is typically flooded during winter rains and the plant emerges as waters recede in the spring.

Arundo impacts: *Crownscale does occur in wash areas/floodplain on Alberhill Creek north of Lake Elsinore, where significant Arundo stands also occur. Therefore the two species interact and compete with each other for resources and space.*

Status/Distribution or Historic and Current Range:
San Jacinto Valley crownscale has a narrow range of distribution and is only known to occur in western Riverside County. Within western Riverside County, there are four general population centers of the plant – in the floodplain of the San Jacinto River at the San Jacinto Wildlife Area/Mystic Lake; in the San Jacinto River floodplain between the Ramona Expressway and Railroad Canyon Reservoir; in the Upper Salt Creek Vernal Pool Complex in the west Hemet area; and in the floodplain of Alberhill Creek north of Lake Elsinore. The San Jacinto Valley crownscale experienced a severe decline between 1992 and 1999, when it lost 70 % of its population; it continues to decline today. Because floodwaters carry crownscale seeds over long distances, population ranges may shift from year to year.

Arundo impacts: *As shown in Appendix B Arundo and San Jacinto Valley crownscale overlap in range. Closer examination of polygon data shows clear co-occurrence within the riparian areas.*

Decline and Threats:
The San Jacinto Valley crownscale is in particular danger from increased urbanization because its habitat is nearly flat and therefore easy to develop. It is also threatened by habitat fragmentation, agricultural weed-control measures where its habitat is repeatedly disked, off-road vehicle use, alteration of hydrology, deliberate manure and sludge dumping, trampling by livestock, and competition from nonnative species.

Arundo impacts: *The sites have all of these impacts: agricultural use, urban use, water management facilities. Arundo adds to the population's stress by directly competing against it. Arundo is also dense enough to add biomass debris over crownscale habitat following flood events. Fire could also impact habitat and sedimentation. Of added concern is response to fire and flood events that are of greater magnitude due to high Arundo cover. The area has heavy infrastructure (roads, water transfer, levees, agriculture use, etc.) that would likely lead to damaging emergency actions in response to events.*

Overall impact metric for *Arundo* on the San Jacinto Valley crownscale: High Impact, score of 7.

Interaction of *Arundo* distribution and San Jacinto Valley crownscale occurrence is presented by watershed in Table 7-3 and Appendix B.

Sources:
Species Profile for San Jacinto Valley crownscale (*Atriplex coronata notatior*), U.S. Fish and Wildlife Service, http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=Q2ZR

7.2.21 Nevin's Barberry (*Berberis nevinii)*

Federal status: Endangered, October 13, 1998. Critical habitat designated on February 13 2008.
State status: Endangered, January 1987.
Arundo impact score: 4

General Ecological Needs/Habitat Affinities:
Nevin's barberry is a large rounded shrubby member of the barberry family (Berberidaceae) that grows up to 13 ft (4 m) tall, with blue-green, spiny pinnate leaves. It is widely cultivated and popular in xeric gardens, in part for its bright red edible berries and bright yellow flowers that bloom March through April. Nevin's barberry generally grows within sandy, gravelly soil, on north facing slopes or low gradient washes. On north-facing slopes, it is associated with coastal scrub and chaparral habitat, while in low gradient washes it is found in alluvial and riparian scrub. In general, the plant occurs from 800-5200 ft (1,585 m) above sea level, with local distribution potentially related to the presence of groundwater. Associated plant communities are alluvial scrub, riparian scrub or woodland, coastal sage scrub, chaparral, and/or oak woodland.

Arundo impacts: *Arundo occurs within population ranges of barberry when plants are located within low gradient washes. These are not usually areas where Arundo becomes overly abundant, but it be locally abundant. Direct competition between plants as sites could occur. Abiotic impacts are unlikely due to limited extent of Arundo upstream of washes where barberry occurs.*

Status/Distribution or Historic and Current Range:
The distribution of Nevin's barberry is scattered, with populations located throughout southern California in Los Angeles, Riverside, and San Bernardino counties. There have been a total of 34 occurrences of *Berberis nevinii* reported in southern California, five of which have been or are presumed extirpated and 7 considered to have been introduced. Total number of individuals is estimated at 500, with approximately half of those as naturally occurring individuals. In addition, the majority of occurrences are comprised of only one to few individuals, with little to no reproduction observed.

Arundo impacts: *Arundo and barberry co-occur in Santa Clara (Arundo is scattered to dense), and several area on the Los Angeles and San Gabriel Rivers (Arundo is scattered, Appendix B).*

Decline and Threats:
Population decline is likely related to low fecundity and habitat loss. Populations that occur in alluvial washes are threatened by urban and agricultural development, competition by non-native plant species, off-road vehicle activity, road maintenance, and vegetation clearing and channelization for flood control. While population sizes vary considerably among extant groups, the majority of occurrences are comprised of only one to a few individuals, with little to no reproduction observed. Most of the historic habitat of Nevin's barberry has been eliminated by agriculture, urban development, and flood control and stream channelization.

Overall impact metric for *Arundo* on the Nevin's barberry: Low/moderate impact, score of 4.

Interaction of *Arundo* distribution and Nevin's barberry occurrence is presented by watershed in Table 7-3 and distribution is shown in Appendix B.

Sources:
Stillwater Sciences. 2007. Focal Species Analysis and Habitat Characterization for the Lower Santa Clara River and Major Tributaries, Ventura County, California. Santa Clara River Parkway Floodplain Restoration Feasibility Study.
Center for Plant Conservation, National Collection Plant Profile for Nevin's Barberry, http://www.centerforplantconservation.org/collection/cpc_viewprofile.asp?CPCNum=2777

7.2.22 Spreading Navarretia (*Navarretia fossalis*)

Federal status:	Threatened, October 13 1998. Critical habitat: October 18 2005. A proposal for revised critical habitat was initiated on June 10 2009.
State status:	None
Arundo impact score:	6

General Ecological Needs/Habitat Affinities:
Spreading navarretia is an annual plant in the Polemoniaceae (phlox family). It is a low, mostly spreading or ascending plant 4 - 6 inches (10 - 15 cm) tall. The leaves are long and finely divided into slender spine-tipped lobes and the lavender-white flowers are arranged in flat-topped, compact, leafy heads. Each seed is covered by a layer that becomes sticky and viscous when the capsule is moistened. Spreading navarretia is typically found in vernal pool (seasonal depression wetlands) habitat, particularly in Los Angeles and San Diego Counties. In western Riverside County, however, *Navarettia fossalis* is associated with seasonally flooded alkali vernal plain habitat that includes alkali playa (highly alkaline, poorly drained), alkali scrub, alkali vernal pool, and alkali annual grassland components. *Navarretia fossalis* depends on the inundation and drying cycles of its habitat for survival. It germinates from seeds left in the seed bank. Most *Navarretia* species have indehiscent fruit, or fruit with fibers that absorb water and expand to break open the fruit after a substantial rain. The timing of germination is important so that the plant germinates under favorable conditions in the spring rather than the summer, autumn, or winter. *Navarretia fossalis* abundance also varies from year to year depending on precipitation and the inundation/drying time of the vernal pool. The occurrences of plants can also vary spatially in alkali playa habitat where pools are not in the same place from year to year. After germination, the plant usually flowers in May and June as the vernal pool is devoid of water. The plant then produces fruit, dries out, and senesces in the hot, dry summer months.

Arundo impacts: *Although navarretia habitat sounds restrictive Arundo co-occurs with the Riverside San Jacinto Valley navarretia population (Appendix B). This area is a broad floodplain and is the same area where San Jacinto crownscale is found. This area has a narrow river thread heavily invaded with*

Arundo bordered by flat floodplains. Impacts described in the crownscale section ally to this species as well (risk of fire, Arundo debris, flood damage and 'emergency actions' to repair and protect infrastructure.

Status/Distribution or Historic and Current Range:
Spreading navarretia extends from northwestern Los Angeles County to western Riverside County, and coastal San Diego County in California, to San Quintin in northwestern Baja California, Mexico.

Arundo impacts this by: *As noted these species co-occur in San Jacinto Valley (Appendix B).Populations of navarretia that occur in San Diego County watersheds typically occur in vernal pools where Arundo is not present. The Santa Clara navarretia population also occurs in a vernal pool.*

Decline and Threats:
Threats include agriculture, fragmentation, grazing and urbanization.

Overall impact metric for *Arundo* on spreading navarretia: Moderate/high Impact, score of 6.

Interaction of *Arundo* distribution and spreading navarretia occurrence is presented by watershed in Table 7-3.

Sources:
Center for Plant Conservation, National Collection Plant Profile for spreading navarretia, http://www.centerforplantconservation.org/collection/CPC_ViewProfile.asp?CPCNum=2930
5-Year Review for spreading navarretia (*Navarretia fossalis*) U.S. Fish and Wildlife Service, http://ecos.fws.gov/docs/five_year_review/doc2574.pdf

Table 7-3. Examination of *Arundo* impacts on federally listed species by watershed.
'*Arundo* impact rank' and 'overlap rank' (potential for interaction between *Arundo* and listed species distribution and abundance) for each species. The cumulative impact score is in Table 7-4.

Category	Federal Listing[1]	Scientific name	Common name	*Arundo* Impact	Tijuana Estuary	Otay	Sweet-water	S.Diego/ Penasquitos	San Dieguito	Carlsbad	San Luis Rey	Santa Margarita	San Juan	San Francisquito Crk/ Newport	Santa Ana	L.A./ San Gabriel/ Santa Monica	Calleguas	Santa Clara	Ventura	S.Barbara, SouthCoast &S.Ynez	Estero Bay	Salinas	S.Cruz/ Benito	Count
Amphibian	En	*Ambystoma californiense*	California tiger salamander[2]	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	2
Amphibian	En	*Bufo californicus*	Arroyo toad	10	-	-	5	3	7	-	10	10	7	7	-	3	-	4	-	-	-	2	-	10
Amphibian	Th	*Rana aurora draytonii*	California red-legged frog	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	2	5	2	3	5
Amphibian	En	*Rana muscosa*	Mountain yellow-legged frog	4	-	-	-	-	-	-	-	-	-	-	4	6	-	-	-	-	-	-	-	2
Bird	Th	*Charadrius alexandrinus nivosus*	Western snowy plover	5	1	1	1	6	-	8	-	9	-	-	0	4	0	1	-	1	-	-	-	9
Bird	Sp of Concern	*Coccyzus americanus occidentalis*	Western yellow-billed cuckoo	7	-	-	1	-	-	-	-	1	0	-	7	-	-	4	-	-	1	-	-	5
Bird	En	*Empidonax traillii extimus*	Southwestern willow flycatcher	8	-	-	2	2	3	2	10	10	3	-	6	1	-	2	-	2	-	-	-	11
Bird	Sp of Concern	*Passerculus sandwichensis beldingi*	Belding's savannah sparrow	2	3	3	3	3	3	3	-	-	-	2	2	2	6	-	-	2	-	-	-	11
Bird	Th	*Polioptila californica californica*	Coastal California gnatcatcher	2	3	3	3	3	3	3	4	4	3	4	4	2	2	1	-	-	-	-	-	14
Bird	En	*Rallus longirostris levipes*	Light-footed clapper rail	3	2	2	3	2	2	4	2	3	-	2	-	-	1	-	-	1	-	-	-	11
Bird	En	*Sterna antillarum browni*	California least tern	4	-	1	-	3	2	4	-	7	-	1	-	1	-	1	-	-	-	-	-	8
Bird	En	*Vireo bellii pusillus*	Least Bell's vireo	9	4	4	4	4	4	3	9	10	6	6	10	4	3	3	3	1	-	-	-	14
Fish	En	*Eucyclogobius newberryi*	Tidewater goby	7	-	-	-	-	-	4	8[a]	8[a]	-	-	-	-	3	6[a]	8	5	3	4	1	7
Fish	En	*Gasterosteus aculeatus williamsoni*	Unarmored three spine stickleback	8	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-	-	1
Fish	En&Th[3]	*Oncorhynchus mykiss*	Steelhead	7	-	-	-	-	-	-	1	-	1	-	-	4	-	8	8	7	5	8	5	9
Fish	Th	*Catostomus santaanae*	Santa Ana sucker	6	-	-	-	-	-	-	-	-	-	-	9	7	-	4	-	-	-	-	-	3
Mammal	En	*Vulpes macrotis mutica*	San Joaquin kit fox	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1
Plant	En	*Ambrosia pumila*	San Diego ambrosia	7	-	2	-	-	7	-	7	-	-	-	2	-	-	-	-	-	-	-	-	4
Plant	En	*Arenaria paludicola*	Marsh sandwort	4	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Plant	En	*Atriplex coronata var. notatior*	San Jacinto Valley crownscale	7	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-	-	0
Plant	En	*Berberis nevinii*	Nevin's Barberry	4	-	-	-	-	-	-	-	-	-	-	-	5	-	3	-	-	-	-	-	2
Plant	Th	*Navarretia fossalis*	Spreading navarretia	6	-	-	-	-	-	-	-	-	-	-	10	-	-	1	-	-	-	-	-	1

[1] En = Endangered, Th = Threatened, Sp of Concern = Species of Concern
[2] Santa Barbara Distinct Population Segment (DPS)
[3] Southern California (DPS) is endangered, South-Central California Coast DPS is threatened.
[a] Recent historic 1990s/2000

Table 7-4. Cumulative impact scores for *Arundo* impacts on threatened and endangered species by watershed.
The cumulative impact score is calculated by multiplying the *Arundo* impact rank by overlap rank. Impact scores are for each watershed and species, and are totaled for each watershed and species.

Category	Federal Listing[1]	Scientific name	Common name	Tijuana Estuary	Otay	Sweet-water	S.Diego/ Penasquitos	San Dieguito	Carlsbad	San Luis Rey	Santa Margarita	San Juan	San Francisquito Crk/ Newport	Santa Ana	L.A./ San Gabriel/ Santa Monica	Calleguas	Santa Clara	Ventura	S.Barbara, SouthCoast &S.Ynez	Estero Bay	Salinas	S.Cruz/ Benito	Total
Amphibian	En	*Ambystoma californiense*	California tiger salamander[2]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	**6**
Amphibian	En	*Bufo californicus*	Arroyo toad	-	-	50	30	70	-	100	100	70	70	-	30	-	40	-	-	-	20	-	**580**
Amphibian	Th	*Rana aurora draytonii*	California red-legged frog	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	6	15	6	9	**60**
Amphibian	En	*Rana muscosa*	Mountain yellow-legged frog	-	-	-	-	-	-	-	-	-	-	16	24	-	-	-	-	-	-	-	**40**
Bird	Th	*Charadrius alexandrinus nivosus*	Western snowy plover	5	5	5	30	-	40	-	45	-	-	-	20	-	5	-	5	-	-	-	**160**
Bird	Sp of Concern	*Coccyzus americanus occidentalis*	Western yellow-billed cuckoo	-	-	7	-	-	-	-	7	-	-	49	-	-	28	-	-	7	-	-	**98**
Bird	En	*Empidonax traillii extimus*	Southwestern willow flycatcher	-	-	16	16	24	16	80	80	24	-	48	8	-	16	-	16	-	-	-	**344**
Bird	Sp of Concern	*Passerculus sandwichensis beldingi*	Belding's savannah sparrow	6	6	6	6	6	6	-	-	-	4	4	4	12	-	-	4	-	-	-	**64**
Bird	Th	*Polioptila californica californica*	Coastal California gnatcatcher	6	6	6	6	6	6	8	8	6	8	8	4	4	2	-	-	-	-	-	**84**
Bird	En	*Rallus longirostris levipes*	Light-footed clapper rail	6	6	9	6	6	12	6	9	-	6	-	-	3	-	-	3	-	-	-	**72**
Bird	En	*Sterna antillarum browni*	California least tern	-	4	-	4	8	16	-	28	-	4	-	4	-	4	-	-	-	-	-	**72**
Bird	En	*Vireo bellii pusillus*	Least Bell's vireo	36	36	36	36	36	27	81	90	54	54	90	36	27	27	27	9	-	-	-	**702**
Fish	En	*Eucyclogobius newberryi*	Tidewater goby	-	-	-	-	-	-	56	56	-	-	-	-	21	42	-	35	21	28	7	**266**
Fish	En	*Gasterosteus aculeatus williamsoni*	Unarmored three spine stickleback	-	-	-	-	-	-	-	-	-	-	-	-	-	64	-	-	-	-	-	**64**
Fish	En&Th[3]	*Oncorhynchus mykiss*	Steelhead	-	-	-	-	-	-	7	-	7	-	-	28	-	56	56	49	35	56	35	**329**
Fish	Th	*Catostomus santaanae*	Santa Ana sucker	-	-	-	-	-	-	-	-	-	-	54	42	-	24	-	-	-	-	-	**120**
Mammal	En	*Vulpes macrotis mutica*	San Joaquin kit fox	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	**2**
Plant	En	*Ambrosia pumila*	San Diego ambrosia	0	14	-	-	49	-	49	-	-	-	14	-	-	-	-	-	-	-	-	**126**
Plant	En	*Arenaria paludicola*	Marsh sandwort	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	**4**
Plant	En	*Atriplex coronata var. notatior*	San Jacinto Valley crownscale	-	-	-	-	-	-	-	-	-	-	70	-	-	-	-	-	-	-	-	**70**
Plant	En	*Berberis nevinii*	Nevin's Barberry	-	-	-	-	-	-	-	-	-	-	-	20	-	12	-	-	-	-	-	**32**
Plant	Th	*Navarretia fossalis*	Spreading navarretia	-	-	-	-	-	-	-	-	-	-	60	-	-	6	-	-	-	-	-	**66**
			Total:	**59**	**77**	**135**	**134**	**205**	**123**	**387**	**423**	**161**	**146**	**417**	**220**	**67**	**326**	**107**	**127**	**78**	**115**	**54**	**3,361**

[1] En = Endangered, Th = Threatened, Sp of Concern = Species of Concern
[2] Santa Barbara Distinct Population Segment
[3] Southern California Distinct Population Segment (DPS) is endangered, South-Central California coast DPS is threatened.

Table 7-5. Cumulative *Arundo* impact score for each species for all watersheds combined, and sum and average for each taxa group.

Category	Federal Listing[1]	Scientific name	Common name	Cumulative Impact Score for all watersheds	Summary for Taxa Group
Amphibian	En	*Ambystoma californiense*	California tiger salamander[2]	6	Sum – 686 Ave – 171.5
Amphibian	En	*Bufo californicus*	Arroyo toad	580	
Amphibian	Th	*Rana aurora draytonii*	California red-legged frog	60	
Amphibian	En	*Rana muscosa*	Mountain yellow-legged frog	40	
Bird	Th	*Charadrius alexandrinus nivosus*	Western snowy plover	160	Sum – 1,596 Ave – 199.5
Bird	Sp of Concern	*Coccyzus americanus occidentalis*	Western yellow-billed cuckoo	98	
Bird	En	*Empidonax traillii extimus*	Southwestern willow flycatcher	344	
Bird	Sp of Concern	*Passerculus sandwichensis beldingi*	Belding's savannah sparrow	64	
Bird	Th	*Polioptila californica californica*	Coastal California gnatcatcher	84	
Bird	En	*Rallus longirostris levipes*	Light-footed clapper rail	72	
Bird	En	*Sterna antillarum browni*	California least tern	72	
Bird	En	*Vireo bellii pusillus*	Least Bell's vireo	702	
Fish	En	*Eucyclogobius newberryi*	Tidewater goby	266	Sum – 779 Ave – 194.8
Fish	En	*Gasterosteus aculeatus williamsoni*	Unarmored three spine stickleback	64	
Fish	En&Th[3]	*Oncorhynchus mykiss*	Steelhead	329	
Fish	Th	*Catostomus santaanae*	Santa Ana sucker	120	
Mammal	En	*Vulpes macrotis mutica*	San Joaquin kit fox	2	2
Plant	En	*Ambrosia pumila*	San Diego ambrosia	126	Sum – 298 Ave – 59.6
Plant	En	*Arenaria paludicola*	Marsh sandwort	4	
Plant	En	*Atriplex coronata var. notatior*	San Jacinto Valley crownscale	70	
Plant	En	*Berberis nevinii*	Nevin's Barberry	32	
Plant	Th	*Navarretia fossalis*	Spreading navarretia	66	
			Total:	**3,361**	

7.3 Results

7.3.1 Summary by Species and Group

7.3.1.1 Impact Scores

Within the study area, 22 federally protected species were found to be impacted at some level by the presence of *Arundo*. The magnitude of the impact score ranged from 10 (very severe) to 1 (very low/improbable) (Table 7-3). Five taxonomic groups are represented: amphibian, avian, fish, mammal, and plant. All groups have a minimum of four species with the exception of mammal, which had one.

Amphibians had the widest range of *Arundo* impact scores among the groups. Arroyo toads had severe impacts from *Arundo*, both abiotic and biotic. The other amphibian species (California tiger salamander, California red-legged frog, and mountain yellow-legged frog) were less impacted due to greater habitat use in foothills and mountains where *Arundo* is less abundant. In these areas, *Arundo* is less likely to directly impact the species or to generate enough biomass to degrade habitat significantly.

Avian species fell into two general classes based on the habitat they use. Species that use riparian habitat had impact scores that ranged from high (7) to severe (9), reflecting both abiotic and biotic impacts. This included the least Bell's vireo, southwestern willow flycatcher and yellow-billed cuckoo. Species that use estuary and beach areas were also impacted by *Arundo*, usually as a function of biomass accumulating in habitat areas (discharged from upstream riparian areas), but also to a lesser degree from *Arundo* growing in estuaries and on beaches. Avian species that use beach and estuary habitat had impact scores ranging from moderate (5) to very low (2), reflecting *Arundo* impacts on breeding and predation. In addition to these two classes, the gnatcatcher had a low impact score (2), because it does not breed or feed exclusively in riparian habitat. Avian species were also, as a group, susceptible to physical changes in habitat structure, encouraging predators that use *Arundo* as perches and/or dense cover for denning.

Fish species had fairly uniform impacts from *Arundo* related to modification of abiotic processes that control geomorphology and hydrology. Modification of channel form and depth is a significant change to habitat structure. *Arundo* biomass and shading also have possible effects on habitat quality. Fish habitat varies depending on the species. It may occur only near the river mouth (tidewater goby), reside along river/stream corridors (Santa Ana sucker, stickleback), or pass through the main river corridor to headwaters that are relatively uninvaded by *Arundo* (southern steelhead). Southern steelhead also reside for part of their life-cycle in estuaries. *Arundo* impact scores ranged from very high (8) to moderate/high (6).

The only federally listed mammal species examined was the San Joaquin kit fox, which resides in the northern part of the study area. It has a very low/improbable (1) impact score from *Arundo*. The kit fox does not utilize riparian habitat frequently, and is not dependent on it. It may use riparian areas as corridors for movement.

Water use, fire, biomass and modification of geomorphology are the primary *Arundo* impacts on the five plant species examined. Four of the plant species occur on upper portions of the riparian zone (San Diego ambrosia and Nevin's barberry) or broad areas within the floodplain (San Jacinto crownscale and spreading navarretia). These four species have *Arundo* impact scores ranging from high (7) to low/moderate (4). San Jacinto crownscale and spreading navarretia occur at a single location within the San Jacinto/Santa Ana watershed, so it is possible to look at very specific interactions for these two species. The fifth plant species, marsh sandwort, occurs in inland freshwater marsh. It is a historic occurrence, so *Arundo* impacts were projected to the species' habitat preferences. Although it is

unlikely that marsh sandwort still occurs at this location, *Arundo* is having abiotic and biotic impacts that degrade habitat characteristics favored by the plant.

7.3.1.2 Overlap or Spatial Interaction Scores

Overlap rank scores are given in Table 7-3. These were generated by interpreting distribution maps of *Arundo* and each listed species. Species occurring in downstream portions of the watersheds (river mouth, estuaries, beaches) can receive high scores if significant *Arundo* infestations occur upstream. Scores ranged from 1 (no interaction) to 10 (very high interaction).

Overlap scores captured the interaction between *Arundo* and each species' distribution and abundance. Avian species were the widest ranging, with high numbers of watersheds recording occurrences, particularly in the southern and middle of the study area. Fish species also had large numbers of watersheds with occurrences, but more in the middle and northern portions of the study area. Plants were the most restricted, each species typically occurring on only one or two watersheds.

7.3.1.3 Cumulative Impact Scores

The *Arundo* impact score is multiplied by the overlap score to generate a cumulative impact score for each species in each watershed. This metric highlights watersheds, species and taxa groups that are under the most significant pressure from *Arundo*. The avian group is the most impacted by *Arundo*, with a score of 1,596 (199.5 average). This is followed closely by amphibians at 686 (171.5 average). The plant group has the lowest score at 298 (59.6 average), largely due to very limited population ranges for the listed species. Mammals also rank very low, being represented by a single species with low abundance and low impacts from *Arundo*.

Several species stand out as having severe cumulative *Arundo* impact scores across the study area (Figure 7-1). The highest scoring species in the 'severe' category are the least Bell's vireo (702) and the arroyo toad (580). The southwestern willow flycatcher has a 'very high' cumulative impact score of 344. The three species are frequently cited as being under significant pressure from *Arundo* within their ranges. These data strongly supports these accounts.

The cumulative impact scores for the fish are 'very high' for two species (steelhead and tidewater goby), 'high' for the third (Santa Ana sucker) and 'moderate' for the fourth species (unarmored three spine stickleback). *Arundo* impacts on fish have not been recognized in the literature or explored in detailed studies. *Arundo*'s influence on abiotic processes indicates that significant impacts and degradation are likely occurring on heavily *Arundo* invaded watersheds.

The 'high' score for the western snowy plover (160) and the tidewater goby (266), and to a lesser degree the California least tern (72), demonstrate that estuaries, beaches and river mouth areas that support these listed species are impacted by *Arundo* on a number of watersheds within the study area. This has been alluded to in numerous studies and it appears to be a valid area of concern. *Arundo* not only degrades riparian habitat, but it also impacts estuaries and beaches, both of which are wetlands of high value and diversity.

Watershed totals for cumulative *Arundo* impact scores clearly demonstrate that those highly-invaded larger watersheds have the most severe impacts to federally listed species (Santa Margarita = 423, Santa Ana = 417, San Luis Rey = 387 and Santa Clara = 326) (Figure 7-2). The Salinas River is the exception, likely due to its more northern position and its lower diversity and abundance of federally listed species. The next tier of highly-impacted watersheds is well separated from the higher tier with scores of 220 for Los Angeles./San Gabriel/Santa Monica and 205 for San Dieguito. The moderate impact tier includes

eight watersheds whose cumulative *Arundo* impact scores range from 161 to 107 (Figure7-2). These include San Juan, San Francisquito/Newport, Sweetwater, San Diego, Ventura, Carlsbad, Santa Barbara, and Salinas. The low cumulative *Arundo* impact tier includes five watersheds whose values range from 78 to 54 (Figure 7-2).:Estero Bay, Otay, Calleguas, Tijuana, and Santa Cruz/Benito. The cumulative *Arundo* impact scores highlight watersheds with *Arundo* impacts to a number of federally listed species. Low ranking watersheds may still have a high cumulative impact for a single species, such as steelhead on the Ventura watershed.

7.3.2 Discussion

Arundo impact scores are very severe (10) to moderate/high (6) for 11 out of the 22 evaluated federally listed species. This indicates that *Arundo*'s modification of abiotic and biotic ecosystem processes is having significant impacts on a wide range of species:

Listed fish as a taxonomic group has high impact scores from *Arundo*. This has not been widely recognized in conservation biology. Listed avian species that fairly exclusively use riparian habitat (least Bell's vireo, southwestern willow flycatcher, yellow-billed cuckoo) had high impact scores and are recognized as being impacted by fires and habitat degradation. Arroyo toads appear to be severely impacted by *Arundo* invasion as they are dependent on geomorphic forms and hydrology that are severely degraded by *Arundo*. Listed plants also had significant impacts tied to specific sites where populations occur.

The cumulative impact scores, which account for the interaction in actual distributions of *Arundo* and the individual listed species, highlight particular species that are under significant pressure within the study area. Five species stand out: least Bell's vireo, arroyo toad, southwestern willow flycatcher, steelhead and tidewater goby. Arroyo toad, steelhead and tidewater goby have not been previously highlighted as species under significant pressure due to habitat and ecosystem modification by *Arundo*.

The impacts described to estuarine and beach avian species are an important extension of impacts to additional habitat types. These impacts typically rank as moderate to low, but they are well documented as pressures on breeding areas, as well as predation.

Prioritization of watersheds by impacts caused by *Arundo* to federally listed species is complicated. The larger watersheds clearly have the greatest impacts on federally listed species (Figure 7-2). These systems are heavily invaded and are having the most severe modification of abiotic and biotic processes, which is reflected in impact scores. It is interesting to note that three of the four systems also have the most active and comprehensive *Arundo* eradication programs. These systems have already been prioritized in terms of on the ground activity.

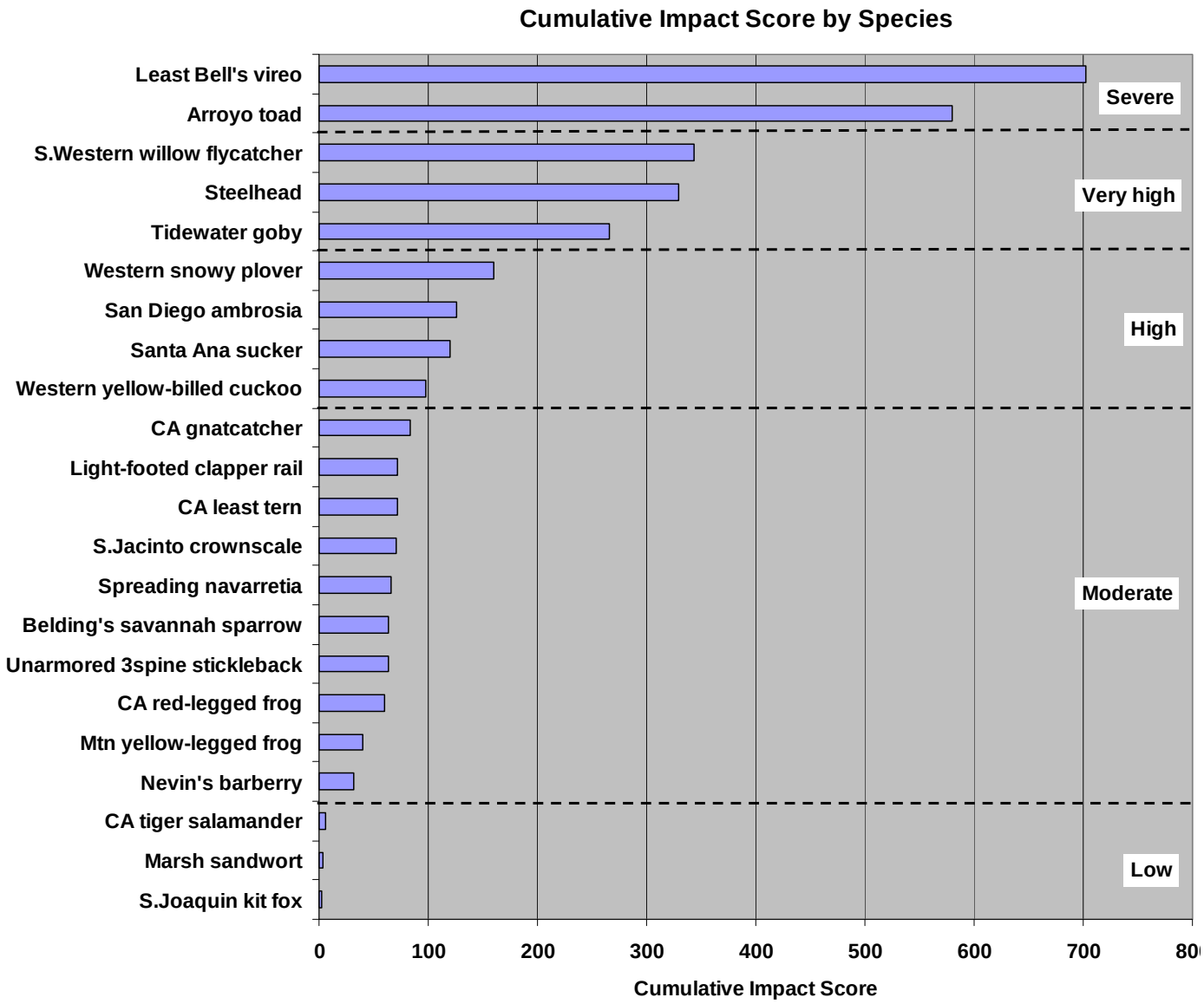


Figure 7-1. Cumulative *Arundo* impact score by species for all watersheds.

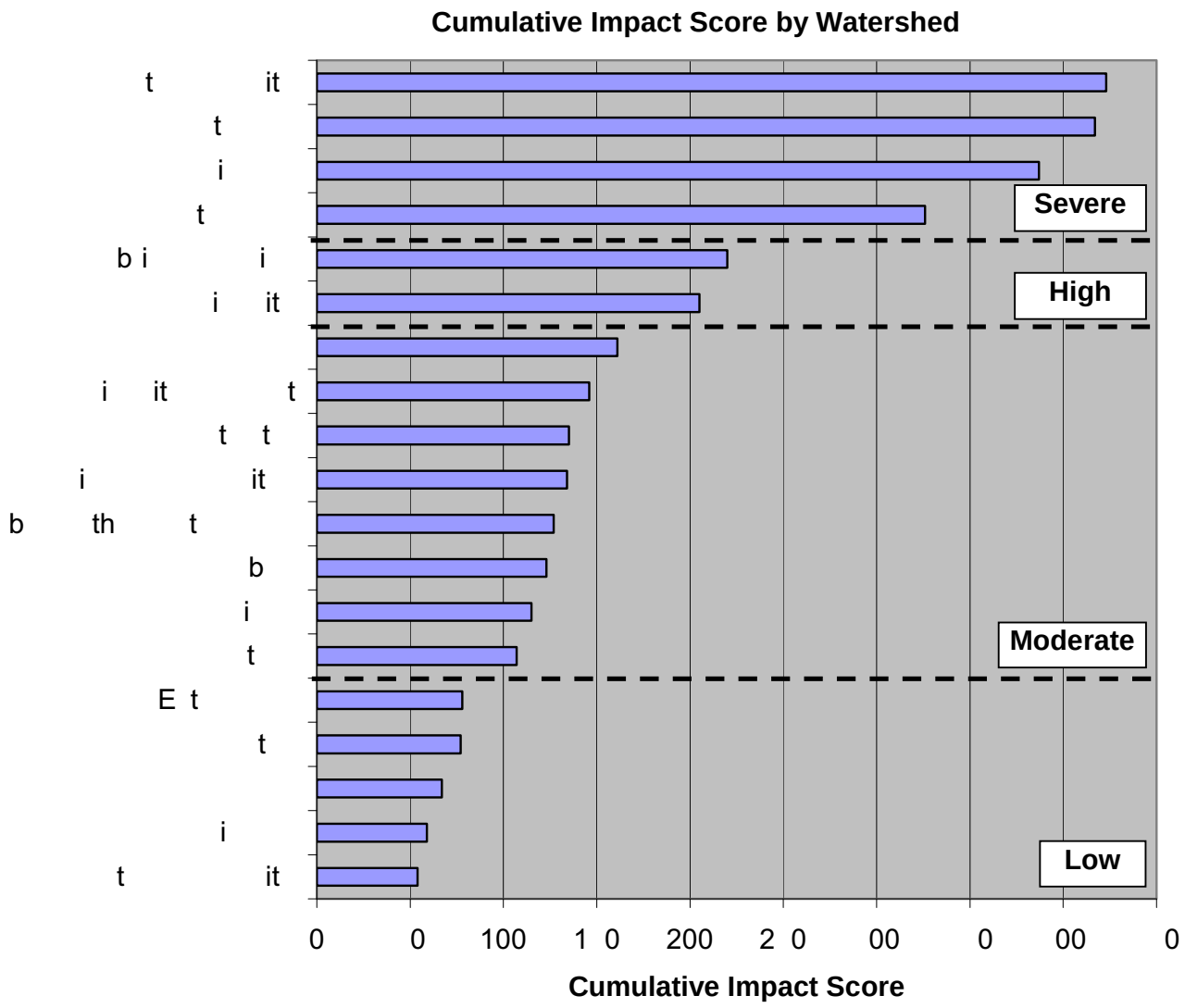


Figure 7-2. Cumulative *Arundo* impact scores by watershed for all federally listed species combined.

8.0 COST TO BENEFIT ANALYSIS

A cost-to-benefit analysis (CBA) is often used to evaluate the desirability of a given action or intervention. CBAs use a monetary valuation of costs and benefits, which are then expressed as a ratio. This allows the many impacts of an invasive species, such as *Arundo*, to be synthesized into a common measure, namely dollars. The results can then be used to show how much benefit is obtained by removing the species and where the most substantial benefits accrue. This in turn could help focus control efforts on watersheds or sites with the greatest potential benefit.

Multiple CBAs have examined the potential net economic benefit of programs to control *Arundo*. A detailed examination of benefits related to water savings on the Rio Grande River in Texas found a net benefit four to eight times greater than the cost (Seawright 2009). Broader CBAs covering multiple factors on watersheds within California have found benefit to cost ratios of 3.9:1 for the Santa Clara (Swezey 2008) and 1.1:1 for the Santa Margarita (Hastings et al. 1998). These CBAs were far less intensive analyses compared to the Seawright study. All CBAs for *Arundo* that could be found showed a positive benefit to cost ratio.

Completing a CBA for *Arundo* control is more straightforward than many that are completed for other types of environmental programs. This is due to reasonably well-defined impacts (potential benefits when *Arundo* is controlled) and applicable cost valuations. Impacts from *Arundo* within the study area have been quantified in this report using the mapped spatial distribution of *Arundo*. This information is used in this CBA, which applies to the entire study area. Cost and benefits are generated for both the peak *Arundo* distribution and current infestation level (which reflects control work over the past 15 years). A ten-year evaluation period was selected as many impacts are periodic in nature and control programs typically take many years to implement. This CBA is a rudimentary analysis and was not completed by an economist. Many complexities were excluded from the analysis including discounting and depreciation over time. As both the benefits and the costs are accrued on a similar timeline, this simplification is not likely to adversely affect the analysis. Also, unlike other CBA studies (such as Seawright 2009), this CBA did not project future increases in acreage of *Arundo* (increases the valuation of benefits in the future).

For this CBA, the costs of controlling *Arundo* will be evaluated, and then the benefits will be presented. This includes an analysis for each benefit (impact) class to clearly outline what approach was used in determining valuations. Results are then presented as a Benefit to Cost ratio to determine the net benefit or cost of controlling *Arundo* within the study area. The higher the benefit is in relation to the cost, the better the economic justification for the action.

8.1 Cost

Generating the cost of controlling *Arundo* for watersheds within the study area is straightforward. The spatial data set gives acreage for *Arundo* within each watershed, and therefore a good estimate of cost per acre for control is all that is needed. Over $70 million have already been spent controlling *Arundo* within the study area over the past 15 years. The approximate amount of money spent treating *Arundo* on each watershed is known as most programs share this information in news updates, proposals and other outreach material. For each watershed treated, acreage and cost of work completed is given in Table 8-1. This data is based on the author's knowledge of federal, state, and local funding of implementation programs, as well as information published by watershed programs. The average cost is $25,000 per acre of *Arundo* controlled. This is a strongly supported valuation based on over fifty projects within nine watersheds that have large implementation programs. This cost is subdivided into $5,000 for management and $20,000 for implementation, based on the author's knowledge of typical cost subdivisions in proposals and reports. Program management costs are high (management of

contractors, right of entry agreements, permitting, etc.) as are implementation costs (treatment, biomass reduction, re-vegetation, etc.). It is not surprising that *Arundo* control is an expensive undertaking given that *Arundo* stands have high biomass per acre, are difficult to control, and exist in sensitive habitat that is highly regulated. *Arundo* is also distributed across the landscape making program implementation complex and management intensive.

It should be noted that control costs vary substantially between watersheds and projects. This can be attributed to different treatment approaches, how biomass is dealt with, efficiency, and if re-vegetation is included in the project. The $25,000 average cost per acre for control is a well-supported cost estimate for watersheds taken as a whole, or for larger implementation projects. This estimate should not necessarily be used for site-specific projects, particularly if they are small.

The total cost of controlling all *Arundo* at the peak of its acreage would have been $196 million for 7,859 net acres (Table 8-2). A significant amount of control has already occurred, and the current cost of controlling *Arundo* at current distribution levels is $124 million for 4,997 net acres.

Table 8-1. Existing program costs used to generate cost basis for *Arundo* control by watershed within the study area.

Watershed	Treated net acres	Expenditure	Cost per acre
Calleguas	1.4	-	-
Carlsbad	98.7	1,500,000	15,201
Estero Bay	1.2	-	-
Los Angeles River	16.3	250,000	15,379
Otay	-	-	-
Pajaro River	-	-	-
Penasquitos	2.2	-	-
Pueblo San Diego	0.0	-	-
Salinas	106.4	500,000	4,700
San Diego	56.2	1,000,000	17,798
San Dieguito	89.8	1,500,000	16,701
San Gabriel River	0.0	-	-
San Juan	13.1	250,000	19,025
San Luis Rey	612.4	7,500,000	12,246
Santa Ana	1006.9	40,000,000	39,724
Santa Clara	0.3	-	-
Santa Margarita	684.7	10,000,000	14,605
Santa Monica Bay	0.3	-	-
Santa Ynez	-	-	-
South Coast	7.8	-	-
Sweetwater	5.7	-	-
Tijuana	41.1	1,500,000	36,496
Ventura River	117.4	7,500,000	63,909
TOTALS:	**2861.9**	**$71,500,000**	**$24,983**

Table 8-2. Estimated control costs by watershed within the study area for peak *Arundo* levels and current *Arundo* levels.

Watershed	PEAK Net Acres	Cost peak distribution			CURRENT Net Acres	Cost current infestation		
		Management: 5k	Implementation: 20k	Total		Management: 5k	Implementation: 20k	Total
Calleguas	229	1,145,750	4,583,000	5,728,750	228	1,138,539	4,554,155	5,692,693
Carlsbad	148	739,472	2,957,889	3,697,362	49	246,088	984,352	1,230,440
Estero Bay	10	48,828	195,310	244,138	9	42,953	171,811	214,764
Los Angeles	131	656,886	2,627,543	3,284,429	115	575,608	2,302,431	2,878,039
Otay	19	92,945	371,781	464,726	19	92,945	371,781	464,726
Pajaro River	8	40,681	162,723	203,404	8	40,681	162,723	203,404
Penasquitos	24	117,737	470,947	588,683	21	106,860	427,440	534,300
Pueblo S.Diego	15	75,009	300,035	375,043	15	74,834	299,336	374,170
Salinas	1,332	6,658,544	26,634,177	33,292,721	1,225	6,126,663	24,506,651	30,633,314
San Diego	149	747,328	2,989,310	3,736,638	93	466,390	1,865,559	2,331,949
San Dieguito	175	874,894	3,499,577	4,374,471	85	425,825	1,703,299	2,129,124
San Gabriel	44	221,535	886,141	1,107,677	44	221,465	885,858	1,107,323
San Juan	173	867,083	3,468,333	4,335,416	160	801,380	3,205,519	4,006,899
San Luis Rey	684	3,419,392	13,677,570	17,096,962	71	357,237	1,428,946	1,786,183
Santa Ana	2,534	12,668,913	50,675,651	63,344,563	1,527	7,634,222	30,536,887	38,171,109
Santa Clara	1,019	5,093,858	20,375,431	25,469,289	1,018	5,092,328	20,369,313	25,461,641
Santa Margarita	689	3,444,463	13,777,850	17,222,313	4	20,972	83,890	104,862
Santa Monica	18	92,430	369,722	462,152	18	90,964	363,857	454,821
Santa Ynez	6	30,104	120,414	150,518	6	30,104	120,414	150,518
South Coast	30	149,075	596,300	745,375	22	110,003	440,014	550,017
Sweetwater	42	208,866	835,464	1,044,330	36	180,474	721,897	902,371
Tijuana	131	653,115	2,612,459	3,265,574	90	447,615	1,790,459	2,238,074
Ventura River	250	1,249,462	4,997,848	6,247,311	133	662,691	2,650,762	3,313,453
TOTALS:	**7,859**	**$39,296,369**	**$157,185,475**	**$196,481,844**	**$4,997**	**$24,986,839**	**$99,947,355**	**$124,934,194**

8.2 Benefit

The CBA included six *Arundo* impact classes. Each of these impacts is a 'benefit' when the agent causing the impact (*Arundo*) is removed. The six classes are: fire, water use, sediment trapping, flood damage, habitat enhancement, and beach debris.

8.2.1 Reduced Fire Impacts (Benefit)

Benefits related to reduced fire impacts resulting from *Arundo* control are presented in Table 8-3. This information is generated from data presented in Chapter 6 on fires that were initiated in *Arundo* stands, as well as wildfire events that burned *Arundo*. *Arundo*-initiated fires have costs associated with fire suppression (Table 8-3). A conservative fire response and suppression cost of $50,000 per event was used in generating cost estimates. The number of events over a ten-year period was based on data for the San Luis Rey watershed. This was then extrapolated to all watersheds based on their acreage of *Arundo*. Fire suppression costs are related to the number of units responding, work hours spent suppressing the fire, equipment costs, and other support. Fires usually involve multiple units that frequently use air suppression and often have fire lines cut by crews and/or mechanized equipment. The impacts from the fire suppression activities indicate the level of effort exerted during the action (suppression disturbance impacts are outlined in Chapter 6). *Arundo*-initiated fire impacts to habitat are also included in the cost estimate. The value of burned *Arundo* riparian habitat is priced lower ($20,000 per acre) then the valuation of un-invaded riparian habitat that burns ($80,000 per acre). These per acre cost valuations are based on mitigation costs associated with restoring riparian habitat, excluding easements and land purchase. Both the actual fire acreage and fire suppression acreage are aggregated in the cost estimate.

Arundo-initiated fires were estimated to generate $74.6 million of impacts over 10 years at peak *Arundo* distribution, and $38.8 million over 10 years at current *Arundo* levels (Table 8-3).

Wildfires represent a potentially open-ended impact class in terms of cost. As discussed in Chapter 6, *Arundo* stands may be conveying fires across the landscape, linking upland areas and spreading fire into urbanized areas. This seems to have occurred in Santa Clara, where a smaller 8,474-acre fire spread across the river via *Arundo* stands to the southern mountain range where it burned 107,560 acres. Other fires such as the Freeway Complex fire in Orange/Riverside County and western portions of the Witch Fire in San Diego County may also have had increased fire conveyance as the fires burned through riparian zones containing *Arundo* surrounded by urbanized areas. Impact costs were hundreds of millions of dollars with large losses to both habitat and developed areas. These landscape-level wildfire costs are too complicated to include in this CBA, but they clearly constitute a significant unmeasured cost that should be partially applied to *Arundo*. Further documentation needs to occur to more clearly define the role *Arundo* is having in wildland fires.

Wildfires can burn riparian habitat, particularly in firestorm/Santa Ana type events. *Arundo*-invaded habitat burns during these events along with un-invaded habitat. The *Arundo*-invaded areas burn much hotter than native vegetation due to the large amount of biomass per acre and the high levels of fuel per unit of biomass (Chapter 6). This results in more intense and complete fires that have a greater impact on the habitat. Post-fire recovery of *Arundo* stands is rapid, typically resulting in further domination of *Arundo* in areas that have burned (Ambrose 2007). A valuation of *Arundo's* degradation of habitat during wildfire events was valued at $2,500 per acre of burned *Arundo*-invaded habitat. This is an

extremely conservative valuation of the impacts to habitat, and it specifically excludes valuation of the fire conveyance impacts that *Arundo* has during wildfire events.

Wildfires that burn *Arundo* stands were estimated to generate $17.6 million of impacts over 10 years at peak *Arundo* distribution and $10.4 million over 10 years at current *Arundo* levels (Table 8-3).

8.2.2 Reduced Water Use (Benefit)

Water use of *Arundo*-invaded habitat was estimated in Section 4.2. Specific adjustments were made for replacement vegetation. Water use and net water savings are exceedingly difficult to validate in field studies, but it seems clear from the high productivity of *Arundo* (i.e. the very high stand biomass, the high leaf area recorded in studies, and the high water use of C_3 plants in general) that it does indeed have substantially higher water use than native vegetation and/or open areas that would exist in post-control riverine sites. The calculated water savings generated are significant (Section 4.2). It is important to note that most of the areas where *Arundo* is present within the study area have water available throughout the year. Many watersheds have significant amounts of imported water that generate these year-round flows or, at a minimum, make water tables high enough to support *Arundo* throughout the growing season.

Putting a valuation on water 'saved' after *Arundo* removal is complicated. In a more comprehensive study, this value would vary by watershed and be based on the specific benefit that the saved water is generating. One key benefit may be the potential for an increase in groundwater recharge. This may benefit domestic use (Santa Ana, Santa Margarita) or heavy agricultural use (Salinas, Santa Clara) of groundwater in a system. For those watersheds (San Luis Rey, San Diego) that have only moderate use of groundwater, the focus may turn to other potential benefits. An increase of water in the riverine system can also benefit habitat and recreation. Longer baseline flows can be critical to several endangered species, particularly on systems with high levels of water management (dams and reservoirs). All of these benefits could be priced out at different rates. For this analysis, a single low value of $50 per acre-foot (ac-ft) of water was used in calculating benefit of water savings. This is a conservative valuation, particularly for southern California. A valuation of $50 per ac-ft of water was the lower end value in the Rio Grande *Arundo* water use CBA study, with the higher end coming in at $200 per ac-ft (Seawright 2009). Valuations for domestic water use are $527 per ac-ft (Metropolitan Water District) and for agricultural water range from $70 (Coachilla) to $482 per ac-ft (MWD). Much of the water is priced at highly subsidized rates. Nearly all watersheds in the study area import water at a high absolute cost. Additionally, water transfer and pumping costs range from $70–$200 ac-ft (MWD). Water recycling and conservation measures typically cost $70–$150 per ac-ft and are usually considered to be a net benefit.

The estimated valuation of water saved over 10 years by controlling *Arundo* is $78.2 million at its peak distribution and $49.6 million at current distribution level (Table 8-4).

Table 8-3. Estimated reduction of fire impacts (benefit).

Watershed	PEAK *ARUNDO* LEVELS					CURRENT *ARUNDO* LEVELS				
	Fire Started by *Arundo*				Wildfires	Fire started by *Arundo*				Wildfire
	50k per event	Habitat damage: *Arundo* $20K ac	Habitat damage: rip $80K ac	*Arundo* fires 10 yr total	Wildfire: 500K per 200 ac	50k per event	Habitat damage: *Arundo* $20K ac	Habitat damage: rip $80K ac	*Arundo* fires 10 yr total	Wildfire: 500K per 200 ac
Calleguas	115,742	401,857	2,129,655	2,647,254	578,711	115,000	395,814	2,149,120	2,659,934	575,000
Carlsbad	73,947	256,745	1,360,629	1,691,321	369,736	24,609	98,862	459,889	583,360	123,044
Los Angeles	66,394	230,518	1,221,641	1,518,553	331,968	57,561	202,254	1,075,696	1,335,510	287,804
Otay	9,322	32,365	171,519	213,205	46,608	9,295	32,278	173,696	215,268	46,473
Penasquitos	11,810	41,004	217,300	270,114	59,049	10,686	37,407	199,700	247,793	53,430
Salinas	1,003,061	348,263	1,845,632	3,196,956	501,000	100,000	223,336	1,744,000	2,067,336	501,000
San Diego	75,111	260,787	1,382,050	1,717,948	375,557	47,000	169,675	878,336	1,095,011	235,000
San Dieguito	87,491	303,768	1,609,833	2,001,092	437,455	42,582	160,061	795,781	998,425	212,912
San Gabriel	22,281	77,359	409,967	509,607	111,404	22,146	76,929	413,873	512,948	110,732
San Juan	87,575	304,061	1,611,385	2,003,022	437,876	80,138	280,262	1,497,619	1,858,019	400,690
San Luis Rey	341,939	1,187,213	6,291,682	7,820,834	1,709,696	35,724	207,323	667,604	910,651	178,618
Santa Ana	1,361,931	4,728,624	25,059,526	31,150,080	6,809,654	820,000	2,813,396	15,324,160	18,957,556	4,100,000
Santa Clara	540,629	1,877,065	9,947,580	12,365,274	2,703,147	540,500	1,776,596	10,100,864	12,417,960	2,702,500
S. Margarita	344,446	119,592	633,781	1,097,819	1,722,231	-	-	-	0	0
Santa Monica	9,314	32,340	171,385	213,038	46,572	9,096	31,642	169,994	210,732	45,482
South Coast	14,908	51,759	274,298	340,965	74,538	11,000	39,256	205,575	255,831	55,002
Sweetwater	21,172	73,510	389,567	484,249	105,861	18,047	63,511	337,270	418,828	90,237
Tijuana	67,785	235,350	1,247,246	1,550,381	338,926	47,250	161,674	883,008	1,091,932	236,250
Ventura	165,997	576,341	3,054,344	3,796,682	829,985	94,000	257,212	1,756,672	2,107,884	470,000
TOTALS:	**$4,420,856**	**$11,138,520**	**$59,029,021**	**$74,588,396**	**$17,589,972**	**$2,084,635**	**$7,027,490**	**$38,832,856**	**$47,944,981**	**$10,424,174**

Table 8-4. Estimated reduction of water use by *Arundo* (benefit).

Watershed	10 Year Water Use	
	Peak *Arundo* levels	Current *Arundo* levels
Calleguas	2,290,974	2,290,974
Carlsbad	1,478,605	492,060
Los Angeles River	1,313,470	1,150,950
Otay	185,848	185,848
Penasquitos	235,419	213,650
Salinas	13,314,032	12,250,510
San Diego	1,494,312	932,570
San Dieguito	1,749,387	851,450
San Gabriel River	442,969	442,969
San Juan	1,733,768	1,602,390
San Luis Rey	6,837,215	714,310
Santa Ana	25,332,010	15,264,940
Santa Clara	10,185,377	10,185,377
Santa Margarita	6,887,344	41,940
Santa Monica Bay	184,819	184,819
South Coast	298,082	219,960
Sweetwater	417,636	360,870
Tijuana	1,305,930	895,020
Ventura River	2,498,351	1,325,080
TOTALS:	**$78,185,547**	**$49,605,686**

8.2.3 Reduced Sediment Trapping (Benefit)

As outlined in Section 5.1, it is likely that *Arundo* has impacts to sediment transport, particularly in low gradient areas where *Arundo* cover is high (>40%). Many of these areas are highly urbanized, have large-scale agricultural operations, or have significant infrastructure present. Localized sediment trapping is likely occurring in portions of these highly invaded reaches, resulting in loss of flow conveyance. *Arundo* stands on their own, not even considering sediment trapping, were demonstrated to reduce flow conveyance by five feet where they occurred (Section 5.1). This is a significant loss of conveyance, likely larger than the sediment trapping effect. If these areas are managed for flood risk, agencies (particularly ACOE, municipalities, and counties) may be forced to undertake vegetation reduction or sediment removal to maintain flow conveyance. For example, levees on the San Luis Rey River were designed to contain flows up to a 120–year event. Vegetation and *Arundo* growth reduced this to a 90–year event capacity (ACOE pers. comm. 2009). This can result in areas being designated as 'high flood risk' (i.e. raising insurance costs) or being designated as uninsurable. Both of these scenarios result in lower property values. When sediment removal and vegetation clearing are not permitted or are considered too costly, the alternative is building new levees or increasing existing levee heights. Both

Santa Margarita and San Luis Rey have required either modification or installation of levee structures and/or vegetation reduction programs to maintain flow conveyance. The Salinas River has had channel maintenance activities to reduce flood risk and bank/bridge failure. Other riverine systems in the study area are likely to have had actions in the past and/or will require actions in the future. Cost of implementing vegetation reduction and or sediment removal is also very high. While costs include the removal work itself, this is often a small proportion of the total project cost. Projects typically require complicated regulatory clearance that can take years to obtain, as well as significant mitigation for habitat disturbance/impacts. No specific cost valuation data exist other than the authors' familiarity with actions carried out on various rivers and the high costs associated with programs undertaking these types of activities. Therefore, valuations assigned in the benefit analysis are again highly conservative. Alternative activities, such as increasing levee heights or constructing new levees are not included here, but these actions do occur and the costs associated with them are high, both in terms of construction cost, permitting and mitigation for permanent wetland loss. True costs of *Arundo* impacts could be one or two orders of magnitude greater than presented here.

The valuation of avoided sediment removal or vegetation reduction costs over 10 years by controlling *Arundo* was estimated to be $2,500,000 (Table 8-5).

Table 8-5. Estimated reduction of sediment trapping (benefit).

Watershed	Sediment Removal
Calleguas	$250,000
Carlsbad	
Los Angeles River	$250,000
Otay	
Penasquitos	
Salinas	$1,000,000
San Diego	
San Dieguito	
San Gabriel River	$250,000
San Juan	
San Luis Rey	$500,000
Santa Ana	$250,000
Santa Clara	
Santa Margarita	
Santa Monica Bay	
South Coast	
Sweetwater	
Tijuana	
Ventura River	
TOTALS:	**$2,500,000**

8.2.4 Reduced Flood Damage: Bridges (Benefit)

Arundo biomass mobilizes during high flow events. This material can contribute or cause loss of structures that cross or are located within (power poles, sewer, gas, and water lines) the river channel. The exact proportion of damage costs associated with the presence of *Arundo* is difficult to determine. The most easily verified flood damage events involving *Arundo* are related to massive amounts of *Arundo* debris that form dams against bridges (Section 5.2.5.1). Loss of bridges has occurred on numerous watersheds that have high levels of *Arundo* invasion. Not all bridges were observed at the time of failure, but observations of bridges that have been damaged and operations to clear bridges of *Arundo* during flow events demonstrate that *Arundo* is a factor. High flow events that mobilize *Arundo* biomass also move large woody material such as trees. This combination of material collects and backs up against bridge pylons, or if flows are high enough, against the bridge itself. Older bridges with narrow spans are at greater risk of failing. Smaller bridges are also at higher risk as they typically have low clearance and narrow spans. Each watershed was reviewed for bridges (road and rail) that cross over river habitat with significant levels of *Arundo* around or upstream of them. These bridges were classified into three groups and conservative replacement costs were applied: large ($5 million), medium ($1.5 million), and small ($500,000). These valuations are extremely conservative, as bridge construction often requires costly environmental review and mitigation. Results were multiplied by 20% to estimate the likelihood of bridge loss within the 10-year period and to account for a portion of cost that is due to large flood events taking out bridges regardless of whether *Arundo* material is in the system or not.

The valuation of avoided bridge losses at peak *Arundo* distribution was estimated to be $24.2 million over 10 years. Control programs have cleared *Arundo* around and above several bridges, reducing estimated projected impacts to $17.3 million over 10 years (Table 8-6).

8.2.5 Habitat Enhancement (Benefit)

As explored in multiple chapters within this report, *Arundo* has many abiotic and biotic impacts. Some of the most severe impacts to riparian systems are to abiotic processes that are nearly impossible to quantify monetarily in terms of their environmental consequences. Changes to geomorphic form and function, hydrology, water use, and other abiotic functions affect the entire system. Most of the valuations for these types of impacts in previous sections were limited to anthropogenic costs including infrastructure, water for urban and agriculture use, or flood damage. Environmental costs were not included. This CBA will limit valuation of environmental impacts to the degradation of habitat *Arundo* has invaded. The cost of controlling *Arundo* is used as a valuation of the habitat benefit (habitat restoration as well and threatened and endangered species' benefits). A valuation of $25,000 per acre is used to represent the benefit of habitat enhancement/restoration that occurs when *Arundo* is controlled. This is the same as the cost of the work as outlined in Section 8.1. The total cost is lower, however, reflecting the subtraction of *Arundo* acreage that was counted under the fire benefits evaluation. This avoids double counting benefits. The use of this valuation is corroborated by the common use of *Arundo* control as a form of mitigation for impacts to riparian habitat. This is still a slightly conservative valuation as many other forms of riparian 'mitigation' have higher costs per acre ($50,000 to $100,000) for restoration activities, even when land use restrictions (easements or land costs) are excluded from project costs.

The total 10 year benefit calculated for habitat restoration/enhancement was estimated to be $181 million at peak *Arundo* distribution and $110 million for current distribution levels (Table 8-7).

Table 8-6. Estimated reduction of bridge losses (benefit) by watershed at peak and current *Arundo* levels.

Watershed	Number of Bridges: Large, Medium, & Small	PEAK *ARUNDO* LEVELS		CURRENT *ARUNDO* LEVELS	
		Bridge loss or damage	Flood damage: Bridge 20%	Bridge loss or damage	Flood damage: Bridge 20%
Calleguas	Med: 8, Sm: 1	12,500,000	2,500,000	12,500,000	2,500,000
Carlsbad		0	0	0	0
Los Angeles River	Lg: 1	5,000,000	1,000,000	5,000,000	1,000,000
Otay		0	0	0	0
Penasquitos		0	0	0	0
Salinas	Lg: 4, Med: 2, Sm: 1	22,000,000	4,400,000	22,000,000	4,400,000
San Diego	Med: 1, Sm: 2	2,500,000	500,000	500,000	100,000
San Dieguito		0	0	0	0
San Gabriel River	Lg: 1	5,000,000	1,000,000	5,000,000	1,000,000
San Juan	Med: 1, Sm: 1	2,000,000	400,000	2,000,000	400,000
San Luis Rey	Med: 4	6,000,000	1,200,000	0	0
Santa Ana	Lg: 5	25,000,000	5,000,000	10,000,000	2,000,000
Santa Clara	Lg: 2, Med: 3	14,500,000	2,900,000	14,500,000	2,900,000
Santa Margarita	Lg: 2, Med: 1	11,500,000	2,300,000	0	0
Santa Monica Bay		0	0	0	0
South Coast		0	0	0	0
Sweetwater		0	0	0	0
Tijuana	Sm: 1	500,000	100,000	500,000	100,000
Ventura River	Lg: 2, Med: 2, Sm: 3	14,500,000	2,900,000	14,500,000	2,900,000
	TOTALS:	**$121,000,000**	**$24,200,000**	**$86,500,000**	**$17,300,000**

Table 8-7. Estimated habitat enhancement (benefit) by watershed at peak and current *Arundo* levels.

Watershed	Habitat benefit: 25K per ac	
	PEAK *ARUNDO* LEVELS	CURRENT *ARUNDO* LEVELS
Calleguas	5,226,429	5,190,372
Carlsbad	3,376,431	909,509
Los Angeles River	2,996,281	2,589,891
Otay	424,270	424,270
Penasquitos	537,429	483,046
Salinas	32,857,393	30,197,986
San Diego	3,410,654	2,005,966
San Dieguito	3,994,761	1,749,414
San Gabriel River	1,010,978	1,010,624
San Juan	3,955,339	3,626,822
San Luis Rey	15,612,946	302,166
Santa Ana	57,433,784	32,260,330
Santa Clara	23,122,958	23,115,310
Santa Margarita	17,222,313	104,862
Santa Monica Bay	421,728	414,396
South Coast	680,677	485,319
Sweetwater	952,443	810,484
Tijuana	2,971,387	1,943,887
Ventura River	5,526,884	2,593,026
TOTALS:	**$181,735,081**	**$110,217,679**

8.2.6 Reduced Beach Debris

Impacts from clearing *Arundo* debris from beaches in southern California was reviewed in Section 5.2.5.2. These costs are based on information collected from municipalities that remove biomass from beaches. Only watersheds that are near beaches and actively remove biomass were given benefit valuations. The estimated 10–year benefit of reduced *Arundo* biomass on beaches is $1.97 million (Tables 8-8&9).

8.2.7 Total Benefit

The total benefit of controlling *Arundo* at its peak distribution was estimated at $380 million (Table 8-8), and the benefit at its current distribution at $239 million (Table 8-9). This is a conservative

valuation because several types of impacts could not be estimated or quantified, and all evaluated impacts were conservatively valued.

8.3 Benefit to Cost Ratio

The benefit to cost ratio for peak *Arundo* distribution was 1.94 to 1 ($380,767,747 to $196,481,844). Current *Arundo* distribution generates a similar benefit to cost ratio of 1.91 to 1 ($239,461,270 to $124,934,194). A 2:1 return ratio on funds invested is a significant benefit, particularly considering the additional impacts that were not assessed (due to complex valuation), as well as the conservative valuation of factors that were included.

A more rigorous CBA carried out for either specific watersheds or the entire project area would likely generate higher benefit to cost ratios. Higher cost valuations of impacts could be documented and defended, and some of the more complicated impacts, which were not included in this CBA, could be explored and included.

Table 8-8. Estimated benefits at the peak level of *Arundo* distribution.

Watershed	Water use 10 yr	Sediment removal	Flood damage: bridge & levee	*Arundo* fires 10 yr total	Wildfire: 500K per 200 ac	Habitat rest 25K	Beach debris	10 year benefit
Calleguas	2,290,974	250,000	2,500,000	2,647,254	578,711	5,226,429	-	13,493,368
Carlsbad	1,478,605	-	0	1,691,321	369,736	3,376,431	-	6,916,093
Los Angeles	1,313,470	250,000	1,000,000	1,518,553	331,968	2,996,281	328,125	7,738,397
Otay	185,848	-	0	213,205	46,608	424,270	-	869,931
Penasquitos	235,419	-	0	270,114	59,049	537,429	-	1,102,011
Salinas	13,314,032	1,000,000	4,400,000	3,196,956	501,000	32,857,393	-	55,269,381
San Diego	1,494,312	-	500,000	1,717,948	375,557	3,410,654	-	7,498,471
San Dieguito	1,749,387	-	0	2,001,092	437,455	3,994,761	-	8,182,694
San Gabriel	442,969	250,000	1,000,000	509,607	111,404	1,010,978	328,125	3,653,083
San Juan	1,733,768	-	400,000	2,003,022	437,876	3,955,339	-	8,530,006
San Luis Rey	6,837,215	500,000	1,200,000	7,820,834	1,709,696	15,612,946	328,125	34,008,816
Santa Ana	25,332,010	250,000	5,000,000	31,150,080	6,809,654	57,433,784	-	125,975,527
Santa Clara	10,185,377	-	2,900,000	12,365,274	2,703,147	23,122,958	328,125	51,604,881
Santa Margarita	6,887,344	-	2,300,000	1,097,819	1,722,231	17,222,313	328,125	29,557,833
Santa Monica	184,819	-	0	213,038	46,572	421,728	-	866,157
South Coast	298,082	-	0	340,965	74,538	680,677	-	1,394,261
Sweetwater	417,636	-	0	484,249	105,861	952,443	-	1,960,188
Tijuana	1,305,930	-	100,000	1,550,381	338,926	2,971,387	-	6,266,624
Ventura River	2,498,351		2,900,000	3,796,682	829,985	5,526,884	328,125	15,880,026
TOTALS:	**$78,185,547**	**$2,500,000**	**$24,200,000**	**$74,588,396**	**$17,589,972**	**$181,735,081**	**$1,968,750**	**$380,767,747**

Table 8-9. Estimated benefits at current levels of *Arundo*.

Watershed	Water use 10 yr	Sediment removal	Flood damage: bridge & levee	*Arundo* fires 10 yr total	Wildfire: 500K per 200 ac	Habitat rest 25K	Beach debris	10 year benefit
Calleguas	2,290,974	250,000	2,500,000	2,659,934	575,000	5,190,372		13,466,280
Carlsbad	492,060		0	583,360	123,044	909,509		2,107,972
Los Angeles	1,150,950	250,000	1,000,000	1,335,510	287,804	2,589,891	328,125	6,942,280
Otay	185,848		0	215,268	46,473	424,270		871,858
Penasquitos	213,650		0	247,793	53,430	483,046		997,919
Salinas	12,250,510	1,000,000	4,400,000	2,067,336	501,000	30,197,986		50,416,832
San Diego	932,570		100,000	1,095,011	235,000	2,005,966		4,368,547
San Dieguito	851,450		0	998,425	212,912	1,749,414		3,812,201
San Gabriel	442,969	250,000	1,000,000	512,948	110,732	1,010,624	328,125	3,655,399
San Juan	1,602,390		400,000	1,858,019	400,690	3,626,822		7,887,921
San Luis Rey	714,310		0	910,651	178,618	302,166	328,125	2,433,870
Santa Ana	15,264,940	250,000	2,000,000	18,957,556	4,100,000	32,260,330		72,832,826
Santa Clara	10,185,377		2,900,000	12,417,960	2,702,500	23,115,310	328,125	51,649,272
Santa Margarita	41,940		0	0	0	104,862	328,125	474,927
Santa Monica	184,819		0	210,732	45,482	414,396		855,429
South Coast	219,960		0	255,831	55,002	485,319		1,016,111
Sweetwater	360,870		0	418,828	90,237	810,484		1,680,419
Tijuana	895,020		100,000	1,091,932	236,250	1,943,887		4,267,089
Ventura River	1,325,080		2,900,000	2,107,884	470,000	2,593,026	328,125	9,724,115
TOTALS:	**$49,605,686**	**$2,000,000**	**$17,300,000**	**$47,944,981**	**$10,424,174**	**$110,217,679**	**$1,968,750**	**$239,461,270**

9.0 WATERSHED BASED *ARUNDO* CONTROL PROGRAMS: RECOMMENDATIONS, STATUS, AND PRIORITIZATION

9.1 Recommendations and Status of Watershed Based *Arundo* Control Programs

Given *Arundo*'s dependence on asexual propagation (it only spreads from fragments of plant material), control programs that start at the top of watersheds are undoubtedly the most efficient and effective over the long-term. Most watershed-based programs start on the upper portions of rivers and tributaries and proceed downstream to the ocean outfall. Many programs do not control all scattered infestations, such as those occurring in urbanized areas, particularly if these properties are not directly connected to drainages, creeks, or rivers. More comprehensive programs do attempt to eradicate all *Arundo* within the watershed, as any material is potentially a propagule source. Yard waste that is disposed of improperly, such as dumped along roads or creeks, is a pathway of spread. Once a watershed has had all *Arundo* controlled there is still a need to remain alert for new introductions that can occur from other watersheds as: contaminated fill, yard waste, or intentional planting of *Arundo* (even though it is a CDFA listed Noxious Weed, B rated).

General goals of control programs should be the following, but there are site-specific exceptions to these statements:

- Control programs should attempt to achieve eradication on entire watersheds, as this is the most efficient use of limited resources.
- Control programs should start in upper watershed areas and proceed downstream. This is more important on large, highly invaded watersheds that may require 10–20 years to carry out implementation. Small watersheds, or those large watersheds with little acreage, can be treated in any 'order' as long as everything is treated over a reasonable time frame.
- Programs frequently implement control projects in defined sub-sections of the watershed. The program still proceeds from the upper, to the middle, and then the lower watershed as different sub-sections are completed. Within a section, control may occur 'out of order'. This can be beneficial (fuel breaks, creating a mosaic of age classes for restored areas, multiple classes of property ownership, etc.) and is often done intentionally.
- Programs should strive to achieve 100% control within project areas. This is a difficult objective and requires both long-term commitment and substantial tracking. Most *Arundo* is controlled after 5–10 years of work, but re-sprouts will occur, particularly if project areas are large. Areas need to be checked and re-treated for 20 years to assure 100% control. Control and surveying may occur at three-year intervals for older project areas.
- Some highly invaded watersheds may have high-value habitat areas that need or require restoration or *Arundo* control before the larger program has 'reached' the area. These activities may be warranted, even though significant untreated *Arundo* remains upstream. Projects should budget periodic treatment of new *Arundo* invasion onto the property. Re-invasion of a given property is difficult to predict and would be dependent on geomorphic position, amount of *Arundo* upstream, and periodic flow events that mobilize material. Historic review of systems indicates that invasion is very episodic for the most part, and that responding after very large events will be the primary task.
- Watersheds with active programs may prioritize areas for control that have burned. Fires temporarily clear biomass from a site, representing an excellent opportunity for inexpensive

control as biomass reduction or removal is often the most expensive component of a control project.

9.1.1 Entity/Group Leading Watershed Based Work

For a watershed-based control program to succeed it typically needs either a single lead entity or an organization that brings together multiple partners. Larger watersheds without a lead entity or formal coordination have been unable to implement meaningful watershed-based *Arundo* control. There are five main reasons why a program lead is needed: funding, permitting, contracting, permission through right-of-entry agreements (ROEs), and long-term presence. Groups that are unable to receive public funds, hold permits, obtain ROEs, and garner broad support among watershed stakeholders should not attempt to lead projects or programs. Control programs on watersheds with more than 50 acres of *Arundo* or *Arundo* on more than 100 properties will likely only succeed if a program with an identified lead entity exists.

Table 9-1 identifies the specific watershed program leads within the study area. Most larger watersheds with high levels of *Arundo* invasion have already formed watershed based groups to initiate work. There are multiple types of organizations that can function as a lead. Most groups are public entities such as County Departments, Resource Conservation Districts (RCDs), and Joint Power Authorities (JPAs). But it is possible for a non-profit to function as a watershed lead (Carlsbad: San Elijo Conservancy, Tijuana: SWIA). Appealing to a broad range of landowners is a strong benefit, particularly in areas with a mix of private and public landownership. Resource Conservation Districts (RCD's) are frequently leads (Mission, Monterey) or active participants in stakeholder groups (SAWA: RCD's and water districts). Weed Management Areas or WMAs (typically formed by County Agriculture Departments or RCDs) can also play an important role in implementing projects and building watershed control programs.

9.1.2 Status of Permitting Allowing Work to Occur

Watershed programs seeking to control *Arundo* are required to obtain regulatory clearance from multiple agencies. Permits and conditions are dependent on methods being used to control *Arundo*. Typically this includes:

- CEQA: generally Mitigated Negative Declaration, Negative Declaration, or Notice of Exemption. EIRs are rarely required. This can take anywhere from 1-12 months to process depending on the path taken.
- Department of Fish and Game Streambed Alteration Permit 1600: nearly always required. This process can take one month to over a year long and CEQA should be completed first.
- U.S. Fish and Wildlife Service: Section 7/10 or a Technical Assistance Letter may be required if federally listed species are present. If take or harassment is likely to occur, a Section 7/10 is required and this can take 6-12 months or longer. If endangered species are present but impacts can be avoided, a Technical Assistance Letter can be used to outline protective measures. This can be completed in one to three months.
- Two other agencies also regulate protected species: California Endangered Species Act (under CA Department of Fish and Game) may require concurrence with U.S. Fish and Wildlife Service agreements/protective measures and National Marine Fisheries Service (under the National Oceanic and Atmospheric Administration) may require consultation.

Table 9-1. *Arundo* control programs within the study area: program leads, status of permitting and work completed on each watershed.

Watershed Unit	Total net acres	Treated net acres	Percent treated	Group leading control program	Watershed-based permitting completed	Notes
Calleguas	229	2	1%	No clear lead, multiple partners	CEQA	Ventura RCD and County active, but few projects completed to date
Carlsbad HU	148	98	67%	San Elijo Lagoon Consrvncy, San Diego Co	CEQA, DFG 1600, FWS, ACOE	Well established program (2002), strong implementation
Estero Bay	10	1	12%	San Luis Obispo County Ag Dept.	Project based	Work is project by project
Los Angeles River	131	16	12%	None	Project based	Work is project by project
Otay	19		0%	None	None	
Pajaro River	8		0%	None	None	
Penasquitos	23	2	9%	None	Project based	Work is project by project
Pueblo San Diego	15		0%	None	Project based	Work is project by project
Salinas	1,332	106	8%	Monterey RCD	CEQA, DFG,&FWS in process (& existing project based)	Project based but moving toward formal watershed-based program
San Diego	150	56	38%	San Diego River Conservancy	CEQA, DFG 1600, FWS, ACOE 404, SWCB 401	Newer watershed-based program (2009), rapid implementation
San Dieguito	175	90	51%	San Dieguito JPA	CEQA, DFG 1600, FWS	Well established watershed-based program (2006), rapid implementation
San Gabriel River	44	8	19%	None	None	Work is project by project
San Juan	173	13	8%	County of Orange	CEQA, DFG 1600, FWS, ACOE 404, SWCB 401	Newer watershed based program (2009), little implementation to date
San Luis Rey	684	612	90%	Mission RCD	CEQA, DFG 1600, FWS, ACOE 404, SWCB 401	Well established program (2000), strong implementation
Santa Ana	2,534	1,007	40%	SAWA	CEQA, DFG 1600, FWS, ACOE 404, SWCB 401	Well established program (1992), strong implementation
Santa Clara	1,019	1	0%	No clear lead, multiple parties	Some permits for LA County, none for Ventura County	Poorly formed program, no clear lead, low levels of implementation

Watershed Unit	Total net acres	Treated net acres	Percent treated	Group leading control program	Watershed-based permitting completed	Notes
Santa Margarita	689	685	99%	Lower: USMCB Camp Pendleton, Middle: Mission RCD, Upper: none	Lower and middle: NEPA/CEQA, DFG 1600, FWS, ACOE 404, SWCB 401 Upper: none	Well established program (1995), strong implementation- but no clear upper watershed lead
Santa Monica Bay	19	1	2%	None	None	Work is project by project
Santa Ynez	6		0%	Santa Barbara County Ag Commissioner	In Process: CEQA, DFG 1600	Newly forming project (2010)
South Coast	30	8	26%	Multiple parties: County, Cities	Project based	Work is project by project: some watershed units far along, some just starting
Sweetwater	42	6	14%	Sweetwater Authority	Project based	Work is project by project
Tijuana	131	41	31%	Southwest Wetlands Interpretive Assoc. (SWIA)	Project based	Work is project by project- constrained by *Arundo* in Mexico, true watershed-based management may not be possible on lower watershed
Ventura River	250	117	47%	County of Ventura	CEQA, DFG 1600, FWS, ACOE 404, SWCB 401 (project based, but for large sections of watershed)	Well established watershed-based program (2008), rapid implementation
Totals:	**7,864**	**2,862**	**36.4%**			

- Army Corps of Engineers 404 permit may be required for larger control programs using heavy equipment. In Southern California (San Diego up to San Luis Obispo County), a Regional General Permit 41 has been issued for *Arundo* and other non-native plant control programs. This permit, when activated for a specific program or project, fulfills both ACOE 404 permitting requirements and SWCB 401 certification. Completion of the ACOE RGP 41 application process can occur in less than three months. ACOE 404 certification without use of RGP 41 is an open-ended process.
- State Water Control Board or Regional Water Quality Control Board 401 certification or discharge permits can be required for programs depending on methods and equipment used. If obtained under ACOE RGP 41, the process is fast (under a month). If obtained as a 401 certification or discharge permit, the process is open-ended.
- Coastal Commission Permit may be required for certain projects. Exemptions have been obtained for some programs deemed to be restoration. Permitting process is open-ended and typically is the last permit completed.
- Other permits: additional project or watershed-specific permits may be required. This may include California State Historic Office (notification and/or compliance) and municipal or county codes/permits.

The number and complexity of regulatory permits for carrying out *Arundo* control makes it imperative that program leads are familiar with navigating the permitting process and that efficient and competent management of programs and permitting requirements is occurring. Given the number of permits that are required for larger programs, it is of substantial benefit if watershed-based permits can be obtained. Each watershed is identified in Table 9-1 as to the type of permits that are held and programs in place (whether it is watershed or project based). Additionally, *Arundo* control is a long-term process, with projects lasting at least five years and control typically taking 10-15 years. Programs on larger systems may take 15-20 years to complete all initial control. For this reason, obtaining the longest duration permits (particularly for DFG 1600) is the most efficient use of resources, even though these permits cost more initially.

Funding agencies and mitigation programs frequently will not fund projects that have permitting 'in process' or projects that expect to obtain permits after being awarded funding. Having approved and active permits in place from all required regulatory agencies is a primary indicator of a program's ability to execute on a specific project.

9.1.3 Work Completed to Date

Experience and track record of a watershed control program are the best indicators of a specific group's ability to complete projects in a time-efficient and cost-effective manner. Program leads typically are in charge of selecting work areas, obtaining ROEs, obtaining and complying with permits, obtaining funding, and selecting and contracting with groups to carry out the work. These factors are usually well documented in grant and other funding applications, and it is beyond the scope of this report to evaluate successes and failures of specific programs. Table 9-1 does, however, indicate which watersheds have well-established programs, when they started, and the treated acreage. Many of these programs actively participate in sharing information on control methods, mapping methods, permitting approaches, public outreach and other information. The community of control programs across the state is, in general, open and supportive of each other.

9.1.4 Future Program Work

Programs should use mapping data to demonstrate that top-down control is occurring by indicating what has been controlled, what is proposed, and what is planned. Programs should also use high-resolution mapping of *Arundo* stands to calculate budgets presented in proposals and for tracking treated acreage in mitigation programs. The mapping completed for this study and presented in this report represents high-resolution data.

Some programs appear to be vastly over-inflating acreage of *Arundo* stands in their proposals, work plans and mitigation programs. This may not be intentional, but it is misleading, particularly when making comparisons between watersheds or even proposals within a watershed. One example of misrepresentation occurs when gross area is used in place of net area. For example, a 200 acre site that has 15 acres of *Arundo* stands scattered within it should not be characterized as '200 acres of *Arundo* control'. If there are large expanses of native vegetation within areas designated as '*Arundo* project acreage', it can be a clear indication of questionable mapping. This overestimation can easily be detected if the mapped elements are viewed over high-resolution aerial imagery.

Maps presenting project acreage with point and line data can also be particularly suspect, especially if *Arundo* acreage is high. Additionally, maps with large polygons covering long lengths of river from terrace to terrace are questionable. Even in the most invaded portions of highly invaded systems, *Arundo* rarely achieves cover greater than 50% for long lengths of river. The mapping data presented here allows general verification of mapping presented in proposals. Mapping with acreage levels that are within 20 to 30% of this study's acreage is most likely accurate. A large difference in *Arundo* acreage compared to this study's mapping may indicate that a different methodology was implemented (i.e. coarse mapping with low *Arundo* cover) or mapping protocols were of poor quality. Other clues to either a poor understanding of implementation costs ($10-30,000 per acre for a typical project), or mapping that is not accurately representing *Arundo* acreage, can appear in proposed project budgets. For example, projects outlining control of 100 acres of *Arundo* for five years cannot reasonably cost $150,000. It is recommended that future proposals and plans be evaluated to determine if they accurately represent *Arundo* acreage.

9.2 Priority Ranking of Watershed-Based *Arundo* Control

9.2.1 Factors Considered in Ranking: Impacts and Capacity

Ranking watershed programs is a complicated and potentially subjective exercise. Multiple impacts from *Arundo* invasion have been outlined in this report. Some impacts are directly tied to the level of invasion (geomorphology, flooding, fire and water use), while other impacts are tied to specific species co-occurring with *Arundo* (listed species). While different weightings could be used for each factor, this analysis will weigh all factors as equal. Active watershed groups are also assessed in terms of their ability to initiate and complete work (functioning lead entity, completed permits, past execution). A ranking or evaluation of each program's quality of execution was not performed for this assessment.

Watersheds with small amounts of *Arundo* will tend to rank low in the impact assessment, yet these areas may be among the most efficient to treat in terms of preventing future degradation. This will be discussed at the end of the section.

9.2.2 Control Priority

Overall there are three priority actions for funding of *Arundo* control:

1) Fund re-treatments of project areas that have already implemented watershed-based control. This protects the existing investment.
2) Fund control of *Arundo* on watersheds with low levels of invasion. It is more cost efficient to control *Arundo* before it becomes abundant.
3) Fund new control on invaded systems, but prioritize where watershed-based programs/ approaches are being used, and where benefit is greatest. Funding is finite, so efficient use of limited resources should occur.

Re-treatment of *Arundo* within established program areas is the highest priority. The fact that *Arundo* was abundant at these sites prior to control work indicates that these areas have the capacity to support re-establishment of large infestations if left unfinished. Over $70 million has been spent to date on well-established *Arundo* control programs within the coastal watersheds in the study area. Five watersheds have controlled a significant portion (>80%) of the *Arundo* found on their watersheds: Carlsbad HU, San Luis Rey, Santa Ana, Santa Margarita, and Ventura. Maintaining and completing *Arundo* control on the portions of these watersheds treated to date is highest priority. For the most part, funding and management agencies have recognized this and provided funding for re-treatments (years 5 to 20). Continued long-term funding support is needed for re-treatments to achieve true eradication of *Arundo* within these program areas.

Control of *Arundo* on watersheds with low levels of invasion is the next priority. Some watersheds have low levels of *Arundo*, most likely due to more recent introductions. Control of invasive plants early in the invasion process is always more cost effective than responding to a larger, more widespread invasion. Programs should be able to control *Arundo* on many of these smaller populations (Santa Ynez, Estero, Pajaro, and others) with less complicated permitting and low project implementation costs. Treated *Arundo* biomass can often be left standing if it is scattered, also greatly reducing treatment costs.

Funding *Arundo* control on more invaded watersheds should target watersheds experiencing the most severe impacts coupled with the highest likelihood of achieving success. These rankings are based on impacts caused by *Arundo* invasion (four classes) and program capacity (two classes, Table 9-2). This ranking approach is biased in that it selects for watersheds that have moderate to high levels of *Arundo*

invasion (due to correlation of impact level and invasion level). Watersheds with low levels of invasion have already been recognized as being of 'high value' for control, even though few impacts may currently be occurring. It should also be noted that the impact classes reflect the magnitude of *Arundo*'s effect on the watershed, not the importance of the impact issue. For example, groundwater recharge and water savings may be a significant issue on a watershed that scores a 0. This low ranking reflects the low *Arundo* acreage, and corresponding level of impact, but not the importance of water savings on the watershed. Table 9-2 provides guidance in assigning priority among the more invaded watersheds, which may be of use. High ranked watersheds are experiencing severe impacts and have the capacity to implement control. Watersheds with high acreage in the medium class may provide less return on investment in terms of impact reduction.

Programs/projects that do not fit into a watershed-based control program should be evaluated carefully. There are situations where control of *Arundo* at a downstream site can make sense. For instance, control may help protect structures and restore important habitat, or the entity owning the land may have the resources to initiate work. These sites are, however, at significant long-term risk of re-invasion. Funds should be set aside to respond to re-invasion, which is expected to be periodic and varying in intensity. Projects that merely reduce *Arundo* biomass or only carry out one treatment are not effective long-term control projects, and should not be presented as such.

Table 9-2. *Arundo* treatment priority ranking by watershed. Based on *Arundo* impacts and program capacity.

Watershed Unit	Total Net Acres	Percent treated	Group leading control program	*Arundo* Impacts				Capacity		Total	Priority ranking
				Water Use	Geo-morph	Fire	Listed species	Exp. lead	Per-mits		
Santa Ana	2,534	40%	SAWA	5	5	5	5	5	5	30	Very high
San Luis Rey	684	90%	Mission RCD	4	5	5	5	5	5	29	
Santa Margarita	689	99%	Lower: USMCB Camp Pendleton, Middle: Mission RCD, Upper: none	4	5	4	5	5	5	28	
San Dieguito	175	51%	San Dieguito JPA	5	2	4	4	5	5	25	
Ventura River	250	47%	County of Ventura	3	4	5	3	5	5	25	
Santa Clara	1,019	0%	No clear lead, multiple parties	5	4	5	5	1	3	23	High
San Diego	150	38%	San Diego River Conservancy	4	2	4	3	4	5	22	
Salinas	1,332	8%	Monterey RCD	5	5	2	3	3	3	21	
Carlsbad	148	70%	San Elijo Conservancy, S.Diego Co	2	2	2	3	5	5	19	
San Juan	173	8%	County of Orange	2	3	3	3	3	5	19	
Tijuana	131	31%	SWest Wetlands Interpretive Assoc.	2	2	2	2	4	4	16	Medium
Calleguas	229	1%	None	3	3	4	2	1	2	15	
Los Angeles	131	12%	None	2	1	3	4	2	2	14	
Calleguas	229	1%	None	3	3	4	2	1	0	13	
Santa Ynez	6	0%	Santa Barbara County Ag Dept	0	1	1	3	5	3	13	
Sweetwater	42	14%	Sweetwater Authority	1	2	2	3	3	2	13	
San Gabriel	44	8%	None	1	1	2	4	2	2	12	
South Coast	30	26%	Santa Barbara County Ag Dept	0	1	2	3	3	3	12	
Santa Monica	19	2%	None	0	1	2	4	2	2	11	
Otay	19	0%	None	0	1	2	2	3	2	10	
Estero Bay	10	12%	None	0	0	0	2	3	3	8	Low
Penasquitos	23	9%	None	0	1	2	3	1	0	7	
Pueblo San Diego	15	0%	None	0	1	2	1	0	0	4	
Pajaro River	8	0%	None	0	0	0	2	0	0	2	
Totals:	**7,864**	**36.4%**									

10.0 SUMMARY OF DATA FOR *ARUNDO*: PHYSICAL CHARACTERISTICS, DISTRIBUTION, ABUNDANCE, IMPACTS, AND WATERHSHED CONTROL PROGRAMS' STATUS AND PRIORITY

Conclusions from this impact report are presented below and based on collected data and observations for the greater study area: coastal watersheds in California from Monterey to San Diego (Figure 3-1).

Physical Characteristics and Biology

- Mature stands are taller than what has been typically reported in the literature: 6.5 m mean, range of 2.6 – 9.9 m. (Section 2.3)
- Adjustments need to be made when scaling up from cane-specific data to stand data due to canes not emerging within all areas of *Arundo* canopy. Areas along edges and gaps within stands have zero to few canes. (Section 2.3)
- Biomass per unit area is very high for mature *Arundo* stands and it is in general agreement with the literature: 15.5 kg/m^2. (Section 2.4)
- Leaf area of secondary branches is the primary photosynthetic area for older canes, and this constitutes the majority of the mature stand leaf area (75%). This has not been clearly recorded in the literature. (Section 4.1)
- Measurements of leaf area (LAI) in mature *Arundo* stands are very high (15.8 LAI). This is in general agreement with the literature. (Section 4.1)
- Additional studies examining LAI and stand structure would further establish that mature *Arundo* stands have very high LAI. Examination of native riparian vegetation LAI may also be beneficial.
- Reviewed literature demonstrates that *Arundo* spreads through asexual propagation (fragments of rhizomes and infrequently canes). Seeds are not viable. This makes *Arundo* spread dependent on flood action or anthropogenic disturbance. (Section 2.5)
- Review of historic aerial photography indicates that spread of *Arundo* within a watershed is very episodic- large magnitude (50 to 100–year) events are necessary for the plant to actively invade significant new areas in a riparian system, particularly floodplains and terraces. (Section 2.6.4)

These observations are important in that they characterize *Arundo* stands within the study area. These baseline attributes are used to quantify and explore multiple impacts associated with *Arundo* in later sections.

***Arundo* Impacts: Transpiration and Water use**

- Due to high leaf area of mature stands, stand-based transpiration is very high (E_{stand} 40 mm/day). There are two other studies evaluating stand-based *Arundo* transpiration. One study on the Santa Clara watershed (within this project's study area) is in agreement (41.1 mm/day). The other study on the Rio Grande River is lower (9.1 mm/day). (Section 4.1).
- Stand-based transpiration rates of *Arundo*, when used to calculate total water over larger areas, indicate very high levels of water use: 48 ac-ft/ac per year. (Section 4.2)
- Net water savings for areas after *Arundo* removal are high (20 ac-ft/yr), even when *Arundo* water use is lowered 24 ac-ft/ac per yr to reflect levels that may be closer to physiological water transpiration limits. (Section 4.2)

- New studies using different approaches to measure stand-based water use of *Arundo* are needed to corroborate and refine stand-based water use found in this and other studies. New studies need to be on mature stands of *Arundo*. Stands under treatment or in post-fire or flood recovery should be excluded, as these are not representative of the majority of *Arundo* stands within the study area. (Section 4.2)

Water use by *Arundo* appears to be a significant impact on invaded systems. Water use by vegetation is difficult to measure. Additional baseline and comparative studies are needed.

Distribution and Abundance

- *Arundo* mapping documented a total (gross) of 8,907 acres of *Arundo*. Net acreage, adjusted for *Arundo* cover, was 7,864 acres. This represents the peak distribution of *Arundo* in the study area prior to control activities. (Section 3.2)
- Over 3,000 gross acres of *Arundo* have been treated to date within the study area. This is 34% of the *Arundo* occurring within the study area. (Section 3.2)
- Three large, contiguous watershed units have the highest levels of *Arundo* control observed in the study area: Santa Margarita at 99%, San Luis Rey at 90% and Carlsbad at 70%. (Section 3.2)
- Most other invaded watersheds in the study area with more than 100 acres of *Arundo* have had at least 30% of their *Arundo* treated. Noted exceptions to this are Calleguas, Salinas and Santa Clara watersheds, which have less than 10% of their *Arundo* acreage under treatment. (Section 3.2)
- *Arundo* is most abundant in broad, low-gradient riparian areas where it averages 13% cover. (Section 5.2)
- *Arundo* cover can be very high for large sections (reaches > 0.5 mi long). *Arundo* was observed occurring at >40% cover on specific reaches on all three watersheds that were examined in detail: Santa Margarita, San Luis Rey and Santa Ana. (Section 5.1)

Distribution and abundance data is extremely valuable because it quantifies past and current levels of invasion on watersheds, allows detailed examination and quantification of impacts, and facilitates watershed-based control. Programs can use the spatial data to implement watershed-based control, develop proposals and budgets, and manage control programs.

***Arundo* Impacts: Hydrology and Geomorphology**

- Mature *Arundo* stands, due to high cane density, functionally raise the elevation profile by 5 feet, lowering flow capacity. (Section 5.1.4.6)
- *Arundo* stands occur predominantly in floodplain and terrace portions of the river and are nearly absent from the low flow and active channel areas. (Sections 5.1 & 5.2)
- *Arundo* stands on floodplains adjacent to the active channel function as a wall or levee, focusing flows within channel areas. Over time this results in a deepening of the channel and a transformation of the system from a braided unstable channel form to a laterally stable single-thread channel form. (Section 5.1.4.6)
- Floodplain areas (floodplains and low terraces) have become much more vegetated on most systems over the last eighty years. This vegetation is both native woody vegetation and *Arundo*. Mature *Arundo* stands, however, have much higher stem density and biomass per unit area, generating the observed effects noted above. (Section 5.2.3)

- Active channel areas (low flow and bar channel areas with little vegetation) have significantly declined over time on most systems. (Section 5.2.2)
- The over-vegetated floodplains and narrow stable deep channels result in modifications of sediment transport and stream power during flow events. (Section 5.1.4.7)
- Most riverine systems have become significantly compressed (narrower) over time as terrace and floodplain areas have been permanently separated from the river system with levees that protect both urbanization and agricultural land use. (Section 5.2)
- Most riverine systems in the study area have converted from: broad riparian systems with little vegetation cover and channels that were laterally unstable (braided) to narrow riparian systems with highly vegetated floodplains that have a single deep channel. (Section 5.2)
- Most *Arundo* has been removed from the Santa Margarita River for 13 years. The geomorphic response to large flow events in that time has been a significant widening of the low flow and bar channel area (38% increase). Flows also actively pass through floodplain areas; this is a major change in function and process. Moderately-sized events (15 year) now flow through significant portions of channel, bar, and floodplain areas. Before *Arundo* was removed, flows were restricted to channel and bar areas. (Section 5.2.4)
- Loss of flow capacity and presence of *Arundo* biomass is likely contributing to overbank flows and bridge loss and damage. (Section 5.2.5.1)
- Flow events mobilize large amounts of *Arundo* biomass. Part of this biomass load ends up on coastal beaches where it is frequently removed by public agencies and carries an estimated annual cost of $197,000. This does not include impacts on habitat quality. (Section 5.2.5.2)

Hydro-geomorphic impacts are significant. This has ramifications to both the ecosystem and infrastructure in and around invaded rivers. Watershed-based analysis on sediment movement and impacts should be explored in greater detail to further document and quantify relationships.

Arundo Impacts: Fires

- *Arundo* stands are highly flammable throughout the year with large amounts of fuel (15.5 kg/m^2 of biomass), a large amount of energy (287.1 MJ/m^2), and a tall well-ventilated structure with dry fuels distributed throughout the height profile. (Section 6.1)
- Fires frequently start in *Arundo* stands. The primary ignition sources are transient encampments and discarded cigarettes from highway overpasses. (Section 6.1)
- *Arundo* stands strongly attract transient use (dense cover and shelter). This was documented throughout the study area with numerous high use locations noted in both urban and agricultural areas. (Section 6.3.1)
- Fires initiated in *Arundo* stands occur due to fuel and ignition source occurring at the same location. This is a newly defined class of fire events. (Section 6.4.1)
- Fires that are initiated in *Arundo* burn both *Arundo* stands and native riparian areas. In addition, suppression of fires also impacts riparian habitat. Impacts were calculated for all watersheds using San Luis Rey as a case study. Over a ten-year period for the study area, *Arundo*-initiated fire events are estimated to have burned 513 acres of *Arundo* and 706 acres of native riparian habitat. Fire suppression over a ten-year period has impacted 44 acres of *Arundo* and 32 acres of native riparian vegetation. (Section 6.5)
- Wildfires burn a significant acreage of *Arundo* stands. Over ten years, 6.1% of *Arundo* stands (544 acres) burned within the study area. (Section 6.5)
- Due to high fuel load and stand structure, areas with *Arundo* burn hotter and more completely then native vegetation during wildfire events. (Section 6.4.2)

- *Arundo* stands appear to be conveying fires across riparian zones- linking upland vegetation areas that would have been separated by less flammable riparian vegetation. This can have catastrophic impacts like those observed in the 2008 Simi fire. The 8,474-acre fire crossed the Santa Clara River and then burned an additional 107,560 acres. (Section 6.4.2)
- *Arundo* fires accelerate the dominance of *Arundo* in invaded areas due to rapid re-growth and low mortality of *Arundo*. (Section 6.5.1)
- *Arundo* fire events lead to both direct mortality of wildlife and plants (some of which are sensitive) as well as a longer-term quality reduction of burned riparian areas (post-fire recovery of vegetation and structure). (Section 6.5.2)
- Emergency actions tied to *Arundo* fire suppression also result in impacts (disturbance of both *Arundo* and riparian vegetation) that degrade riparian habitat and/or may result in mortality of species. (Section 6.5.4)

Documentation and separation of *Arundo*-initiated fires from wildland fires that burn *Arundo* is an important finding. Impacts from *Arundo*-initiated fires are common and are the result of *Arundo* invasion. Harboring ignition sources in combination with combustible fuels year round creates this unique fire risk and impact. This needs to be further studied and documented. If validated, impacts to wildfire spread could be the greatest single impact.

Arundo Impacts: Federally Endangered and Threatened Species

- *Arundo* impacts to 22 federally endangered and threatened species from five taxonomic groups varied from: very severe (score of 10) to very low/improbable (score of 1). (Section 7.3.1)
- Documented and potential abiotic and biotic impacts from *Arundo* are described for each species. Abitoic impacts include modification of geomorphology, hydrology, flood disturbance, fire disturbance, water use, and nutrient budgets. Biotic impacts include alteration of vegetation/community structure (displacement of native vegetation), filling in 'open' un-vegetated portions of habitat, creating physical structure that impedes movement, creation of structure in estuaries that facilitates predation, biomass debris that degrades breeding areas, stand structure that is of low value for nesting, and biomass that is of low forage value for both insects and animals. (Section 7.2)
- *Arundo* co-occurs with sensitive species on many watersheds in the study area. This overlap in distribution was evaluated using the *Arundo* mapping data and sensitive species occurrence data (Appendix B). Interaction between *Arundo* and each species was scored. *Arundo* present upstream of sensitive species was specifically accounted for as impacts occur to downstream areas from alteration of sediment loads, geomorphic forms, biomass discharge and other factors. (Section 7.2)
- A cumulative impact score was calculated using the species' specific impact score and the overlap score. This allows each species and each watershed to be evaluated for magnitude of impact. Least Bell's Vireo and Arroyo toad ranked as the most 'severely impacted'. Three species ranked 'very high', four species ranked 'high', ten species were 'moderate', and three species were 'low'. (Section 7.2)
- Several fish species ranked very high on the cumulative impact scoring. This is a group of species that have not been closely associated with *Arundo* impacts prior to this study. Most fish species had impacts related to modification of channel form (single versus braided), channel depth (shallow versus deep), sediment transport, and potential biomass/debris impacts. (Section 7.2)

- Estuaries and beaches were shown to have moderate impacts resulting from both *Arundo* stands, which create physical structure that facilitates predation, and *Arundo* debris that covers open sandy areas required by ground-nesting avian species. (Section 7.2)
- Watershed rankings of *Arundo* impacts on sensitive species shows that there are four watersheds designated as 'severely impacted', two as 'highly impacted', eight as 'moderately impacted', and five as 'lowly impacted'. (Section 7.2)
- Three of the four 'severely impacted' watersheds have well-developed watershed-based *Arundo* control programs in place. (Section 7.2)

Impacts to habitat are significant. *Arundo*'s overlapping distribution with sensitive species creates pressures on a wide range of species. Impacts range from abiotic to direct biotic interaction. The most significant impacts relate to abiotic modification of the system (water, fire, geomorphic form), but these are the most difficult to document and quantify due to their scale. Additional research and documentation are needed to increase our understanding of how *Arundo* modifies ecosystem-regulating processes.

Cost to Benefit Analysis

- Cost of *Arundo* control is $25K per acre, as documented by $70 million of work completed on control programs within the study area over the past 20 years. (Section 8.1)
- This would total $196 million in control costs at the study area's peak *Arundo* distribution and $124 million at current *Arundo* distribution levels. (Section 8.1)
- Benefits from control and reduction of impacts was calculated for fire, water use, sediment trapping, flood damage (bridges), habitat, and beach debris. Analysis was conservative. (Section 8.2)
- Benefits: $380 million at peak *Arundo* distribution and $239 million at current *Arundo* distribution levels. (Section 8.2)
- Benefit to cost ratio of 1.9:1. (Section 8.2)

Arundo control is of substantial net benefit. Many impacts were not included in the analysis, and benefits were valued conservatively. The actual benefit of *Arundo* control is likely much higher than calculated.

Watershed Programs

- Watershed-based control is a priority and is facilitated by a strong lead entity that manages the program. Effective programs must have the capacity to manage project funds, obtain right of entry agreements, and hold regulatory permits. (Section 9.1)
- Permitting is complicated and expensive, but required. Programs with broad and active permits are able to implement programs more effectively and quickly. (Section 9.1)
- Watershed programs should use accurate and standardized mapping to represent *Arundo* acreage. This allows better management of programs, facilitates comparison of projects, and increases accountability. (Section 9.1)
- A significant amount of *Arundo* control has already occurred within the study area and many watershed-based control programs have already formed. (Section 9.1)
- Priorities for *Arundo* control are: (Section 9.2)
    - Long term re-treatment of program areas that have already had initial control: this protects the investment already made.

- Control *Arundo* on watersheds with low levels of invasion: this eradicates populations before they become abundant, which is more cost effective and avoids future impacts.
- Treat watersheds with significant *Arundo* invasion based on: level of impacts and capacity of groups proposing work.

Watershed-based management of *Arundo* is greatly facilitated by the establishment of a program lead. Programs with tracking systems for work completed, in addition to long-term stability, have the greatest ability of completing true watershed based control (eradication).

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APPENDIX A. Detailed Maps of *Arundo* Distribution Within the Study Area

***Arundo* distribution data from Monterey to San Diego, CA**
(see Chapter 3 for information on mapping methodology)

Spatial data set (GIS geo database) are available for download at:

http://www.cal-ipc.org/ip/research/arundo/index.php

or

http://www.cal-ipc.org/ip/mapping/arundo/index.php

The spatial data set is also viewable at the DFG BIOS web site:

http://bios.dfg.ca.gov/

Project data sets are named:
Invasive Plants (Species) - Central_So. Cal Coastal Watersheds [ds645]
Invasive Plants (Prct Cover) - Central_So. Cal Coastal Watersheds [ds646]

APPENDIX B. Occurrence Data and Critical Habitat Areas for Federally Listed Species and Distribution of *Arundo*.

Spatial data for federally listed species includes:

- **Critical habitat areas designated by USFWS**
- **Occurrence data compiled by the Ventura USFWS Office**
- **Occurrence data from the California Natural Diversity Database (CNDDB: CA DFG)**
- **Additional occurrence data from USGS, SANDAG, and other sources**

Spatial data set (GIS geo database) are available for download at:

http://www.cal-ipc.org/ip/research/arundo/index.php

or

http://www.cal-ipc.org/ip/mapping/arundo/index.php

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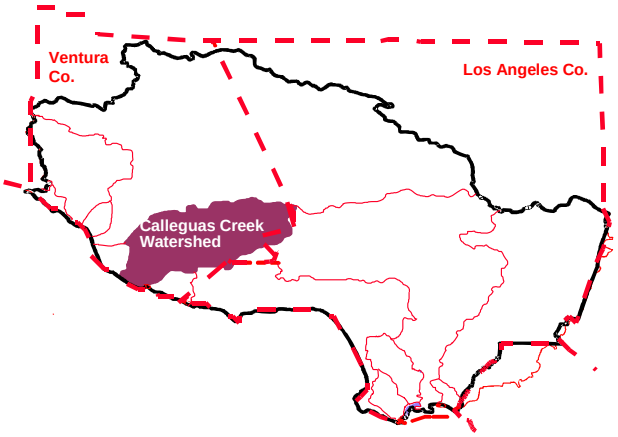
Invasive Plants (Prct Cover) - Central_So. Cal Coastal Watersheds [ds646]

2.10 CALLEGUAS CREEK WATERSHED

This watershed will be targeted in FY2011/2012.

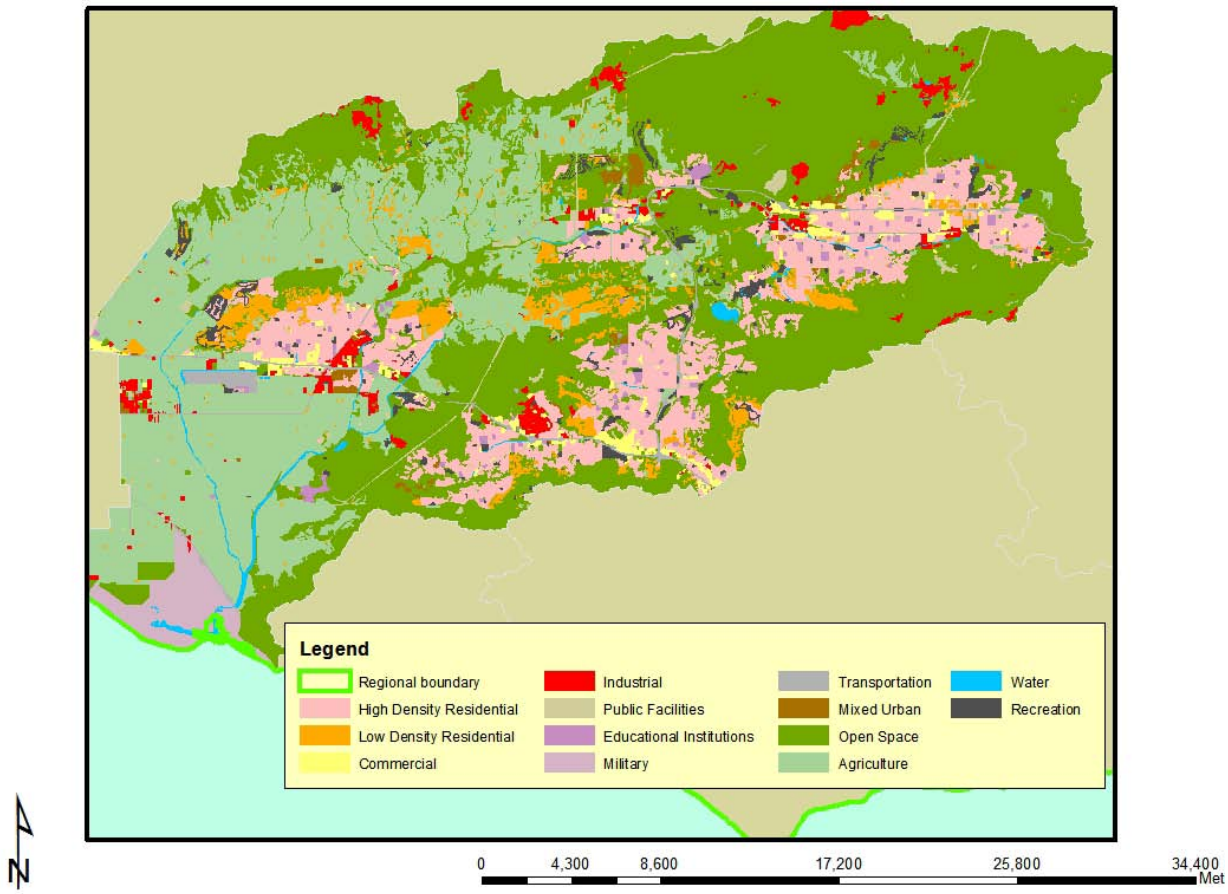
Overview of Watershed



Calleguas Creek and its major tributaries, Revolon Slough, Conejo Creek, Arroyo Conejo, Arroyo Santa Rosa, and Arroyo Simi drain an area of 343 square miles in southern Ventura County and a small portion of western Los Angeles County. This watershed, which is elongated along an east-west axis, is about 30 miles long and 14 miles wide. The northern boundary of the watershed is formed by the Santa Susana Mountains, South Mountain, and Oak Ridge; the southern boundary is formed by the Simi Hills and Santa Monica Mountains.

Land uses vary throughout the watershed. Urban developments are generally restricted to the city limits of Simi Valley, Moorpark, Thousand Oaks, and Camarillo. Although some residential development has occurred along the slopes of the watershed, most upland areas are still open space; however, golf courses are becoming increasingly popular to locate in these open areas. Agricultural activities, primarily cultivation of orchards and row crops, are spread out along valleys and on the Oxnard Plain as shown in the figure below.

Land Use in the Calleguas Creek Watershed



Mugu Lagoon, located at the mouth of the watershed, is one of the few remaining significant saltwater wetland habitats in southern California. The Point Mugu Naval Air Base is located in the immediate area and the surrounding Oxnard Plain supports a large variety of agricultural crops. These fields drain into ditches which either enter the lagoon directly or through Calleguas Creek and its tributaries. Other fields drain into tile drain systems which discharge to drains or creeks. Also in the area of the base are freshwater wetlands created on a seasonal basis to support duck hunting clubs. The lagoon borders on an Area of Special Biological Significance (ASBS) and supports a great diversity of wildlife including several endangered birds and one endangered plant species. Except for the military base, the lagoon area is relatively undeveloped.

Beneficial Uses in watershed:

Estuary	*Above Estuary*
Wildlife habitat	Wildlife habitat
Contact & noncontact water recreation	Contact & noncontact water recreation
Estuarine habitat	Industrial service supply
Marine habitat	Industrial process supply
Preservation of rare & endangered species	Preservation of rare & endangered species
Navigation	Agricultural supply
Preservation of biological habitats	Groundwater recharge
Wetlands habitat	Wetlands habitat
Migratory & spawning habitat	Freshwater replenishment
Shellfish harvesting	Warmwater habitat

Supplies of ground water are critical to agricultural operations and industry (sand and gravel mining) in this watershed. Moreover, much of the population in the watershed relies upon ground water for drinking.

Water Quality Problems and Issues

Aquatic life in both Mugu Lagoon and the inland streams of this watershed has been impacted by pollutants from nonpoint sources. DDT, PCBs, other pesticides, and some metals have been detected in both sediment and biota collected from surface waterbodies of this watershed. Additionally, ambient toxicity has been revealed in several studies from periodic toxicity testing in the watershed (ammonia from POTWs and pesticides such as diazinon and chlorpyrifos are implicated). Fish collected from Calleguas Creek and Revolon Slough exhibit skin lesions and have been found to have other histopathologic abnormalities. High levels of minerals and nitrates are common in the water column as well as in the groundwater. Sediment toxicity is also elevated in some parts of the lagoon. Reproduction is impaired in the resident endangered species, the light-footed clapper rail due to elevated levels of DDT and PCBs. Overall, this is a very impaired watershed. It appears that the sources of many of these pollutants are agricultural activities (mostly through continued disturbance and erosion of historically contaminated soils), which cover approximately 25% of the watershed along the inland valleys and coastal plain, although the nearby naval facility has also been a contributor. Other nonpoint sources include residential and urban activities, which are present over approximately 25% of the watershed. The remaining 50% of the watershed is still open space although there is a severe lack of benthic and riparian habitat.

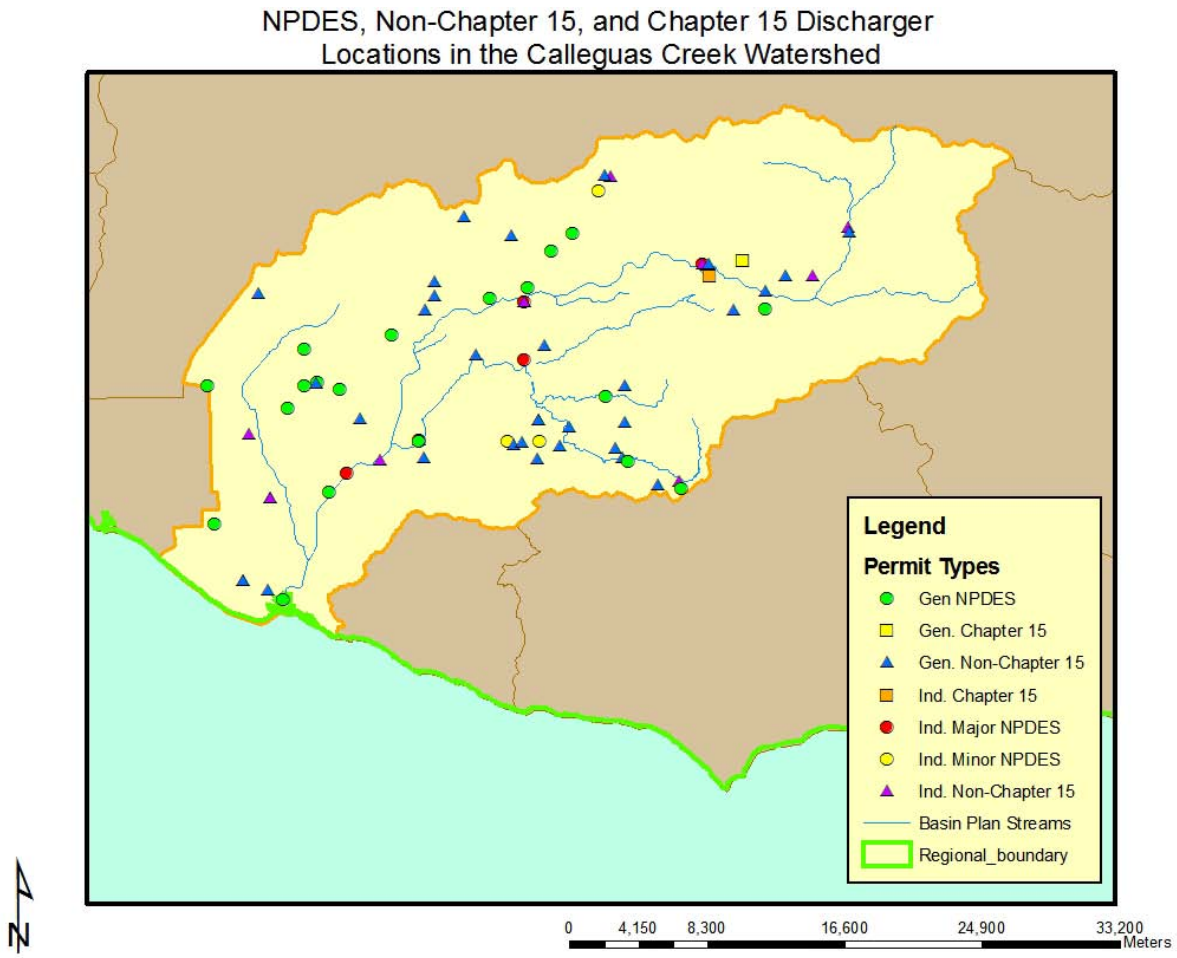
Permitted discharges:

- 26 NPDES discharges; five major discharges (POTWs); three minor discharges; eighteen discharges covered by general permits
- 73 dischargers covered under the industrial storm water permit
- 292 dischargers covered under the construction storm water permit
- Municipal storm water permit

Mugu Lagoon as well as the Calleguas Creek Estuary is considered a toxic hot spot under the Bay Protection and Toxic Cleanup Program (BPTCP) due to reproductive impairment (the endangered clapper rail), exceedance of the state Office of Environmental and Health Hazard Assessment (OEHHA) advisory level for mercury in fish, and exceedance of the NAS guideline level for DDT in fish, sediment concentrations of DDT, PCB, chlordane, chlorpyrifos, sediment toxicity and degraded benthic infaunal community.

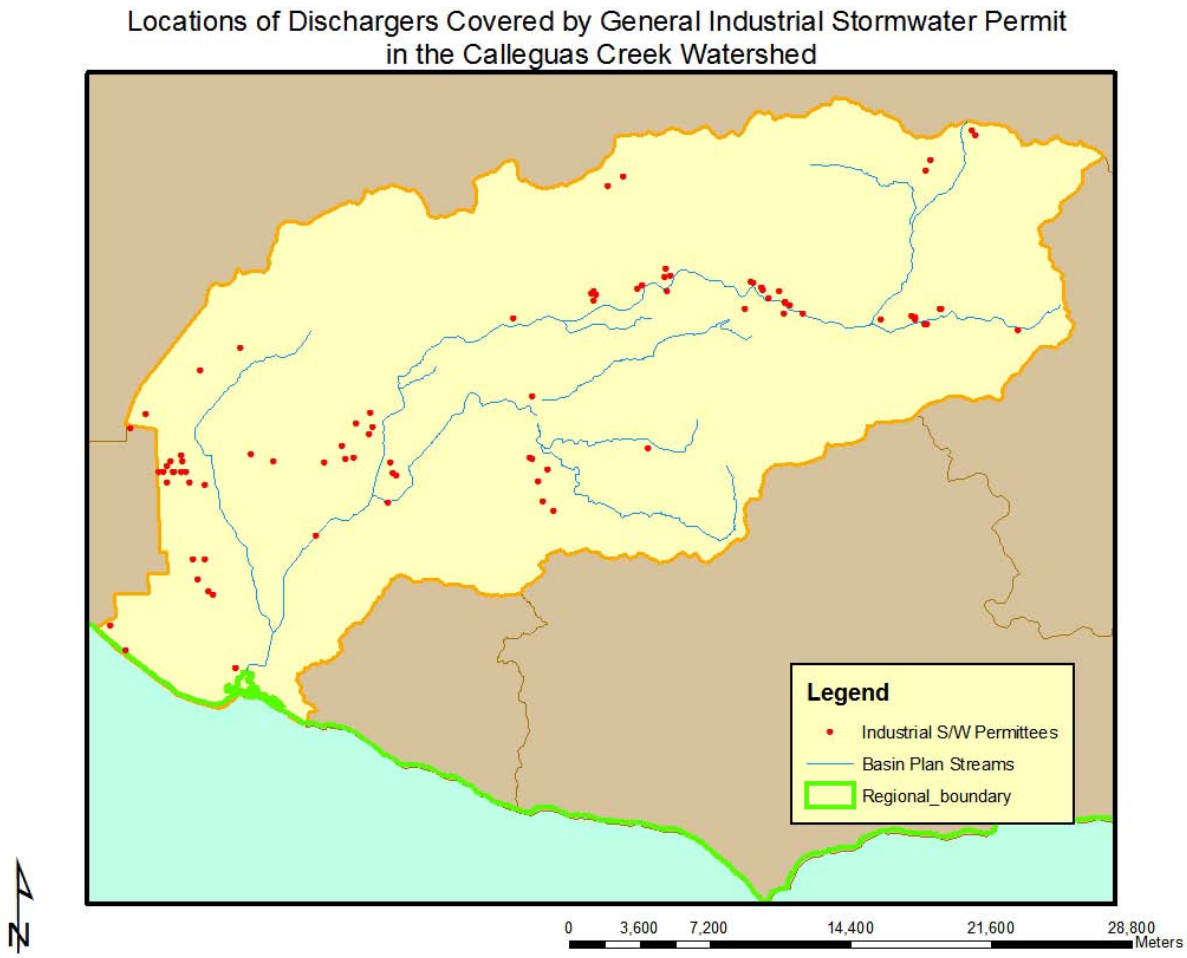
Primary issues related to POTW discharges include ammonia toxicity and high mineral content (i.e., salinity), the latter, in part, due to imported water supplies.

The locations of facilities with discharges to surface water or to the ground (other than those covered by general industrial or construction stormwater permits) are shown in the following figure. Major NPDES discharges are from either POTWs with a yearly average flow of over 0.5 MGD, from an industrial source with a yearly average flow of over 0.1 MGD, or are those discharges with lesser flows but with potential acute or adverse environmental impacts to surface waters. Minor NPDES discharges are all other discharges to surface waters that are not categorized as a Major. Minor discharges may be covered by general NPDES permits, which are issued administratively, for those that meet the conditions specified by the particular general permit. Non-Chapter 15 discharges are those to land or groundwater such as commercial septic systems or percolation ponds that are covered by Waste Discharge Requirements, a State permitting activity. Chapter 15 discharges generally relate to land disposal (landfills) under Chapter 15 of the California Code of Regulations, again an exclusively State permitting activity.



Discharges are fairly evenly spread around the watershed; four of the 26 NPDES discharges go to the Arroyo Conejo, while six discharge to Revolon Slough and twelve discharge to the Creek's various reaches.

Of the 90 dischargers enrolled under the general industrial storm water permit in the watershed, the largest numbers are located in the cities of Simi Valley and Camarillo. There is a diverse mix of industries represented including electric, gas and sanitary services; local and interurban passenger transit; electric and electronic equipment; and stone, clay and glass products based on their Standard Industrial Classification (SIC) codes. The locations of facilities with discharges covered by the general industrial stormwater permit are shown in the following figure.



There are 292 construction sites enrolled under the general construction storm water permit. About one-half of the sites are residential and about one-half are five acres or larger in size; one site is about 1,000 acres. Most of the sites are located in Camarillo, Simi Valley, and Thousand Oaks.

The table below gives the impairments for the watershed from the 2006 303(d) list:

Water Quality Limited Segment Name	Pollutant
Calleguas Creek Reach 1 (was Mugu Lagoon on 1998 303(d) list)	Chlordane (tissue)[1] Copper[2] DDT (tissue & sediment)[1] Endosulfan (tissue)[1] Mercury[2] Nickel[2] Nitrogen[3] PCBs (tissue)[1] Sediment Toxicity[1]

	Sedimentation/Siltation[1]
Calleguas Creek Reach 2 (estuary to Potrero Rd- was Calleguas Creek Reaches 1 and 2 on 1998 303d list)	Ammonia[3] ChemA (tissue)[1*] Chlordane (tissue)[1] Copper, Dissolved[2] DDT (tissue & sediment)[1] DDT[1] Endosulfan (tissue)[1] Fecal Coliform Nitrogen[3] PCBs (tissue)[1] Sediment Toxicity[1] Sedimentation/Siltation[1] Toxaphene (tissue & sediment)[1]
Calleguas Creek Reach 3 (Potrero Road upstream to confluence with Conejo Creek on 1998 303d list)	Chlordane Chloride DDT[1] Dieldrin[1] Nitrate and Nitrite[3] Sedimentation/Siltation[1] Total Dissolved Solids Toxaphene[1]
Calleguas Creek Reach 4 (was Revolon Slough Main Branch: Mugu Lagoon to Central Avenue on 1998 303d list)	Boron ChemA (tissue)[1*] Chlordane (tissue & sediment)[1] Chlorpyrifos (tissue)[1] DDT (tissue & sediment)[1] Dieldrin (tissue)[1] Endosulfan (tissue & sediment)[1] Fecal Coliform Nitrate as Nitrate (NO3)[3] Nitrogen[3] PCBs (tissue)[1] Sedimentation/Siltation[1] Selenium[2] Sulfates Total Dissolved Solids

	Toxaphene (tissue & sediment)[1] Toxicity[4] Trash
Calleguas Creek Reach 5 (was Beardsley Channel on 1998 303d list)	ChemA (tissue)[1*] Chlordane (tissue & sediment) Chlorpyrifos (tissue)[1] Dacthal (sediment)[1] DDT (tissue & sediment)[1] Dieldrin (tissue)[1] Endosulfan (tissue & sediment)[1] Nitrogen[3] PCBs (tissue)[1] Sedimentation/Siltation[1] Toxaphene (tissue & sediment)[1] Toxicity[4] Trash
Calleguas Creek Reach 6 (was Arroyo Las Posas Reaches 1 and 2 on 1998 303d list)	Ammonia[3] Chloride DDT (sediment)[1] Fecal Coliform Nitrate and Nitrite[3] Nitrate as Nitrate (NO3)[3] Sedimentation/Siltation[1] Sulfates Total Dissolved Solids
Calleguas Creek Reach 7 (was Arroyo Simi Reaches 1 and 2 on 1998 303d list)	Ammonia[3] Boron Chloride Fecal Coliform Organophosphorus Pesticides[4] Sedimentation/Siltation[1] Sulfates Total Dissolved Solids
Calleguas Creek Reach 8 (was Tapo Canyon Reach 1)	Boron Chloride Sedimentation/Siltation[1] Sulfates Total Dissolved Solids

Calleguas Creek Reach 9A (was lower part of Conejo Creek Reach 1 on 1998 303d list)	ChemA (tissue)[1*] Chlordane (tissue)[1] DDT (tissue)[1] Dieldrin (tissue)[1] Endosulfan (tissue)[1] Fecal Coliform Lindane/HCH (tissue)[1] Nitrate as Nitrate (NO3)[3] Nitrogen, Nitrate[3] PCBs (tissue)[1] Sulfates Total Dissolved Solids Toxaphene (tissue & sediment)[1]
Calleguas Creek Reach 9B (was part of Conejo Creek Reaches 1 and 2 on 1998 303d list)	Ammonia[3] ChemA (tissue)[1*] Chloride DDT (tissue)[1] Endosulfan (tissue)[1] Fecal Coliform Sulfates Total Dissolved Solids Toxaphene (tissue & sediment)[1] Toxicity[4]
Calleguas Creek Reach 10 (Conejo Creek (Hill Canyon)-was part of Conejo Ck Reaches 2 & 3, and lower Conejo Ck/Arroyo Conejo N Fk on 1998 303d list)	Ammonia[3] ChemA (tissue)[1*] Chloride DDT (tissue)[1] Endosulfan (tissue)[1] Fecal Coliform Nitrogen, Nitrite[3] Sulfates Total Dissolved Solids Toxaphene (tissue & sediment)[1] Toxicity[4]
Calleguas Creek Reach 11 (Arroyo Santa Rosa, was part of Conejo Creek Reach 3 on 1998 303d list)	Ammonia[3] ChemA (tissue)[1*] DDT (tissue)[1]

	Endosulfan (tissue)[1] Fecal Coliform Sedimentation/Siltation[1] Sulfates Total Dissolved Solids Toxaphene (tissue & sediment)[1] Toxicity[4]
Calleguas Creek Reach 12 (was Conejo Creek/Arroyo Conejo North Fork on 1998 303d list)	Ammonia[3] Chlordane (tissue)[1] DDT (tissue)[1] Sulfates Total Dissolved Solids
Calleguas Creek Reach 13 (Conejo Creek South Fork, was Conejo Cr Reach 4 and part of Reach 3 on 1998 303d list)	Ammonia[3] ChemA (tissue)[1*] Chloride DDT (tissue)[1] Endosulfan (tissue)[1] Sulfates Total Dissolved Solids Toxaphene (tissue & sediment)[1] Toxicity[4]
Duck Pond Agricultural Drains/Mugu Drain/Oxnard Drain No 2	ChemA (tissue)[1*] Chlordane (tissue)[1] DDT (tissue & sediment)[1] Nitrogen[3] Sediment Toxicity[1] Toxaphene (tissue)[1] Toxicity[4]
Fox Barranca (tributary to Calleguas Creek Reach 6)	Boron Sulfates Total Dissolved Solids
Rio De Santa Clara/Oxnard Drain No. 3	ChemA (tissue)* Chlordane (tissue) DDT (tissue) Nitrogen PCBs (tissue) Sediment Toxicity Toxaphene (tissue)

* ChemA refers to the sum of the chemicals aldrin, dieldrin. chlordane, endrin, heptachlor, heptachlor epoxide, HCH (including lindane), endosulfan, and toxaphene

[1]Calleguas Creek, its Tributaries, and Mugu Lagoon OC Pesticides, PCBs, and Siltation TMDL, 2005

[2]Calleguas Creek, its Tributaries, and Mugu Lagoon Metals and Selenium TMDL, 2007
[3]Calleguas Creek Nitrogen TMDL, 2003
[4]Calleguas Creek Toxicity TMDL, 2005

CURRENTLY SCHEDULED TMDLS:

- salts
- trash

Stakeholder Groups

Calleguas Creek Watershed Management Committee and Technical Subcommittees: Recognizing that many of the water quality problems in the lagoon stem from land use practices and pollutant sources above the lagoon, members of these committees meet regularly to exchange data and discuss coordinated approaches to solving the many problems in this watershed, including development of a watershed management plan. The watershed group consists of about 130 stakeholders who have been meeting since November 1996 with the purpose of developing a watershed management plan. As we expect that much effort will need to be focused on resolving agricultural and flood control issues, a concerted effort to include appropriate stakeholders. Besides the main management committee of stakeholders, five technical subcommittees deal with more specific issues such as water quality, flood protection/ sediment management, habitat/open space/recreation, public outreach, and land use. A Steering Committee attends to the details of management plan development. The full Management Plan Committee meets on a quarterly basis, generally conducting business in a half-day session. Staff have been and will continue to work with these committees. For further information concerning this group, please visit their website at http://www.calleguas.com/cc.htm.

A number of the above committee members were also on the *Mugu Lagoon Task Force* which was formed in 1990 in response to concerns about sedimentation filling in Mugu Lagoon which is at the mouth of the Calleguas Creek Watershed. A major focus of the early meetings was exchange of information on the extent of sedimentation with related concerns such as pesticide transfer. A sediment and erosion control plan was prepared for the Ventura County RCD by the U.S. Natural Resource Conservation Service (USNRCS) using Coastal Conservancy funds ("Calleguas Creek Watershed Erosion and Sediment Control Plan for Mugu Lagoon", May 1995). This group no longer meets; however, information gained from this effort continues to be used by the other Calleguas Watershed Committees.

Significant Past Activities

CORE REGULATORY

The majority of Calleguas Creek Watershed permits were revised in June 1996. This watershed, as well as the Ventura River Watershed, were pilot watersheds in our implementation of the watershed management approach. The Ventura County Municipal Stormwater NPDES Permit had most recently been adopted in 2000. The watershed was targeted again for NPDES permit renewals in FY01/02.

MONITORING AND ASSESSMENT

As the first integrated watershed monitoring program in the Region, the six POTWs in the watershed each implemented a portion (Characterization Study) in 2000 which also included other agencies in the effort. In conjunction with the receiving water monitoring, land-use based monitoring was done as a part of the Ventura County Municipal Storm Water Program. The monitoring supported compliance valuation, nonpoint source identification, and potential TMDL development. The expanded monitoring by the dischargers also served to evaluate beneficial uses.

Calleguas Creek was a focus for SWAMP monitoring in FY00/01 as the watershed was targeted in the rotating watershed cycle. Since extensive monitoring has already occurred here, particularly in the lower watershed, a more directed approach to sampling site selection was taken. A short-term watershed-wide regional monitoring program was created to fill in data gaps and eliminate duplicative and unnecessary monitoring. A total of thirteen sites were sampled once by SWAMP in the Calleguas Creek Watershed. Twelve directed sites were sampled for toxicity, bioassessment, conventional water chemistry and organophosphate chemistry in the water column. One estuary station was sampled for bioaccumulation in addition to abovementioned analyses. POTWs contributed significant resources to do a surface and ground water characterization study. It also served to assess nonpoint source pollution from a variety of land uses.

UCLA was under contract with the State Board to provide data needed for establishment of nutrient TMDLs in several watersheds within the Region including Calleguas Creek, Santa Clara River, and Malibu Creek. By understanding the inter-relationships between water quality and habitat condition and the resulting effects that these interactions have on the biological communities of coastal watersheds, this research was intended to further our understanding of the ecology of southern California watersheds. Besides providing information supporting the establishment of nutrient TMDLs for these three impaired coastal watersheds, the data collected would provide insight into how these TMDLs might be complied with in the future. Three specific objectives of this project were: 1) investigate the relationships between water quality (e.g. nutrients), habitat quality, and the biological community, 2) investigate how water quality and biological communities change throughout particular target reaches representing different land uses, and 3) compare the relationships between water quality, habitat quality, and biological communities among different watersheds. The work was a continuation and extension of a Regional Environmental Monitoring and Assessment Program (R-EMAP) project in the watershed. R-EMAP us part of a larger national effort by the USEPA to assess the condition of the nation's ecological resources.

BASIN PLANNING

In 1990, the Regional Board adopted Resolution No. 90-004 (**Drought Policy**) which had a term of three years and provided interim relief to dischargers who experienced difficulty meeting chloride objectives because of a state-wide drought. The policy adjusted effluent limits to the lesser of 1) 250 mg/l or 2) the chloride concentration in the water supply plus 85 mg/l. In 1995, the Regional Board extended the interim limits for three years and directed staff to develop a long-term solution to deal with the impact of changing water supply, especially during droughts. In 1997, the Regional Board adopted Resolution No. 97-002 (**Chloride Policy**) which set the chloride objective at 190 mg/l except in the Calleguas Creek and Santa Clara River Watersheds where, due to the great concern for protection of agriculture, staff were directed to determine the chloride concentrations sufficient to protect agricultural beneficial uses.

WETLANDS PROTECTION AND MANAGEMENT

The Wetlands Recovery Project funded a restoration project in the watershed, the Grimes Canyon Stream Restoration Project.

NONPOINT SOURCE PROGRAM

Work on nonpoint source problems in the watershed has been a long-term effort, initiated in 1990, with the support of 319(h) funds and other funding from, and support by, stakeholders. The 319(h) grant projects, special studies, and other activities that have been completed to date include:

- ***Irrigation Demonstration Project***: In 1994, the Ventura County Resource Conservation District successfully completed an irrigation project that demonstrated the water quality and conservation benefits of drip irrigation. This project was funded through a 319(h) grant.

- ***Toxicity Testing***: In order to detect sources of toxicity, we had collected water samples under three sequential studies (toxicity testing by UC Davis). Results of this sampling indicated sporadic toxicity, generally during wet weather seasons, with strong implication of organophosphate pesticides. A peer-reviewed paper on the results is pending.

- ***Calleguas Creek Watershed Treatment – Phases I and II***: The Ventura County Resource Conservation District served as contractor for this project which focused on Best Management Practices that involved small, individual landowners/ farmers. This demonstration project was designed to implement streambed protection practices. The two phases were funded through 319(h) grants.

Current Activities

The following is a summary of current regional board activities and strategies for dealing with point and nonpoint source pollution as well as other issues of concern in the Calleguas Creek Watershed.

CORE REGULATORY

Current regulatory activities include compliance inspections, review of monitoring reports, response to complaints, and enforcement actions, as needed.

Most urban areas in Ventura County, including this watershed, are implementing Best Management Practices (BMPs) under the Municipal Storm Water Permit (revised in 2000). The "Discharger" consists of the co-permittees Ventura County Flood Control District, the County of Ventura, and the Cities of Camarillo, Fillmore, Moorpark, Ojai, Oxnard, Port Hueneme, San Buenaventura, Santa Paula, Simi Valley, and Thousand Oaks. The Discharger is required to implement the Ventura Countywide Stormwater Quality Urban Impact Mitigation Plan (SQUIMP), which requires the implementation of BMPs to reduce the discharge of pollutants in storm water from new development and significant redevelopment. Other requirements of the Municipal Storm Water Permit include a public education program, an educational site inspection program for industrial and commercial facilities, program for construction sites, public agency activities, and a storm water monitoring program.

The Calleguas Creek receives municipal storm drain discharges from the City of Camarillo, City of Moorpark, City of Simi Valley, City of Thousand Oaks (part), and unincorporated Ventura County (part).

The storm water monitoring program has consisted of land-use based monitoring, receiving water and mass emission station monitoring, and bioassessment. The Discharger also participates in regional monitoring activities, such as the Storm Water Monitoring Coalition, organized by the Southern California Coastal Water Research Project. Furthermore, the Discharger participates in the development and implementation of volunteer monitoring programs in the Ventura Coastal watersheds.

Regulation of groundwater protection activities is intended to eventually become fully integrated into the watershed management approach; currently, groundwater monitoring (for POTWs using ponds) is being coordinated with surface water monitoring.

MONITORING AND ASSESSMENT

The BPTCP has identified the lagoon and tidal prism as "toxic hot spots" based on sediment contamination. Staff have completed a preliminary cleanup plan for the areas which was adopted as part of a statewide consolidated plan by the State Board in June 1999. Cleanup/remediation alternatives identified include dredging, in-situ capping, and treatment; however, dedicated funding for cleanup activities has not been provided by the state. Continuing Regional Board activities include working with stakeholders to further characterize historical sources of pollution as well as the extent of existing contributions. While remediation of the lagoon (as part of a military facility) may proceed on its own timeline, in general, there is a concerted effort by all stakeholders to prepare a comprehensive watershed management plan to address all problems in the watershed.

The Calleguas Creek Watershed Management Plan Habitat/Recreation and Land Use Subcommittees are jointly working on aspects of a Watershed Evaluation Study that is scheduled to be finished in 2002. This is a GIS-based effort with the goals of identifying high quality habitat and those areas that would help link them, the current level of protection, land ownership, and information from local entities land use plans. Another goal is to make the information available via the Internet.

NONPOINT SOURCE PROGRAM

We expect that stakeholders will continue work on developing a watershed management plan, which will include measures for reducing pollutants from nonpoint sources. Accordingly, our efforts in the Calleguas Creek watershed will focus on continuing the nonpoint source phase of the watershed cycle, including integrating results of our on-going nonpoint source efforts. The 319(h) grant projects, special studies, and other activities that are currently on-going include:

319(h) Grants

Calleguas Creek Water Quality Monitoring Program: The Wishtoyo Foundation received 319(h) grant funds in 2001 to educate and train volunteers to conduct a citizen monitoring program in the watershed. The goal is to measure the effectiveness of BMPs created to manage the flow of nutrients, pesticides, and sediments. Bioassessments will also be conducted.

We continue to support as high priorities for grant funding projects relating to implementation of TMDLs, habitat enhancement/restoration, and reduction of pollutants from agricultural activities.

Other NPS Activities

Our efforts to involve stakeholders also shall include exploration of funding options (especially for implementation of nonpoint source measures) and continuation of other outreach activities, such as speeches, meetings, and participation in environmental events.

Mugu Lagoon/Revolon Slough is identified as Critical Coastal Area (CCA) #58 in the State Water Resources Control Board's and California Coastal Commission's Critical Coastal Area Draft Strategic Plan. It has been identified as such in 1995 as an impaired water body and one of the few remaining saltwater wetland habitats remaining in Southern California. The major efforts listed to implement NPS management measures include: activities of Wishtoyo Foundation and Ventura CoastKeeper; streambank restoration projects conducted by Ventura County Resources Conservation District for growers; the Calleguas Municipal Water District's Regional Salinity Management Project; work conducted by the Calleguas Creek Watershed Management Plan Committee; the Erosion and Sediment Control Plan prepared in 1995 by the Ventura County Resources Conservation District; the watershed-wide monitoring program; BMPs implemented under the Ventura County municipal stormwater permit; and implementation of various TMDLs.

Laguna Point to Latigo Point is identified as CCA #59 in the CCA Draft Strategic Plan. It has been identified as such since the watersheds drain into a Marine Protected Area. This CCA covers parts of both Los Angeles and Ventura Counties from Calleguas Creek to Malibu. The major efforts listed to implement NPS management measures include: activities of the Malibu Creek Watershed Council and construction of Calleguas Municipal Water District's Regional Salinity Management Project.

BASIN PLANNING

Several high priority issues were identified in the 2005 - 2007 Triennial Review which affect this watershed management area and will require Basin Planning resources. As in all watersheds, adopting TMDLs as Basin Plan amendments is required under the Consent Decree with an estimated resource need of 0.5 PY/TMDL. This is considered a currently funded activity. The ongoing Tiered Aquatic Life Uses Pilot Project may affect many watersheds in the Region. The purpose of tiered aquatic life uses (TALUs) is to have more appropriate goals for protecting

aquatic life that account for these inherent physical limitations. The purpose of this pilot project is to develop more tailored water quality standards (through beneficial use designations and associated biocriteria) to protect the biological communities of semi-arid urban coastal streams and, If deemed appropriate, recommend appropriate tiered aquatic life uses for these semi-arid urban coastal streams. Other high priority issues identified by the Triennial Review common to multiple watersheds may be found in the Region-wide Section.

Review and comment on EIRs for the highest priority projects within the watershed will continue; however, there is currently no funding for this program.

WETLANDS PROTECTION AND MANAGEMENT

The Wetlands Recovery Project has listed the Lower Conejo Creek Acquisition as a priority project on the current workplan. Being listed on the workplan is not a guarantee of funding however. More information about the workplan may be found at http://www.scwrp.org.

A wetlands restoration plan for the watershed has been prepared (with Coastal Conservancy and USEPA funding) by a local consultant through the Habitat Subcommittee of the Calleguas Creek Watershed Plan Committee. This document is available on the Calleguas Creek Watershed Management Plan website at http://www.calleguas.com/ccbrochure/cc.htm. The next step in the process, completion of a Wetlands Restoration Feasibility Study, is ongoing.

The Santa Monica Mountains Conservancy is a state agency created by the Legislature in 1979 charged with primary responsibility for acquiring property with statewide and regional significance, and making those properties accessible to the general public. The Conservancy manages parkland in the Santa Monica Mountains, Santa Susana Mountains, the Simi Hills, the Santa Clarita Woodlands, the Whittier-Puente Hills, the Sierra Pelona, the Los Angeles River Greenway, the Rio Hondo, the Verdugo Mountains, the San Gabriel Mountains, and the San Rafael Hills. The agency's goals are to: 1) implement the Santa Monica Mountains Comprehensive Plan, 2) implement the Rim of the Valley Trails Corridor Master Plan, 3) implement the Los Angeles County River Master Plan, 4) further cooperation with local governments in the region to secure open space and parkland, and 5) expand education, public access, and resource stewardship components in a manner that best serves the public, protects habitat, and provides recreational opportunities. Additional information on their priorities may be found at http://www.smmc.ca.gov/.

DOD SITE CLEANUP PROGRAM

The Regional Board is working with the Department of Toxic Substances Control (DTSC) to investigate soil and groundwater quality at Department of Defense (DoD) facilities. Sites currently under assessment/remediation include Mugu Lagoon, a former landfill, the Naval Exchange gas station, two Installation Restoration Program (IRP) sites, numerous underground storage tanks, and the former oxidation sewage ponds.

The Navy disposed of inert, contaminated and hazardous wastes to an unlined unpermitted landfill constructed by depositing and compacting wastes into Calleguas Creek. An erosion berm was installed as an interim remedial measure to prevent further erosion of the former landfill by storm water flowing through the creek during storm events. Long-term groundwater monitoring will be required for this site. Sediments and surface water at IRP Site 5 are contaminated with chrome. An initial emergency removal action (sediment excavation) failed to adequately

remediate all impacted sediments and additional sediment remediation and surface water monitoring is ongoing.

Soil and groundwater at IRP Site 24 is contaminated with chlorinated solvents. Groundwater is being treated by implementation of a new biodegradation technology. It is not yet determined to what extent groundwater remediation or monitoring will be required to restore this site.

It is anticipated the Navy will implement a base-wide groundwater/surface water investigation to evaluate the overall groundwater and surface water quality, evaluate the interactions of surface water and groundwater, and determine the cumulative risk of multiple groundwater-surface water contamination sites on the overall water quality of the area and the risk to human health and the environment.

Prior to 1979, the Navy was allowed to discharge partially treated wastewater to surface water oxidation ponds that were constructed in the Calleguas Creek tidal prism. The ponds were unlined and allowed to percolate unevaporated water to the underlying groundwater, which is located about four feet below grade. The Regional Board rescinded the Navy's discharge permit in 1979 and required the Navy to pump all wastewater to the Oxnard POTW. However, periodic unpermitted discharges of wastewater continued to the ponds during planned repairs of the wastewater discharge line and wastewater overflow conditions, which occurred during heavy rains.

To prevent additional wastewater discharges to the ponds, the Regional Board issued a Cleanup and Abatement Order to the Navy in 1998 directing the Navy to cease all unpermitted discharges, construct a lined emergency wastewater retention basin, upgrade the wastewater discharge line, and remove the sludge that has accumulated in the ponds.

Current funding for the investigation and remediation of contaminated solids, surface water and groundwater at the base is through the DoD/CalEPA funding agreement; however, this funding is not satisfactory for the investigation or control of contaminants from upstream sources for the protection of Mugu Lagoon and continued funding cuts have had significant impacts on the level of oversight by Regional Board staff on these areas.

Near-term Activities

Specific resource needs are described in the Region-wide Section of this document.

NPDES Permits in the watershed will come up for renewal in FY 2003/04. In the meantime, core regulatory activities will focus on permit compliance, monitoring report review, and enforcement as needed. In addition, integration of stormwater and nonpoint source issues will continue. Members of the watershed team will be involved with periodic updates of the State of the Watershed Report. Additionally, there will be on-going interaction with stakeholders and followup on goals established during the permit renewal phase. Pending results from the discharger pollutant characterization study, a decision on waste load and load allocations will be pursued.

A review of resources for core regulatory activities against cost factors has determined that our region is seriously underfunded for our baseline program. We will be seeking more funding for our core program activities.

We shall have made significant progress later in this watershed's first cycle, toward identifying and assessing problems (through the characterization study) and involving stakeholders. At that point we (and the stakeholders) may also enough information to get a headstart on establishing load allocations for certain pollutants of concern.

Additional monitoring and assessment tasks include continued involvement in updates to the baseline State of the Watershed Report, focusing on filling data gaps and evaluating cumulative impacts as monitoring data become available from dischargers, evaluating the results of the SWAMP monitoring, follow-up on pollutants identified through toxicity identification evaluations, implement TMDLs to actually begin to solve problems found through monitoring, and implementing the municipal storm water program.

Our efforts to involve stakeholders shall also include exploration of funding options (especially for implementation of nonpoint source measures) and continuation of other outreach activities, such as speeches, meetings, and participation in environmental events. We shall continue our involvement in the watershed group's efforts to develop and implement a watershed management plan.

We will maintain involvement with stakeholder activities and pursue funding options, especially those involving implementation of nonpoint source measures (coordinate grant activities) as well as other outreach activities such as speeches, meetings, and participation in environmental events. As resources permit, we will also work with stakeholders to implement provisions of the Coastal Zone Act Reauthorization Amendments.

Potential Mid- to Long-term Activities

In the long-term, activities will include continued participation in both internal and external watershed planning efforts and further implementation of watershed-specific solutions. Several Basin Planning issues will be addressed through the Characterization Study and watershed planning efforts. More resources are needed for these activities.

Other mid- to long-term issues include:

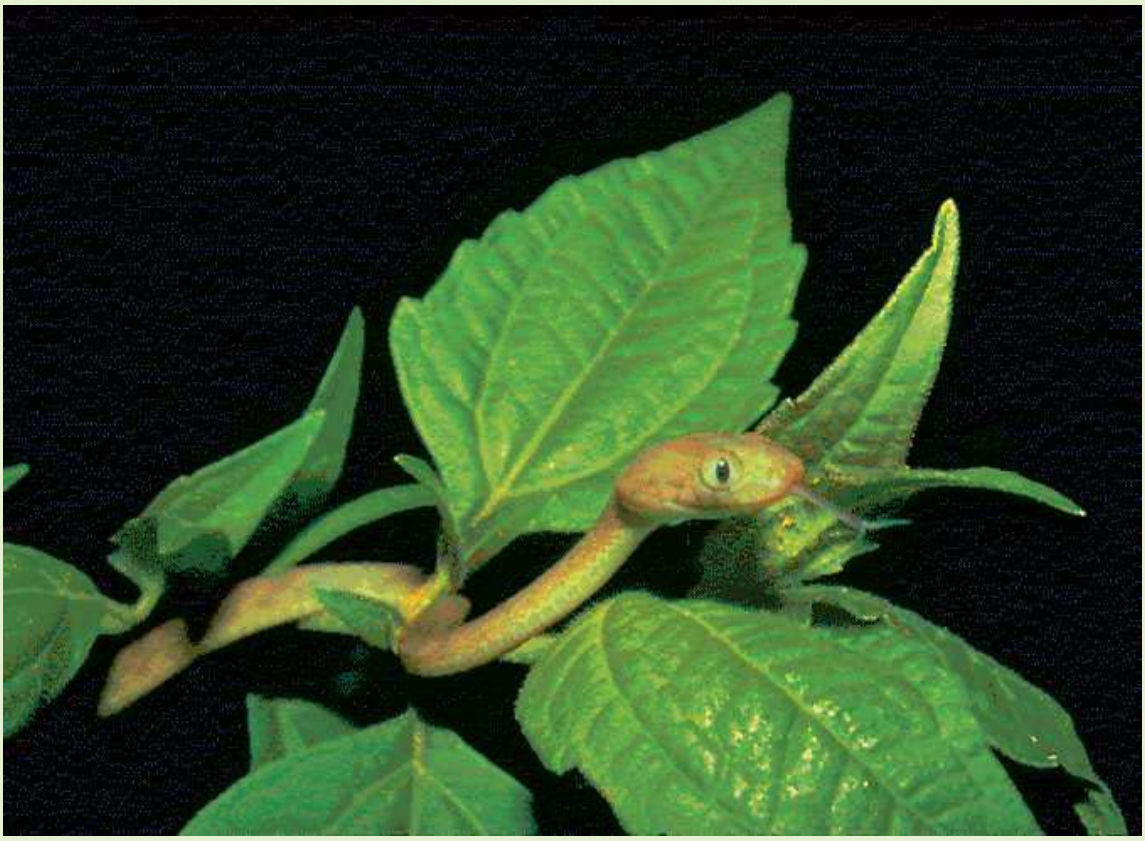
- Beneficial uses: Studies to evaluate beneficial use issues.
- Site specific objectives: Review studies conducted by dischargers or other watershed interests.
- Land use planning: Integrate water supply and quality issues with local land use planning and management.
- Groundwater: Integrate inter-related ground and surface waters--optimizing protection for both.
- Flood control: Institute better coordination of multi-agency reviews of environmental impacts for flood control and development projects, including the consideration of regional mitigation programs. Optimize the use of environmentally-friendly flood control facilities.
- Implementation of watershed-wide biological monitoring is a long-term goal for all of our watersheds.

Review and comment on watershed issues in CEQA documents (for the highest priority projects) will also continue; however, this is currently an unfunded program.

Under the BPTCP, we estimated that about 20% of the Western Arm and 10% of the Eastern Arm of Mugu Lagoon contain contaminated sediments (about 725,000 cubic yards). We estimate that about 3 miles of Calleguas Creek contains 50,000 to 100,000 cubic yards of contaminated sediments. We want to work with local groups to develop remediation plans. Due to sensitive nature of Mugu Lagoon, we would suggest no action or in-situ treatment, rather than dredging, as remediation options. Treatment is expensive (probably would exceed $100 per cubic yard). Dredging could be used to remediate Calleguas Creek, although finding a suitable disposal site could be difficult; it would cost $1 to 5 million.

100 OF THE WORLD'S WORST INVASIVE ALIEN SPECIES

A SELECTION FROM THE GLOBAL INVASIVE SPECIES DATABASE



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FONDATION D'ENTREPRISE TOTAL

Cover image: Brown tree snake *(Boiga irregularis).*
Photo: Gordon Rodda

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Biological Invasion

What happens when a species is introduced into an ecosystem where it doesn't occur naturally? Are ecosystems flexible and able to cope with change, or can a new arrival have far-reaching repercussions and do permanent damage? Will something special be lost forever? Does it matter?

In the distant past, the earth's mountains and oceans represented formidable natural barriers to all but the hardiest of species. Ecosystems evolved in relative isolation. Early human migration saw the first intentional introductions of alien species as our ancestors attempted to satisfy physical and social needs, but the magnitude and frequency of those early introductions were minor compared to those associated with today's extensive global trade and passenger movements.

History is rich with tales of the disastrous outcomes of some intentional introductions such as that of the Nile perch, which resulted in the extinction of more than 200 other fish species. We can avoid repeating such mistakes by learning from history. Yet surprisingly, potentially damaging introductions continue. The ongoing release of the mosquito fish that feature in this brochure, is a good example. Another is the questionable behaviour of some participants in the international garden seed and pet trade.

Careless behaviour leads to unintentional introductions. So-called 'accidents' now account for the majority of successful invasions. The list of "100 of the World's Worst Invasive Alien Species" in this booklet illustrates the incredible variety of species that have the ability, not just to travel in ingenious ways, but also to establish, thrive and dominate in new places. Today, alien invasion is second only to habitat loss as a cause of species endangerment and extinction.

The genes, species and ecosystems that make up the earth's biological diversity are important because their loss and degradation diminishes nature. Species other than our own have a right to exist and to retain their place in the world. We do not know how to estimate which species are essential to ecosystem functioning, which are redundant, and which will be the next to flourish as the world changes. When we introduce a new species into an ecosystem, the full impact is often not immediately apparent. Invasion by species such as *Miconia calvescens* can change entire habitats, making them unsuitable for the original native community.

Safeguarding the earth's diversity is the best way to maintain our life support system. There is evidence to suggest that the biosphere acts as a self-regulating whole and that diverse systems may be more resilient. Island ecosystems, which have evolved in isolation often have relatively fewer plants, herbivores, carnivores and decomposers to maintain essential processes and are more vulnerable to invasion. On islands around the world species extinction is increasing at an unprecedented rate. A number of the invasive alien species featured in this booklet are contributing to these losses.

Useful initiatives, which contribute to better management practices and a reduced incidence of biological invasion, are being taken by communities all over the world. Invasive alien species are now a major focus of international conservation concern and the subject of cooperative international efforts, such as the Global Invasive Species Programme (GISP). As awareness grows, people and their communities are able to make informed choices that will have lasting effects on their descendants.

The list of "100 of the World's Worst Invasive Alien Species" that is presented here is designed to enhance awareness of the fascinating complexity, and also the terrible consequences, of invasive alien species. Species were selected for the list according to two criteria: their serious impact on biological diversity and/or human activities, and their illustration of important issues surrounding biological invasion. To ensure the inclusion of a wide variety of examples, only one species from each genus was selected. There are many other invasive alien species, in addition to those on this list of examples. Absence from the list does not imply that a species poses a lesser threat. We hope that, by raising general awareness, the risks of further harmful invasions will be reduced in future.

Crazy Ant (*Anoplolepis gracilipes*)

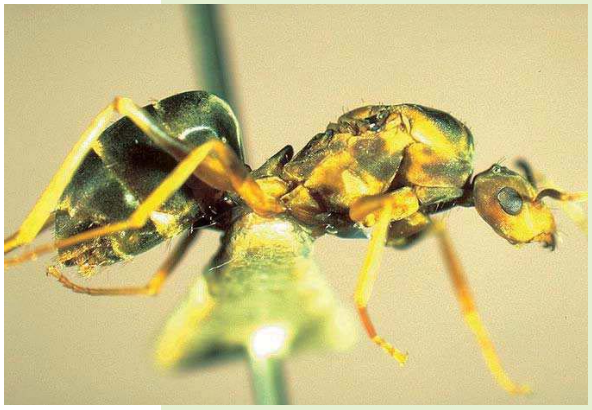

Photo: H. T. Imai and M. Kubota

Crazy ants (so called because of their frenetic movements) have invaded native ecosystems and caused environmental damage from Hawai'i to the Seychelles and Zanzibar. On Christmas Island in the Indian Ocean, they have formed multi-queen supercolonies in at least eight areas of rainforest, foraging in all habitats, including the rainforest canopy. They are also decimating the red land crab *(Gecarcoidea natalis)* populations. In 18 months the crazy ants were able to kill 3 million crabs. The land crabs play an important role in Christmas Island's forest ecosystem helping in litter breakdown and influencing forest composition by eating leaves and seedlings of rainforest trees. Crazy ants also prey on, or interfere in, the reproduction of a variety of arthropods, reptiles, birds and mammals on the forest floor and canopy. Their ability to farm and protect sap-sucking scale insects, which damage the forest canopy on Christmas Island, is one of their more surprising attributes. Although less than 5% of the rainforest on Christmas Island has been invaded so far, scientists are concerned that endangered birds such as the Abbott's booby *(Sula abbotti)*, which nests nowhere else in the world, could eventually be driven to extinction through habitat alteration and direct attack by the ants.

Brown Tree Snake (*Boiga irregularis*)

A native of Australia, Indonesia, Papua New Guinea, and the Solomon Islands, the brown tree snake is thought to have hitchhiked to Guam on military aircraft in the late 1940s or early 1950s. The lack of natural predators and ample prey allowed the snake population to explode. By the 1970s it was found island-wide and had done extensive economic and ecological damage. It has caused major power outages across the island and sometimes bites people, but is most infamous for its near complete extermination of Guam's native forest birds. The brown tree snake is a serious threat to the biological diversity of other tropical islands. It is able to conceal itself in cargo on boats and aircraft and even in airplane wheel-wells and has reached destinations as far afield as Micronesia, Hawai'i, mainland United States and Spain. Areas most at risk are wet tropical locations that receive large volumes of human and commercial traffic.

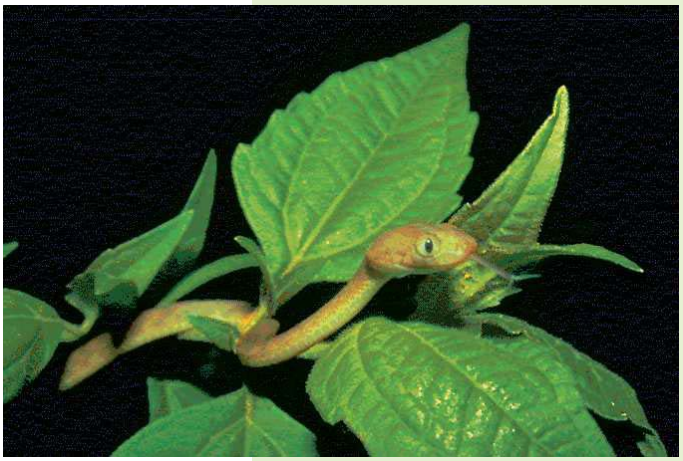

Photo: Gordon Rodda

Caulerpa Seaweed *(Caulerpa taxifolia)*

Caulerpa was introduced to the Mediterranean around 1984, possibly as waste from the Monaco Aquarium. There is speculation that the species released into the Mediterranean was a hardier clone of the original tropical seaweed. It adapted well to colder waters and has spread throughout the northern Mediterranean where it is a serious threat to the native marine flora and fauna. New colonies are able to start from small segments of this plant and, being an opportunistic hitchhiker, it is a threat to the whole of the Mediterranean. Wherever it has established itself, it has smothered habitats such as the beds of native sea grass that serve as nurseries for many species. On 12th June 2000, divers in a lagoon near San Diego in the United States discovered a patch of Caulerpa measuring 20 metres by 10 metres. In this case too, it is thought that the infestation occurred after somebody emptied a fish tank into a storm-water drain. Luckily this invasion was discovered at an early stage and measures were taken to eradicate it.

Photo: Alexandre Meinesz

Caulerpa infestation

Avian Malaria (*Plasmodium relictum*)

Avian malaria was introduced to Hawai'i in exotic birds kept by settlers, but it needed a vector to spread. This was made possible following the introduction of the southern house mosquito (*Culex quiquefasciatus*) in the water barrels of a sailing ship in 1826. Hawaii's unique native birds succumbed quickly because, unlike non-native birds, they have no resistance to avian malaria. Unique birds such as the colour-ful honeycreepers, which evolved into a diverse array of species and subspecies to fill different niches, are threatened by this disease and by habitat loss. Avian malaria, through its mosquito vector has contributed to the extinction of at least 10 native bird species in Hawai'i and threatens many more.

Photo: Jack Jeffrey Photography

Honeycreeper with malaria carrying mosquitos

100 OF THE WORLD'S WORST INVASIVE ALIEN SPECIES

MICRO-ORGANISM

avian malaria	*(Plasmodium relictum)*
banana bunchy top virus	*(Banana bunchy top virus)*
rinderpest virus	*(Rinderpest virus)*

MACRO-FUNGI

chestnut blight	*(Cryphonectria parasitica)*
crayfish plague	*(Aphanomyces astaci)*
Dutch elm disease	*(Ophiostoma ulmi)*
frog chytrid fungus	*(Batrachochytrium dendrobatidis)*
phytophthora root rot	*(Phytophthora cinnamomi)*

AQUATIC PLANT

caulerpa seaweed	*(Caulerpa taxifolia)*
common cord-grass	*(Spartina anglica)*
wakame seaweed	*(Undaria pinnatifida)*
water hyacinth	*(Eichhornia crassipes)*

LAND PLANT

African tulip tree	*(Spathodea campanulata)*
black wattle	*(Acacia mearnsii)*
Brazilian pepper tree	*(Schinus terebinthifolius)*
cogon grass	*(Imperata cylindrica)*
cluster pine	*(Pinus pinaster)*
erect pricklypear	*(Opuntia stricta)*
fire tree	*(Myrica faya)*
giant reed	*(Arundo donax)*
gorse	*(Ulex europaeus)*
hiptage	*(Hiptage benghalensis)*
Japanese knotweed	*(Fallopia japonica)*
Kahili ginger	*(Hedychium gardnerianum)*
Koster's curse	*(Clidemia hirta)*
kudzu	*(Pueraria montana var. lobata)*
lantana	*(Lantana camara)*
leafy spurge	*(Euphorbia esula)*
leucaena	*(Leucaena leucocephala)*
melaleuca	*(Melaleuca quinquenervia)*
mesquite	*(Prosopis glandulosa)*
miconia	*(Miconia calvescens)*
mile-a-minute weed	*(Mikania micrantha)*
mimosa	*(Mimosa pigra)*
privet	*(Ligustrum robustum)*
pumpwood	*(Cecropia peltata)*
purple loosestrife	*(Lythrum salicaria)*
quinine tree	*(Cinchona pubescens)*
shoebutton ardisia	*(Ardisia elliptica)*

LAND PLANT (CONTINUED)

Siam weed	*(Chromolaena odorata)*
strawberry guava	*(Psidium cattleianum)*
tamarisk	*(Tamarix ramosissima)*
wedelia	*(Sphagneticola trilobata)*
yellow Himalayan raspberry	*(Rubus ellipticus)*

AQUATIC INVERTEBRATE

Chinese mitten crab	*(Eriocheir sinensis)*
comb jelly	*(Mnemiopsis leidyi)*
fish hook flea	*(Cercopagis pengoi)*
golden apple snail	*(Pomacea canaliculata)*
green crab	*(Carcinus maenas)*
marine clam	*(Potamocorbula amurensis)*
Mediterranean mussel	*(Mytilus galloprovincialis)*
Northern Pacific seastar	*(Asterias amurensis)*
zebra mussel	*(Dreissena polymorpha)*

LAND INVERTEBRATE

Argentine ant	*(Linepithema humile)*
Asian longhorned beetle	*(Anoplophora glabripennis)*
Asian tiger mosquito	*(Aedes albopictus)*
big-headed ant	*(Pheidole megacephala)*
common malaria mosquito	*(Anopheles quadrimaculatus)*
common wasp	*(Vespula vulgaris)*
crazy ant	*(Anoplolepis gracilipes)*
cypress aphid	*(Cinara cupressi)*
flatworm	*(Platydemus manokwari)*
Formosan subterranean termite	*(Coptotermes formosanus shiraki)*
giant African snail	*(Achatina fulica)*
gypsy moth	*(Lymantria dispar)*
khapra beetle	*(Trogoderma granarium)*
little fire ant	*(Wasmannia auropunctata)*
red imported fire ant	*(Solenopsis invicta)*
rosy wolf snail	*(Euglandina rosea)*
sweet potato whitefly	*(Bemisia tabaci)*

AMPHIBIAN

bullfrog	*(Rana catesbeiana)*
cane toad	*(Bufo marinus)*
Caribbean tree frog	*(Eleutherodactylus coqui)*

FISH

brown trout	*(Salmo trutta)*
carp	*(Cyprinus carpio)*
large-mouth bass	*(Micropterus salmoides)*

FISH (CONTINUED)

Mozambique tilapia	*(Oreochromis mossambicus)*
Nile perch	*(Lates niloticus)*
rainbow trout	*(Oncorhynchus mykiss)*
walking catfish	*(Clarias batrachus)*
Western mosquito fish	*(Gambusia affinis)*

BIRD

Indian myna bird	*(Acridotheres tristis)*
red-vented bulbul	*(Pycnonotus cafer)*
starling	*(Sturnus vulgaris)*

REPTILE

brown tree snake	*(Boiga irregularis)*
red-eared slider	*(Trachemys scripta)*

MAMMAL

brushtail possum	*(Trichosurus vulpecula)*
domestic cat	*(Felis catus)*
goat	*(Capra hircus)*
grey squirrel	*(Sciurus carolinensis)*
macaque monkey	*(Macaca fascicularis)*
mouse	*(Mus musculus)*
nutria	*(Myocastor coypus)*
pig	*(Sus scrofa)*
rabbit	*(Oryctolagus cuniculus)*
red deer	*(Cervus elaphus)*
red fox	*(Vulpes vulpes)*
ship rat	*(Rattus rattus)*
small Indian mongoose	*(Herpestes javanicus)*
stoat	*(Mustela erminea)*

Species were selected for the list using two criteria: their serious impact on biological diversity and/or human activities, and their illustration of important issues of biological invasion. To ensure a wide variety of examples, only one species from each genus was selected. **Absence from the list does not imply that a species poses a lesser threat**.

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For further information on these and other invasive alien species consult The *Global Invasive Species Database*:

www.issg.org/database

Feral Pig (*Sus scrofa*)

Photo: Jim Mitchell

Feral pigs are escaped or released domestic animals. Introduced to many parts of the world, they damage crops, stock and property and transmit many diseases such as Leptospirosis and foot and mouth disease. Rooting pigs dig up large areas of native vegetation and spread weeds, disrupting ecological processes such as succession and species composition. They are omnivorous and their diet can include juvenile land tortoises, sea turtles, sea birds and endemic reptiles. Management of this invasive species is complicated by the fact that complete eradication is often not acceptable to communities that value feral pigs for hunting and food.

Strawberry Guava (*Psidium cattleianum*)

Photo: Wendy Strahm

The strawberry guava is native to Brazil, but has been naturalised in Florida, Hawai'i, tropical Polynesia, Norfolk Island and Mauritius for its edible fruit. It forms thickets and shades out native vegetation in tropical forests and woodlands. It has had a devastating effect on native habitats in Mauritius and is considered the worst plant pest in Hawai'i, where it has invaded a variety of natural areas. It benefits from feral pigs (*Sus scrofa*) which, by feeding on its fruit, serve as a dispersal agent for its seeds. In turn, the guava provides favourable conditions for feral pigs, facilitating further habitat degradation.

Miconia *(Miconia calvescens)*

A highly ornamental tree from South America, Miconia was introduced to a botanical garden on the island of Tahiti in 1937. Its huge red and purple leaves made it highly desirable for gardeners. It was spread into the wild by fruit-eating birds and today, more than half the island is heavily invaded by this plant. It has a superficial and tentacular rooting system that contributes to landslides and has become the dominant canopy tree over large areas of Tahiti, shading out the entire forest under-story. Scientists estimate that several of the island's endemic species are threatened with extinction as a result of habitat loss due to Miconia. It has been introduced to other Pacific islands, including Hawai'i where it was introduced as an ornamental in the 1960s. The plant has since been found in many locations on the Hawai'ian islands. It is still sold as an ornamental plant in the tropics.

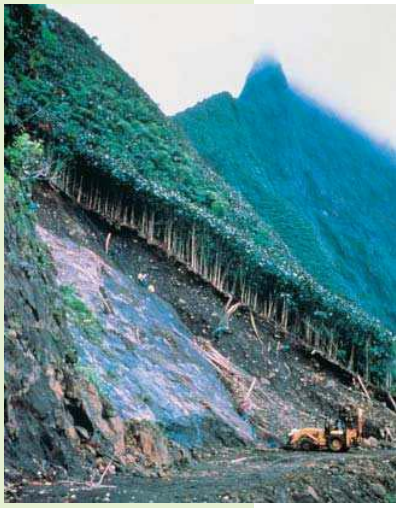

Photo: The Nature Conservancy

Miconia on a mountainside in Tahiti

Western Mosquitofish (*Gambusia affinis*)

The mosquito fish is a small, harmless-looking fish native to the fresh waters of the eastern and southern United States. It has become a pest in many waterways around the world following initial introductions early last century as a biological control of mosquito. In general, it is considered to be no more effective than native predators of mosquitoes. The highly predatory mosquito fish eats the eggs of economically desirable fish and preys on and endangers rare indigenous fish and invertebrate species. Mosquito fish are difficult to eliminate once established, so the best way to reduce their effects is to control their further spread. One of the main avenues of spread is continued, intentional release by mosquito-control agencies.

Mosquitofish; male and female pair

Photo: Bob McDowall

Small Indian Mongoose (*Herpestes javanicus (auropunctatus)*)

Photo: Jack Jeffrey Photography

This voracious and opportunistic predator is native to areas from Iran, through India to Myanmar and the Malay Peninsula. It was introduced to Mauritius and Fiji and to the West Indies and Hawai'i in the late 1800s to control rats. Unfortunately, this early attempt at biological control has had disastrous impacts. Island populations of native fauna, which had evolved without the threat of a fast-moving, mammalian predator, were no match for the mongoose. It has caused the local extinction of several endemic birds, reptiles and amphibians and threatens others including the rare Japanese Amami rabbit (*Pentalagus furnessi*). The small Indian mongoose is also a vector of rabies.

Rosy wolfsnail (*Euglandina rosea*)

Native to the southeastern United States, the predatory rosy wolf snail was introduced to islands in the Pacific and Indian Oceans from the 1950s onwards as a biological control agent for another alien species, the giant African snail (*Achatina fulica*). The giant African snail was intended as a food source for humans but became an agricultural pest. In French Polynesia, the fast moving rosy wolf snail rapidly eliminated local endemic species. One group threatened by the rosy wolf snail is the Partulid tree snails, which evolved separately from each other in isolated valleys and exhibit a variety of unique characteristics. Many Partulid tree snails have been lost already and today the survivors exist in zoos and in the world's first wildlife reserves for snails. This invasion by a biological control agent has caused a significant loss of biodiversity.

Photo: Jack Jeffrey Photography

Water Hyacinth (*Eichhornia crassipes*)

This South American native is one of the worst aquatic weeds in the world. Its beautiful, large purple and violet flowers make it a popular ornamental plant for ponds. It is now found in more than 50 countries on five continents. Water hyacinth is a very fast growing plant, with populations known to double in as little as 12 days. Infestations of this weed block waterways, limiting boat traffic, swimming and fishing. Water hyacinth also prevents sunlight and oxygen from reaching the water column and submerged plants. Its shading and crowding of native aquatic plants dramatically reduces biological diversity in aquatic ecosystems.

Photo: *Aquarius Systems, North Prairie, Wisconsin, USA*

Water hyacinth on LakeVictoria

Nile Perch (*Lates niloticus*)

The Nile perch was introduced to Lake Victoria, Africa in 1954 to counteract the drastic drop in native fish stocks caused by over-fishing. It has contributed to the extinction of more than 200 endemic fish species through predation and competition for food. The flesh of Nile perch is oilier than that of the local fish, so more trees were felled to fuel fires to dry the catch. The subsequent erosion and run-off contributed to increased nutrient levels, opening the lake up to invasions by algae and water hyacinth (*Eichhornia crassipes*). These invasions in turn led to oxygen depletion in the lake, which resulted in the death of more fish. Commercial exploitation of the Nile perch has displaced local men and women from their traditional fishing and processing work. The far-reaching impacts of this introduction have been devastating for the environment as well as for communities that depend on the lake.

Photo: *Jens Bursell*

The Invasive Species Specialist Group (ISSG) is a New Zealand-based specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN). It is chaired by Dr Mick Clout (University of Auckland).

The goals of ISSG are to reduce threats to natural ecosystems and the native species they contain - by increasing awareness of alien invasions and of ways to prevent, control or eradicate them.

The Global Invasive Species Database, developed as part of GISP Phase I, managed by ISSG, is freely available online at *www.issg.org/database* and mirrored at *www.invasivespecies.net/database*. Priorities range from a focus on the some of the world's worst invasive species to a focus on areas where information and resources are comparatively scarce, including small-island developing states. The database has images and descriptions for a wide variety of invasive species. Records for these species include information on the ecology, impacts, distribution and pathways of the species, and most importantly, information on management methods as well as contact details of experts that can offer further advice. The database also provides links to numerous other sources of information.

Aliens is the bi-annual newsletter of the Invasive Species Specialist Group (ISSG). Its role is to put researchers, managers and/or practitioners in contact with each other and to publish information and news of alien invasive species and issues.

Aliens-L is a listserver dedicated to invasive species. It allows users to freely seek and share information on alien invasive species and issues, and the threats posed by them to the Earth's biodiversity. To subscribe, look for instructions on the ISSG website.

Cooperative Initiative on Invasive Alien Species on Islands: the aims of the Cooperative Initiative on Invasive Island Alien Species on Islands are: to enhance empowerment, capacity, cooperation and sharing of expertise in key areas of invasive alien species (IAS) management on islands; For more information, contact ISSG.

IUCN Guidelines: The IUCN Guidelines For The Prevention Of Biodiversity Loss Caused By Alien Invasive Species (As approved by 51st Meeting of Council, February 2000) can be obtained from the ISSG office, or *http://iucn.org/themes/ssc/pubs/policy/invasivesEng.htm*

BioNET-INTERNATIONAL, the Global Network for Taxonomy, is an initiative that promotes demand-driven capacity building in taxonomy to address sustainable development needs of developing countries. Comprised of a secretariat and nine, government-endorsed subregional LOOPs with a membership of institutions and individuals, BioNET helps coordinate and engage taxonomists, technology providers and others in the capacity building partnerships needed to address priority issues such as invasive alien species. *Why Taxonomy Matters* is a set of case studies, many of which highlight the contribution of taxonomy to IAS management (see: *www.bionet-intl.org/case_studies*).

Websites: Invasive Species Specialist Group: *www.issg.org*
Global Invasive Species Database: *www.issg.org/database*
IUCN-The World Conservation Union: *www.iucn.org*
The Global Invasive Species Programme: *www.GISP.org*
BioNET-INTERNATIONAL: *www.bionet-intl.org*

GROUNDWATER AND SURFACE WATER CONDITIONS REPORT - 2011

United Water Conservation District
Open-File Report 2012-02

PREPARED BY

GROUNDWATER RESOURCES DEPARTMENT
MAY 2012

UWCD OFR 2012-02

GROUNDWATER AND SURFACE WATER CONDITIONS REPORT - 2011

United Water Conservation District
Open-File Report 2012-02

Groundwater Resources Department
May 2012

THIS REPORT IS PRELIMINARY AND IS SUBJECT TO MODIFICATION

BASED UPON FUTURE ANALYSIS AND EVALUATION

Cover Photo: Recharge basin at El Rio Spreading Grounds, February 2011. By John Carman

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GROUNDWATER AND SURFACE WATER CONDITIONS REPORT - 2011

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EXECUTIVE SUMMARY / ABSTRACT

United Water Conservation District is a public agency that encompasses nearly 213,000 acres of central and southern Ventura County. The District covers the downstream (Ventura County) portion of the valley of the Santa Clara River, as well as the Oxnard Plain. The District serves as the steward for managing the surface water and groundwater resources within all or portions of eight groundwater basins. This report includes data and records from the 2011 calendar year, including basic information and discussion on the operation of the District's facilities, weather and hydrologic information, groundwater levels and available storage within the basins, and the quality of surface water and groundwater.

Major water resource issues and concerns are the driving impetus for the District's projects and programs. Projects and programs are implemented to manage, mitigate, or eliminate those issues or concerns that threaten the water resources. Those issues and concerns include, but are certainly not limited to, groundwater overdraft and the intrusion of saline water in the Oxnard Plain and Pleasant Valley basins, the gradual, long-term declining water levels in the Santa Paula Basin, water quality of the Oxnard Forebay basin and the Piru basin, and concerns related to the management of the Piru and Fillmore basin water resources.

To address those issues and concerns, United implements a wide variety of activities. Some of the activities are District-wide, for example: water levels are monitored in an extensive network of water wells thorough the District and a significant number of these wells are sampled as a part of a water quality monitoring program. In addition, stream gauging is performed periodically to quantify surface water volumes and flow rates under various hydrologic conditions. These data are important to United's habitat conservation efforts and the facilitation of fish passage at the Vern Freeman Diversion, as well as optimizing various District operations (e.g., annual conservation release, diversion of water to recharge basins or for use in-lieu of groundwater pumping by agricultural operations on the Oxnard Plain and in Pleasant Valley basin). Currently, the largest District-wide project underway by the groundwater department is the update of the Ventura County Regional Groundwater Flow Model. This is a multi-year, multi-faceted project that requires the expertise of several groundwater science specialties and relies on the District's long record of water-level, water quality, and stream gauging data. When completed, the groundwater flow model will be a primary evaluative tool for various proposed water management scenarios and will assist stakeholders with enhancing the sustainability and reliability of local water resources.

Issue-specific projects are also implemented by United to assist local stakeholders in the management of local water resources (e.g., AB3030 Piru/Fillmore Groundwater Management Plan, analyses of groundwater conditions in the Santa Paula basin as a part of the Technical Advisory Committee) or the pursuit of grant funds (e.g., Local Groundwater Assistance Program grants from CA Department of Water Resources, Fox Canyon Groundwater Management Agency Groundwater

Supply Enhancement Assistance Program) to help defray the costs of some of the groundwater projects.

The benefits of the surface water and groundwater projects and programs operated by United are shared by the many groundwater pumping entities in the District and those who receive those waters. Many of the benefits are in the background and not readily recognized or apparent to individual water users, however, the positive impacts of the District's activities are significant to the agricultural, municipal, and industrial economies of Ventura County.

1 INTRODUCTION AND BACKGROUND

United Water Conservation District (also "United" or "District") is a public agency that encompasses nearly 213,000 acres of central and southern Ventura County. The District covers the downstream (Ventura County) portion of the valley of the Santa Clara River, as well as the Oxnard Plain. The District serves as a steward for managing the surface water and groundwater resources for all or portions of eight groundwater basins (Figure 1-1). It is governed by a seven-person board of directors elected by division, and receives revenue from property taxes, groundwater extraction (pump) charges, recreation fees, and water delivery charges. The developed areas of the District are a mix of agriculture and urban areas, with prime agricultural land supporting high-dollar crops such as avocados, berries, row crops, tomatoes, lemons, oranges, flowers and ornamental nursery stock. Approximately 370,000 people live within the District boundaries, including those living in the cities of Oxnard, Port Hueneme, Santa Paula, Fillmore and eastern Ventura.

The District is authorized under its principal act (California Water Code Section 74000 et seq) to exercise multiple powers. These powers include the authority to conduct water resource investigations, acquire water rights, build facilities to store and recharge water, construct wells and pipelines for water deliveries, commence actions involving water rights and water use, prevent interference with or diminution of stream/river flows and their associated natural subterranean supply of water, and to acquire and operate recreational facilities in connection with dams, reservoirs or other District works.

This report includes general information about the District's mission and detailed data on the operation of the District's facilities, weather and hydrologic information for the past year, groundwater levels and storage within the basins, and the quality of the surface water and groundwater. Recent and current studies and investigations conducted by the District's Groundwater Department are also detailed.

1.1 UWCD MISSION STATEMENT AND GOALS

The District's mission statement is:

United Water Conservation District shall manage, protect, conserve, and enhance the water resources of the Santa Clara River, its tributaries and associated aquifers, in the most cost-effective and environmentally balanced manner.

In order to accomplish this mission, United Water Conservation District follows these guiding principles:

- Construct, operate, and maintain facilities needed now and in the future to put local and imported water resources to optimum beneficial use;

- Deliver safe and reliable drinking water that meets current and future health standards to cities and urban areas;
- Provide an adequate and economical water supply to support a viable and productive agricultural sector;
- Fight overdraft and seawater intrusion and enhance the water quality of the aquifers through the use of District programs;
- Monitor water conditions to detect and guard against problems and to report those conditions to the public;
- Seek opportunities to develop cooperative programs with other agencies in order to maximize use of District resources and promote mutually beneficial projects;
- Acquire and operate high-quality public recreational facilities that are financially self-supporting;
- Balance District operations with environmental needs to maximize use of the region's water resources; and
- Conduct District affairs in a business-like manner that promotes safe investment policy, sound financial audits and the utmost in professional and financial integrity.

The District recognizes that many of the projects and activities required to implement these guiding principles have long timelines for development and initiation, and the positive impacts of these projects and activities may be realized over many years. This is consistent with the District's mission to provide for the long-term health of the water resources within the District. To fulfill its mission, the District retains technical experts in the fields of engineering, hydrogeology, surface water hydrology, environmental science, biology, and regulatory compliance, as well as administrative personnel with specialties in accounting and finance.

1.2 UWCD HISTORY

The original founding organization for United Water Conservation District was called the Santa Clara River Protective Association. It was formed in 1925 to protect the runoff of the Santa Clara River from being appropriated and exported outside the watershed. The Santa Clara Water Conservation District was formed in 1927 to further the goals of the Association by protecting water rights and conserving the waters of the Santa Clara River and its tributaries. The District began a systematic program of groundwater recharge in 1928, primarily through constructing spreading grounds along the Santa Clara River. Sand dikes were constructed on the Santa Clara River near Saticoy to divert river water into spreading grounds in nearby upland areas.

As seawater intrusion on the Oxnard Plain was recognized in the 1940s, it was clear that the District did not have the financial ability to raise money to construct the facilities necessary to combat the problem. With the help of the City of Oxnard, a new district was organized in 1950 under the Water

Conservation District Law of 1931. The new district was called United Water Conservation District for its unification of urban and agricultural concerns. United Water then constructed a number of water conservation projects, including:

- Santa Felicia Dam (1955) to capture and store winter runoff on Piru Creek to release in controlled amounts during the dry season. The 200-foot high dam can currently store about 82,300 acre-feet (AF) in Lake Piru. The reservoir is located downstream of a State Water Project reservoir, enabling the District to receive Northern California water via flows down middle Piru Creek without the construction of expensive delivery pipelines;
- A pipeline to new spreading grounds at El Rio; and
- Wells at the El Rio spreading grounds to produce water for the Oxnard-Hueneme (O-H) pipeline (1954) that supplies drinking water to the cities of Oxnard and Port Hueneme, a number of mutual water companies, and the two Navy bases at the coast. The O-H system supplies water from the Oxnard Forebay basin (the recharge area for the Oxnard Plain basin), rather than pumping individual wells in coastal areas of the Oxnard Plain that could accelerate seawater intrusion.

Following increasing intrusion of seawater from the 1950s to the 1980s, United Water built several new facilities to increase recharge to the aquifers and to decrease groundwater pumping in areas affected by the intrusion. These facilities provide both direct present benefit, and long-term benefits, to the groundwater aquifers and to the groundwater extractors in the District. In 1958 a pipeline was completed to deliver diverted surface water to Pleasant Valley County Water District, which serves agricultural water to the Pleasant Valley basin. The Pumping Trough Pipeline (PTP) was constructed in 1986 to convey diverted river water to agricultural pumpers on the Oxnard Plain, thus reducing the amount of groundwater pumping in critical areas. The Freeman Diversion (1991) replaced the temporary diversion dikes in the Santa Clara River with a permanent concrete structure, allowing diversion of storm flows throughout the winter. A major additional benefit of the Freeman Diversion was the stabilization of riverbed elevations upstream of the facility, correcting the long-term incision of the river related to decades of in-channel gravel mining in the Saticoy vicinity.

Following the construction of the Freeman Diversion, the Noble spreading basins (1995) were constructed to store and recharge additional river water, particularly during wet periods. The Saticoy well field was constructed in 2003 to pump down the groundwater mound that develops beneath the Saticoy spreading grounds during periods of heavy spreading. In late 2009 United acquired the Ferro and Rose basins, former mining pits located in the Oxnard Forebay that will be used for future groundwater recharge activities. United intends to construct facilities to convey Santa Clara River water diverted at the Freeman Diversion to these basins. An additional use for the Ferro basin under consideration is the recharge of recycled water sourcing from the City of Ventura (Carollo Engineers, 2010) or the City of Oxnard. United anticipated that the City of Ventura might desire to move recycled water to the District's recharge basins (or alternatively, potable water

from the Forebay to east Ventura) in the future and arranged for “pipe hangers” to be added to the Highway 118 bridge over the Santa Clara River during its reconstruction in 1993.

1.3 UWCD ORGANIZATION

The District is governed by a seven-person board of directors elected by division, and receives revenue from property taxes, groundwater extraction (pump) charges, recreation fees, and water delivery charges.

1.4 UWCD OPERATIONS AND FACILITIES

United Water Conservation District operates a series of water conservation facilities from the tributaries of the Santa Clara River to the Oxnard Plain and Pleasant Valley (Figure 1-1). These facilities store winter runoff for later release during the dry season, divert water from the Santa Clara River, recharge the aquifers through spreading basins, and deliver surface water and groundwater to cities and growers so that groundwater pumping is reduced in critically overdrafted areas.

1.4.1 SANTA FELICIA DAM AND LAKE PIRU

Santa Felicia Dam was constructed in 1955 for the conservation of runoff on Piru Creek. The main function of the dam is to retain the high flows in Piru Creek during the winter and spring months, and release the stored water in the fall when the downstream basins and the facilities at the Freeman Diversion have the capability to receive the most benefit from the release. The current capacity of the dam is 82,300 AF (See Figure 1.4-1 for storage history). The operational minimum pool is set at 20,000 AF of storage.

The 2010 conservation release reduced the storage volume down to the minimum pool of 20,000 AF. An early rain in December 2010 brought the lake up to 31,000 AF of storage by January 1, 2011. Due to the above normal rainfall in 2011, the Piru watershed produced inflows totaling 61,800 AF, approximately double the historical average. The Santa Felicia Dam is fitted with a hydro electric plant that is currently not operable although a Federal Energy Regulatory Commission (FERC) License is still required. Efforts to re-license this facility are currently underway and as part of this new license, release requirements for Santa Felicia Dam were implemented this year and are discussed in more detail in section 1.6.3.

Summary of surface water hydrology at Lake Piru:

	Calendar year 2011
Minimum Storage	31,000 AF
Maximum Storage	76,400 AF
Inflow at USGS Sta. 11109600	61,800 AF
FERC License minimum releases	4,400 AF
Conservation Release	31,700 AF
State Water (Not released)	2,520 AF

1.4.2 PIRU DIVERSION AND SPREADING GROUNDS

The Piru Diversion is operated to divert surface water into the Piru Spreading Grounds for groundwater recharge. The diversion is located on the western bank of lower Piru Creek just south of the old Center Street Bridge in the town of Piru. Part of the diversion dam is built under the two roadway bridges crossing lower Piru Creek at Center Street.

The existing diversion consists of an earthen berm that extends out across the river channel, a sluice channel that can accommodate approximately 200 cfs, and a diversion structure with a trash rack and four 24-inch inlets leading to a 48-inch diversion pipe that conveys diverted water to the spreading grounds. The structure is not in compliance with National Marine Fisheries (NMFS) standards for diverting water in a stream that may possibly contain endangered southern California steelhead. Therefore the facilities have been included as part of the Habitat Conservation Plan (HCP) so that the facility will be covered for incidental take. The diversion will not be put back into operation until a take permit has been issued.

1.4.3 FREEMAN DIVERSION AND SATICOY SPREADING GROUNDS

The Freeman Diversion is located on the Santa Clara River about 10 miles upstream from its mouth at the Pacific Ocean. The concrete diversion structure was completed in 1991 and replaced the previous diversion method of building temporary sand and gravel diversion dikes, levees, and canals. The prior method of diverting water from the Santa Clara River near Saticoy had been in practice since the 1920s. The Freeman Diversion facility replaced the former method of building temporary sand and gravel diversion dikes, levees, and canals along the Santa Clara River near Saticoy. With each high flow in the river the dikes were washed out, eliminating the ability to divert water until construction crews were able to work in the riverbed. Construction of the Freeman Diversion has increased the conservation of flood flows by extending the time each year when flows can be diverted and not discharged to the ocean. The current facility consists of the following structures: diversion structure, fish passage facilities, canal, headworks, flocculation building, and

desilting basin. A total of 92,600 acre-feet of surface water was diverted from the Santa Clara River at the Freeman Diversion in calendar year 2011.

The diversion is operated to redirect surface water from the Santa Clara River to United's recharge basins located in Saticoy, El Rio and the Noble Basins for the purpose of recharge the aquifers underlying the Oxnard Forebay and Oxnard Plain. In 2011 a total of 71,960 AF was recharged to these basins. The remainder of the diverted water was delivered directly to agricultural users for irrigation purposes. These deliveries are designed to reduce groundwater pumping in areas where overdraft conditions and related water quality issues exist, such as where aquifers are most susceptible to saline water intrusion and the upwelling of saline waters. Water releases from Lake Piru and a portion of the natural runoff from the Santa Clara River are diverted by the Freeman Diversion.

1.4.4 EL RIO FACILITY AND SPREADING GROUNDS

The El Rio Spreading Grounds are located at the terminus of the El Rio branch of the main supply line, approximately two miles southwest of the Saticoy spreading grounds. Surface water diverted from the Santa Clara River is distributed to a series of ponds totaling approximately 80 acres for the purpose of groundwater recharge. During the 2011 water year approximately 37,850 acre-feet of surface water was routed to the El Rio Spreading Grounds and recharged to the Oxnard Forebay groundwater basin.

1.4.5 MUNICIPAL WATER DELIVERIES

United built the Oxnard-Hueneme (O-H) system in 1954 to move municipal groundwater extraction on the Oxnard Plain away from coastal areas subject to seawater intrusion. The well field for the O-H system surrounds the El Rio recharge basins, and water produced by the well field is a blend of recharge water that has filtered down through the aquifer, and water drawn laterally from surrounding areas. The El Rio well field includes both upper and lower aquifer wells, allowing a blending of sources for water quality purposes. In practice, the Lower Aquifer System (LAS) wells are rarely used. Water deliveries on the Oxnard-Hueneme Pipeline totaled 10,750 acre-feet for the 2011 calendar year, some 27,100 AF less than the volume of water that was spread in the nearby El Rio recharge basins over the same time frame.

The California Department of Health Services requires the publication of an annual water quality summary of water delivered by the O-H system. The 2011 Consumer Confidence Report for the O-H water delivery system is included in Appendix A. The O-H delivery system is operated as an enterprise fund, with water rates supporting operation and improvements to the system. Major customers include the City of Oxnard, the Port Hueneme Water Agency, and a number of mutual water companies in the Oxnard Forebay and the northern Oxnard Plain.

1.4.6 AGRICULTURAL WATER DELIVERIES

Water deliveries for agricultural purposes are achieved through two systems, the Pumping Trough Pipeline (PTP) System and the Pleasant Valley Delivery System. These systems are discussed separately in the following two subsections. See Figure 1-1 for locations.

1.4.6.1 PTP DELIVERY SYSTEM

The Pumping Trough Pipeline (PTP) delivery system was designed to serve surface water from the Santa Clara River to a portion of the Oxnard Plain where the Upper Aquifer System was determined to be in severe overdraft. Five Lower Aquifer System wells were constructed along the pipeline to provide additional water to the system when surface water supplies are incapable of meeting demand. During the 2011 calendar year a large conservation release from Lake Piru and greater-than-average flow in the Santa Clara River allowed 90 percent of the demand on the PTP to be met with surface water supplies (Table 1.4-2). Surface water deliveries to this system totaled 7,629 AF in the 2011 calendar year. The four UAS wells of the Saticoy well field, completed in 2004, can also provide groundwater to the agricultural pipelines when groundwater elevations are high near the Saticoy Spreading Grounds. The Saticoy well field pumped a total of 737 AF in calendar year 2011, and 261 AF this water was distributed to the PTP delivery system.

1.4.6.2 PLEASANT VALLEY DELIVERY SYSTEM

Water diverted from the Santa Clara River is delivered to the Pleasant Valley County Water District (PVCWD) via the Pleasant Valley Pipeline. The pipeline terminates at the Pleasant Valley Reservoir, located east of the Camarillo Airport near the City of Camarillo. PVCWD operates the reservoir and eleven LAS wells in the western Pleasant Valley basin, supplying water to agricultural customers via a delivery system linking the wells and the reservoir. The delivery of diverted river water to PVCWD offsets pumping of irrigation wells in the area. Surface water deliveries to PVCWD totaled 12,189 AF in the 2011 calendar year, and an additional 476 AF of water was supplied by the Saticoy well field. Deliveries in 2011 were about 1,300 AF greater than the average annual (water year) delivery since the completion of the Freeman Diversion in 1991. Since 2002 PVCWD has also received surface water from the Conejo Creek Diversion, operated by Camrosa Water District. In 2011 PVCWD received 6,657 AF of surface water from that source. Water year 2011 deliveries to the Pumping Trough and Pleasant Valley pipelines are shown in Figure 1.4-2.

1.5 GROUNDWATER ISSUES AND CONCERNS

United's core mission is to manage, conserve and protect the water resources that exist within the District boundaries. United operates Santa Felicia Dam and maintains contractual arrangements with a number of upstream agencies to store or convey surface runoff to the lower portions of the Santa Clara River watershed. United does not regulate the use of groundwater within the District, but operates a number of facilities intended to maximize the conjunctive use of surface water and

groundwater resources. Aside from United's annual State Water imports of up to 3,150 acre-feet, the lower valley of the Santa Clara River is wholly dependent on local water resources for irrigation and potable supply, an uncommon arrangement in southern California.

Despite long-term efforts to import more water to the District and optimize the use of local resources, water deficits exist in a number of areas throughout the District. In some places the depletion of groundwater reserves has simply resulted in lowered water tables. In other places significant water quality problems developed in response to conditions of overdraft. In some areas water quality problems are related to land use practices, or exist naturally.

Listed below are summaries of several of the water supply and water quality issues that exist within United's district boundaries. In some cases United's involvement includes groundwater recharge or water delivery to actively address issues related to overdraft. In other cases United has conducted or sponsored research in order to better define existing problems and help identify potential physical projects or management strategies to mitigate the problem. United management and staff are knowledgeable concerning groundwater management practices and have expertise in conducting monitoring programs and with applying various methods for evaluating basin conditions (e.g., Bachman et al, 2005).

1.5.1 OVERDRAFT CONDITIONS

Although high chloride levels in groundwater was first documented near Port Hueneme in the 1930s (California Department of Water Resources [DWR], 1954), the conditions for widespread seawater intrusion in the Upper Aquifer System (UAS) on the Oxnard Plain were initiated as early as the 1940s, when groundwater levels beneath the southern portion of the Oxnard Plain basin dropped below sea level (FCGMA, 2007). Within 5 to 10 years, chloride concentrations in wells in the Port Hueneme area started to increase rapidly. At that time, seawater had only affected a few wells in the Port Hueneme area, encompassing an area less than one square mile. Overdraft conditions were recognized in the Lower Aquifer System (LAS) in the late 1980s after the impairment of water quality in the Upper Aquifer System led to the implementation of a Fox Canyon Groundwater Management Agency (FCGMA) strategy to require new or replacement wells to be drilled into the LAS to lessen pumping on the UAS. The overdraft conditions eventually expanded into the adjacent Pleasant Valley groundwater basin and resulted in up to 2.6 feet of permanent land subsidence (Hanson et al, 2003).

Overdraft conditions in the Oxnard Plain and Forebay groundwater basins continue today with the annual overdraft amount estimated to be about 20,000 to 25,000 ac-ft/yr (UWCD, 2012)

1.5.2 SALINE WATER INTRUSION

High chloride levels were first detected on the Oxnard Plain in the vicinity of the Hueneme and Mugu submarine canyons in the early 1930s (CA DWR, 1971) and became a serious concern in the

1950s. Early monitoring programs used only existing production wells and abandoned wells as monitoring points; sampling of these wells indicated that there was a widespread area of elevated chloride concentrations in the Hueneme to Mugu areas. In 1989, the U.S. Geological Survey initiated their Regional Aquifer-System Analysis (RASA) study and cooperative studies with United Water Conservation District on the Santa Clara-Calleguas groundwater basin. As part of those studies, a series of 14 nested well sites, with three or more wells installed at each site, were drilled and completed at specific depths in the Oxnard Plain basin (Densmore, 1996).

Figure 1.5-1 shows the locations of the RASA well sites on the Oxnard Plain. Prior to the RASA study, it was believed that an area of the UAS extending from approximately Channel Islands Blvd. (2 miles north of Port Hueneme) and across to the area near Hwy 1 and Nauman Road, then south to include the area underlying Point Mugu Navy base was intruded by seawater. The installation of a dedicated monitoring network and detailed chemical analysis of water samples from the new wells and other wells yielded new interpretations on the extent of seawater intrusion on the Oxnard Plain. It is now known that some areas of the southern Oxnard Plain are not intruded by seawater, and that high chloride readings from older production wells were the result of perched water leaking down failed well casings and contaminating the aquifer (Izbicki, 1992; Stamos and others, 1992; Izbicki and others, 1995; U.S. Geological Survey, 1996). Maps presented in this report delineate the approximate extent of high-chloride water at various depths on the Oxnard Plain (Section 4.3.6).

In addition to drilling the monitoring wells, the USGS conducted geophysical surveys to determine the general extent of the high-saline areas (Stamos and others, 1992; Zohdy and others, 1993). This work indicated that the high-saline areas consisted of two distinct lobes, with relatively fresh water separating the lobes (U.S. Geological Survey, 1996). These areas were resurveyed in 2010 by United (UWCD, 2012a). The lobes originally identified by the USGS form the basis of the areas of high chloride concentration shown on the maps in this report. Additional down-hole conductivity surveys by the USGS (also resurveyed recently by United) indicate that the edges of the lobes are relatively distinct, with the first saline intrusion occurring in thin individual beds of permeable sand and gravel. As intrusion continues, more individual beds are impacted, resulting in increasing chloride levels. Thus, the interpretation of high-chloride areas shown on Figure 1.5-1 and other enclosed maps combine measured concentrations from the monitoring wells, geophysical measurements, and study results about the nature of the intrusion front.

In addition, isotope studies of samples from the nested wells indicate that the cause of the elevated chloride levels varies on the Oxnard Plain (Izbicki, 1991; Izbicki, 1992; Izbicki et al, 2005a). Four major types of chloride degradation have been documented:

Lateral Seawater Intrusion - the inland movement of seawater adjacent to the Hueneme and Mugu submarine canyons;

Cross Contamination - the introduction of poor-quality water into the fresh water supply via existing wellbores that were improperly constructed, improperly destroyed, or have been corroded by poor-quality water in the Semi-Perched zone;

Salt-Laden Marine Clays - the dewatering of marine clays, interbedded within the sand and gravel-rich aquifers, yields high concentrations of chloride-enriched water. This dewatering is the result of decreased pressure in the aquifers, caused by regional pumping stresses (also see Section 1.5.4); and

Lateral Movement of Brines from Tertiary formations - the lateral movement of saline water from older geologic formations that have been uplifted by faulting. The lateral movement occurs across a buried fault face near Pt. Mugu where Tertiary rocks are in contact with the younger aquifers (also see Section 1.5.4).

Chloride degradation from each of the processes identified above is directly related to water levels in the basin. The water balance of the Oxnard Plain and the offshore component of the aquifer units is a dynamic relationship between groundwater recharge, groundwater extraction and change in aquifer storage. The primary source of groundwater recharge for the Oxnard Plain groundwater basin is the unconfined northeastern portion of this basin, known as the Oxnard Forebay (and formerly the Montalvo Basin). High water levels in the Forebay exert a positive pressure on the confined aquifers of the Oxnard Plain, and water flows from the recharge areas toward the coast (Figure 4.3-22). While the pressure exerted by high water levels in the Forebay propagates rapidly through the aquifers, the actual movement of water is very slow, approximately 3 feet per day or less in the Forebay (Izbicki et al, 1992). The pressure (piezometric) surface of the confined aquifer are diminished by the extraction of water from the system. If pressure heads at the coast fall below sea level, the lateral intrusion of seawater will occur, resulting in aquifers being recharged with seawater due to landward pressure gradients. The dewatering of marine clays will occur if heads in the surrounding sediments remain below their historic levels for prolonged periods, allowing formerly immobile salts to enter surrounding aquifer material. The slow compaction of these clays also contributes to land subsidence.

1.5.3 DECLINING WATER LEVELS

In addition to the overdraft conditions in the coastal basins discussed in previous sections, long-term declining water levels have been observed in the Santa Paula Basin. Groundwater elevations in many of the wells (43 of 57 wells) in both the eastern and western portions of the Santa Paula basin failed to fully recover to 1998 levels after near-record precipitation in 2005. This observation is consistent with an observed long-term, gradual decline in basin groundwater elevations (Santa Paula Basin Technical Advisory Committee, 2011).

An evaluation of the spatial and temporal distribution of groundwater pumping in the basin (UWCD, 2011) concluded that no significant changes in pumping locations occurred over a 30-year study period (1980 to 2009) and that water level fluctuations observed from 1980 to 2009 in the Santa Paula Basin cannot be attributed solely to spatial or temporal variations in pumping. The Santa Paula Basin Technical Advisory Committee has initiated several specialty studies (Section 2.1.3) to provide additional data on the possible hydrologic cause(s) of the observed decline in groundwater elevations.

In 2003, a basin study titled "Investigation of Santa Paula Basin Yield" by experts from the City of Ventura, Santa Paula Basin Pumpers Association and United Water Conservation District suggested that the yield of the basin is probably near the historic average pumping amount (Santa Paula Basin Experts Group, 2003).

In March 1996, as a result of legal action relating to declining groundwater levels in the Santa Paula Basin during the 1984 to 1991 drought and the City of Ventura's stated intention to increase pumping from the basin, the Superior Court of the State of California for the County of Ventura approved a Stipulated Judgment for Santa Paula Basin (*United Water Conservation District vs. City of San Buenaventura,* original judgment March 7, 1996, amended judgment August 24, 2010). The Stipulated Judgment established pumping allocations for each basin pumper.

1.5.4 UPWELLING SALINE WATER

The upwelling of saline waters has been documented in a number of production wells in the Pleasant Valley basin. Advancements in the tools used in sampling pumping production wells has allowed for the documentation of flow and water quality profiles in long-screen production wells (Izbicki et al, 2005a, 2005b). Data from some area wells indicate that poor water quality at the wellhead results from saline water entering the well from specific aquifer zones. High chloride concentrations in the deepest portion of the well can be indicative of brines migrating from deeper zones towards a water level depression (low pressure area) created by long-term overpumping. This upwelling of brines is another form of saline intrusion, and like the compaction of marine clays, occurrence is not limited to coastal areas (Izbicki, 1992).

1.5.5 EXPORTATION OF GROUNDWATER

As agricultural land value continues to increase throughout the District, and as continued urbanization removes farmland from the valley floor, the development of the hillside lands located near a reliable supply of water is also expanding. In many cases the hillside properties will not support a productive well, and water is supplied to the property from a nearby groundwater basin or established surface water diversion. Both options result in the increased use of existing water resources. Most basins within the District lack clear policy or regulation regarding the "export" of water from the basin floor to surrounding uplands, although numerous area ranches have employed such an arrangement for many years. An export policy is currently under development for the Piru and Fillmore groundwater basins.

1.5.6 NITRATE IN FOREBAY GROUNDWATER BASIN

The Oxnard Forebay is vulnerable to nitrate contamination for some of the same reasons the basin is valued for water resource projects. The coarse alluvial sediments common to the area allow the rapid vertical transport of water from the near-surface to the water table. During wet periods, the regional water table is often only tens of feet below the land surface in the Forebay. Nitrate is

highly soluble and very mobile, making it susceptible to leaching from soils and transport to groundwater. Public supply wells in some areas of the Oxnard Forebay periodically exceed the California Department of Public Health's maximum contamination level (MCL) for nitrate, which is 45 mg/l nitrate (or 10 mg/l nitrate as N). Exceedence of this MCL can result in methemoglobinemia (or "blue baby syndrome") a condition where ingested nitrogen interferes with the blood's ability to carry oxygen. Infants less than three months of age are most sensitive to this condition (Canter, 1997). United has conducted a series of studies to determine the extent of nitrate concentrations and the possible causes of this contamination. The Santa Clara River, which provides much of the natural and artificial recharge to the Forebay, is consistently low in nitrate (averaging 7 mg/l nitrate, UWCD, 1996a). Nitrate loading to the groundwater is principally related to land uses within the Forebay, with the most significant sources being agricultural fertilizers and septic systems. United's groundwater recharge activities in the Oxnard Forebay introduce large volumes of low-nitrate water to the groundwater flow system, providing a water quality benefit to both local wells and wells located greater distances down-gradient from the recharge facilities.

Nitrate levels in the El Rio area have fluctuated widely through time, with highest nitrate levels commonly observed during and following drought periods, and relatively low nitrate levels are often recorded during wet periods (UWCD, 1998). Nitrate levels tend to stay relatively low during wet periods when low-nitrate Santa Clara River water is spread by United in the El Rio recharge basins and natural recharge to the basin is abundant. However, when there is not sufficient river water to spread at El Rio, nitrate levels in the O-H wells sometimes rise, particularly in the northeastern portion of the spreading grounds. Blending with water from other O-H wells with low nitrate concentrations keeps nitrate concentrations in delivered water within the health standard for potable supply.

During the drought of the late 1980s and early 1990s, nitrate peaks increased in intensity. Following previous droughts, nitrate concentrations in the wells generally decreased to low levels during the intervening wet years. However, following the 1980s to 1990s drought, nitrate levels in a series of wells even increased during the dry season of wet or average precipitation years when flow in the Santa Clara River was low and United was not recharging water at El Rio. The distribution of nitrate both laterally and with depth is difficult to document with certainty, but the sampling of monitoring wells installed over the past decade has shown that the highest nitrate concentrations are often recorded in the shallowest portions of the aquifer (UWCD, 2008). Whereas the large-scale groundwater flow patterns within the Upper Aquifer System (UAS) of the Forebay are believed to be fairly well understood, the individual flow paths of small volumes of water are often complex. This complexity of flow paths, unknown travel times, and an imprecise knowledge of nitrogen inputs often limits what can be concluded about nitrate provenance from the basic chemical analyses common to many routine groundwater monitoring programs.

In response to long-term concerns about water quality in the Oxnard Forebay and down-gradient areas, and a regulatory order issued by the Los Angeles Regional Water Quality Control Board, areas of high-density septic systems in the greater El Rio area have been converted to sanitary

sewers. More than 1,400 properties were connected to sewer between the years 2005 and 2011, with project costs totaling $35 million. The County of Ventura managed the eleven phases of this successful project. Ongoing programs also exist to promote efficient irrigation and fertilizer practices among area growers. These educational programs are conducted regularly by the University of California Cooperative Extension, the Ventura County Farm Bureau and various agricultural product suppliers or manufacturers.

1.6 SURFACE WATER ISSUES AND CONCERNS

Complex and variable interactions between surface water and groundwater flow systems exist within the valley of the Santa Clara River. Along the length of the Santa Clara River there are several areas where flow in the river commonly percolates entirely, resulting in dry reaches of the riverbed. Surface flow resumes some distance downstream as "rising groundwater" and discharges flow to the river, usually near a boundary of one of the groundwater basins in the valley. Flow from tributary streams sometimes reaches the confluence with the river, while at other times stream flow percolates to groundwater upstream of the main river channel.

Given the complex dynamics related to the gaining and losing reaches of the Santa Clara River and its major tributaries, management activities for both water resources and environmental protection are more complicated than might be imagined. Flows in the river are naturally variable seasonally and annually, but dry reaches are common in all but the wettest of years. These variables often complicate permitting requirements and management efforts to maintain various river habitats. In addition, water quality issues generally require consideration of the interaction of surface water and groundwater, as do efforts to convey stored surface water to points lower in the watershed via natural stream channels.

1.6.1 SANTA CLARA RIVERBED STABILIZATION

The construction of the Vern Freeman Diversion structure accomplished two primary objectives for the District: creating a diversion structure highly resistant to storm damage, and stabilizing the elevation from which surface water is diverted from the river. Following extensive mining of aggregate from the channel of the Santa Clara River in the Forebay area, riverbed elevations near Saticoy had dropped by about twenty feet by the late 1980s. Scour associated with large flow events in the river allowed the riverbed degradation to propagate ever farther upstream, and United was repeatedly required to move its Saticoy diversion location farther upstream. The completed structure has prevented further down-cutting of the river upstream of the facility as expected, and some recovery of channel elevations between Santa Paula Creek and the Freeman Diversion has been documented (Stillwater Sciences, 2007). Since completion in 1991 the elevation of the Freeman diversion point has been stable at 162 feet, and the facility has enabled the diversion of river flow soon after large storm events.

When the Freeman Diversion was constructed, the riverbed elevation upstream of the structure was elevated about ten feet, and materials excavated during construction were used to raise floodplain elevations in an area extending approximately 2,000 feet upstream of the facility. The dam structure extends about 90 feet in the subsurface and rests on a bench of low-permeability Pico Formation. While the facility was not intended to pond surface water, it does act as a dam in the subsurface. Groundwater elevations at an upstream location near the diversion structure vary little from the crest elevation of 162 feet, as groundwater moving through shallow river alluvium stages up behind the Freeman structure (Figure 1.6-1). Construction of the Freeman Diversion has benefited groundwater elevations in the Santa Paula basin as incision of the river was lowering the discharge elevation for shallow groundwater in the basin was arrested and partially restored (Santa Paula Basin Experts Group, 2003).

1.6.2 INCREASED CHLORIDE CONCENTRATION IN SANTA CLARA RIVER

The watershed of the Santa Clara River is one of the largest in southern California, draining over 1,600 square miles in Los Angeles and Ventura Counties. The Piru groundwater basin underlies the Santa Clara River just west of the LA-Ventura County line, and the nature of the river channel is such that much of the time the entire flow of the river emanating from upstream areas infiltrates to groundwater in the eastern portions of the Piru basin. Water quality in the river has suffered periodically due to land use practices in Los Angeles County, and water quality impacts have been shown to persist in the groundwater of the Piru basin for many years after corrections have been made to restore quality in surface water.

In the 1950s and 1960s brines from oil production in the greater Newhall area were discharged to the Santa Clara River, and very high chloride and TDS concentrations were recorded during this period. These practices ceased in the early 1970s after the passage of the federal Clean Water Act, but residual degradation of groundwater quality was noted when water quality objectives were formulated by the Regional Water Quality Control Board years later (UWCD, 2006). Another episode of chloride contamination has occurred more recently and is associated with wastewater discharges from the City of Santa Clarita. Beginning in 1999, rapid urban growth and the increasing popularity of self-regenerating water softeners resulted in increased flow and rising chloride concentrations in the Santa Clara River at the Los Angeles County line. A clear trend of increasing chlorides continued until late 2004, when recorded chloride concentrations in the river peaked around 150 mg/l. Wells in the eastern Piru basin responded rapidly to the changes in the quality of the recharge water to the basin, and a group of concerned growers and other Ventura County interests repeatedly requested to the Regional Board to take action to regulate the chloride discharges which exceeded regulatory limits and advisory thresholds for agricultural use (100 mg/l).

Following several years of study and a successful groundwater modeling effort to predict the impacts of various discharge scenarios on downstream areas, a compromise solution emerged that was endorsed by most area stakeholders and approved by the Regional Board in fall 2008. The approved project was to allow chloride discharges as high as 117 mg/l to the Santa Clara River,

and to construct a series of extraction wells, desalting facility and pipeline to convey blended water across the dry reach of the Piru basin. The local (Santa Clarita) board of the Sanitation Districts of Los Angeles County has refused to authorize the rate increases necessary to implement the approved project. In the meantime, the successful removal of most water softeners from Santa Clarita and lower chloride concentrations in imported State Water has resulted in wastewater chloride concentrations below the peak concentrations seen in the mid-2000s. The chloride plume associated with the worst of the past discharges continues to migrate with groundwater flow across the Piru basin, and now extends past the midpoint of the basin.

1.6.3 WATER FOR ENVIRONMENTAL INITIATIVES

Because of the Federal regulatory mandates, both Santa Felicia Dam and the Freeman Diversion have implemented bypass flows to maintain migration corridors for southern California steelhead and habitats downstream of the facilities. Santa Felicia Dam is regulated by the Federal Energy Regulatory Commission (FERC) due to a small 1.2 Mega Watt hydroelectric plant at the outlet works. The Freeman Diversion is included in a Habitat Conservation Plan (HCP) that is under development and is expected to take several years to complete.

1.6.3.1 SANTA FELICIA DAM ENVIRONMENTAL FLOWS.

The original water rights license for Santa Felicia Dam requires a minimum release of 5 cfs or natural inflow, whichever is less. Due to the conditions in the FERC license which were adopted in 2011, the bypass flows have now been changed to a minimum of 7 cfs with conditions which require higher flows to maintain downstream habitat when the monthly cumulative precipitation is above the historic average measured at County Station 160, located at the guard station entering Lake Piru. Release migration flows of 200 cfs have been implemented for fisheries migration in Piru Creek when the Santa Clara River has elevated flows due to storm runoff. The trigger to initiate migration releases occurs when the USGS gauging station on the Santa Clara River above Piru measures over 200 cfs at 8:00 am and is expected to stay above 200 cfs through the following day. Migration flows are to continue as long as flows at the county line are over 200 cfs.

Based on recommendations from NMFS, FERC has also imposed license conditions on the rate at which United may decrease flows when ending conservation releases or environmental flows. Release ramping rates are to be adjusted so that flow in Piru Creek never decreases more than two inches per hour. Ramping down the conservation release in fall 2011 took five days and a minimum of 25 adjustments to go from 300 cfs down to seven cfs.

The FERC bypass flow plan was not adopted until late May 2011. As a result of the license a habitat flow of a minimum of nine cfs was implemented on May 27, 2011 and maintained until October 1st. After October 1st minimum flows were decreased to 7 cfs until the appropriate triggers are met to change the flows.

Before the final bypass flows were accepted for the license, United proposed several plans during negotiations with NMFS. Each plan was rejected for various reasons. On October 6th 2009 NMFS recommended bypass flows that would have substantially reduced the yield of the Santa Felicia Dams operations. After further negotiations, and due to United's efforts and familiarity with the hydrology, the agencies agreed upon the above mentioned plan that is now part of the license. A yield calculation was done for the operations at Santa Felicia Dam comparing the actual operations to both the approved bypass flows in the FERC license and the recommended flow proposed by NMFS during the negotiations. In 2011 the actual storage in the lake started at 31,000 Acre-Feet in January 1st, and ended up at 75,500 Acre- Feet by June 1st. If the new FERC bypass flow plans were implemented the total storage of the lake by June 1st would have been 71,700 due to some storms that would have triggered migration releases and additional habitat flows. The recommended release schedule by NMFS required a substantially higher migration flow release from the dam which would have resulted in the final storage reaching only 56,300 AF, or a loss of storage of 19,200 Acre-Feet over the actual conditions, and 15,400 acre-feet over the proposed license (Figure 2.2-1).

After the conservation release, a short duration high impulse release of 600 cfs was done in order to perform a geomorphology study as a part of the FERC license conditions. This study took an additional 2,400 AF of water and was designed to evaluate sediment transport in various reaches within Piru Creek. The experimental release water was either diverted at the Freeman Diversion or percolated upstream. Figure 2.2-1 shows the average daily flows of the geomorphic test with the conservation release.

1.6.3.2 HABITAT CONSERVATION PLAN

The Freeman Diversion currently provides bypass flows for the upstream and downstream migration of the endangered southern California steelhead. State Water Rights Permit 18908 allows United to divert its license amounts as long as 40 cfs is provided through the fish ladder for 48 hours after the total river flow subsides below 415 cfs. These migration flow requirements are limited to storms that occur between February 15th and April 31st of each year. As part of the HCP development United remains consultation with National Marine Fisheries Service (NMFS) and is currently operating the bypass flows to better meet the needs of the species for migration between the ocean and the Freeman Diversion. In 2011, four storms provided sustained flow in the Santa Clara River and allowed for the fish ladder to be in operation nearly continuously from February 19th to June 8th, 2011. An estimated 2,400 to 3,000 AF of water was directed to fish migration flows that otherwise would have been used for groundwater recharge. However during this same year 92,600 AF were diverted from the river and Forebay water levels near the Saticoy Spreading Grounds reached maximum elevations due to groundwater mounding in this vicinity.

2 PROJECTS AND INITIATIVES

Figure 2.1-1 is a matrix introducing United's current projects underway by the Groundwater Department and the issues those projects address. The projects vary in scope and application. The groundwater and surface water projects are discussed in the following sections of this report.

2.1 GROUNDWATER

Section 2.1 introduces the groundwater projects that have been conducted by United. These consist of a wide range of projects which are discussed separately in the following sub-sections of this report. These are the same projects introduced in Figure 2.1-1.

2.1.1 UPDATE REGIONAL GROUNDWATER FLOW MODEL

The Ventura Regional Groundwater Model (VRGWM) is a numerical modeling tool developed to evaluate multifaceted conjunctive use, water recycling, and water conservation projects designed to alleviate seawater intrusion, overdraft, land subsidence, and other problems. A calibrated groundwater flow model allows the prediction of benefits or impacts associated with either specific water supply projects (such as well fields, water deliveries, recharge projects, reservoir releases, etc.) or more global changes within the model domain (changing irrigation demands, changing rainfall patterns, extended drought). Both United and the FCGMA have relied upon the existing VRGWM for planning and groundwater management activities.

The VRGWM was originally developed by the U.S. Geological Survey as part of the Regional Aquifer Systems Analysis (RASA) in the late 1980s and early 1990s. The VRGWM simulates regional groundwater flow in the Piru, Fillmore, Santa Paula, Mound, and Oxnard sub-basins of the Santa Clara River Valley Basin, and the Pleasant Valley Basin, Arroyo Santa Rosa Valley Basin, and Las Posas Valley Basin in the Calleguas Creek watershed. The MODFLOW model uses a finite difference grid consisting of 114 rows and 229 columns for a total of over 24,000 active cells with nodal spacing of approximately 900 feet throughout most of the model domain. The model presently uses 3 layers to simulate regional groundwater flow in the region's Upper Aquifer System, Lower Aquifer System, and shallow alluvial aquifers.

Since completion of the original model by the USGS in 1996, UWCD has completed several modifications to the VRGWM to improve its predictive capabilities and better address project-specific questions:

- Model Grid Size Reduction – Reduced cell size from 1/2 mile to 1/6 mile for improved accuracy;

- Model Layer Addition – Added a third model layer to simulate groundwater flow and groundwater-surface water interactions in the shallow alluvial units in the Piru, Fillmore, and Santa Paula sub-basins;
- Conceptual Model Updates – Added/modified groundwater flow barriers and hydrogeologic properties;
- Expanded Calibration Period - Added 1994 to 2000 hydrology;
- Model Recalibration – Recalibrated the Oxnard Basin to 1998 to better reflect the new conjunctive use projects built after USGS originally calibrated the model; and
- Improved Predictive Simulations – Expanded the forward model (predictive tool) period to a full 55 years that reflect the climate and hydrology of the years 1944 through 1998.

While the existing VRGWM has been successfully used in this capacity for more than a decade, the model must be updated in order to answer the increasingly complex and detailed questions water managers are now faced with. As environmental stewardship, climate change, drought preparedness, and recycled water have become integral aspects of groundwater management, the level of analysis required to support planning has become increasingly more detailed in both time and space, as compared to the early 1990s when the model was developed. In its current form, the VRGWM is not fully capable of evaluating the complex issues Ventura County water managers are faced with today or expect to confront in future years.

Grant funds were used to start the VRGWM update process. The VRGWM update is divided into two geographic areas that will be completed in two separate, but linked project phases. The first phase includes the Oxnard Forebay and Oxnard Plain. The second phase will include other basins such as Mound, Piru, Fillmore, Santa Paula, and Pleasant Valley. Each project phase has three tasks: (1) Develop Basin Conceptual Model; (2) Develop Groundwater Flow Model; and (3) Calibrate Groundwater Flow Model. The grant funding is to facilitate completion of Tasks 1 and 2 of the first project phase, which will be completed within the two year grant period (estimated: fall 2013). The remaining VRGWM update tasks are funded via other sources.

The basin conceptual model provides the basis for developing the numerical groundwater flow model. The goal of Task 1 is to update the basin conceptual model for the Oxnard Forebay and Plain with improved geologic understanding so a more detailed groundwater flow model can be constructed. Currently, the VRGWM is based on a conceptual model that uses an aquifer system framework where multiple aquifers are grouped into upper and lower systems. This approach ignores difference in water levels and properties between the aquifers in each system, which are significant in most areas. As groundwater management issues become more complex, the need for aquifer-specific answers increases. Thus, a key objective of Task 1 is to expand the basin conceptual model to include aquifer-specific data.

Updating the basin conceptual model is a two-step process – data collection and data analysis. Data collection includes identifying and compiling available geological data. United has focused on

subsurface data contained in water, oil, and gas well logs. District staff have identified available geophysical logs and prioritized the logs for digitization. The digitized logs were georeferenced and input into GIS for analysis. United's hydrogeologists thereafter identified and correlated regional hydrogeologic units (aquifers and aquitards); constructed geologic cross-sections; and identified regional facies changes that affect the occurrence and movement of groundwater within the hydrogeologic units. Geologic maps and studies were also reviewed to identify geologic structures (faults and folds) that are barriers or partial barriers to groundwater flow. Ultimately, the goal is to use this work to build a 3-dimensional (3-D) geologic model of the basins for use in developing the numerical groundwater flow model (Task 2).

The goal of Task 2 is to develop the numerical model architecture and initial inputs that will be used for calibration. The model will be constructed using USGS's Modular Three-Dimensional Ground Water Flow Model code (MODFLOW) and the commercial pre-processing package Groundwater Vistas offered by Environmental Simulations, Inc. Groundwater model development is a three-step process that includes: (1) grid design, (2) establishing boundary conditions, and (3) assigning initial parameter values. As part of the model construction process, data will be georeferenced and input into GIS.

Grid Design

United's groundwater staff will construct a finite-difference grid for the model domain based on the 3-D geologic model prepared in Task 1. Model layers will be used to represent the different hydrogeologic units, where possible. The grid node spacing will be determined by evaluating the impact of cell size on model calculation run times. The goal will be to minimize the nodal spacing while not creating excessive run times. This will depend on the number of layers and the geographic extent of the model domain. If necessary, the numerical model will be broken into separate (but linked) models for different sets of basins to achieve an acceptable level of detail and run times.

Boundary Conditions

Boundary conditions are used to represent flow barriers (no-flow boundary), recharge and discharge processes (i.e. stream percolation, pumping, etc.), and inflow/outflows to/from other basins and the ocean. The geologic model will dictate the location of no-flow barriers representing low permeability bedrock units and fault barriers. Recharge estimates will be derived from prior studies and agency records of artificial recharge, as updated by new data collected by UWCD and others since the early 1990s. The primary discharge mechanism is pumping. Pumping locations and rates are available from UWCD and FCGMA pumping records. Other Inflows and outflows to the model domain will be implemented as either specified-flux boundaries or as head-dependent flow boundaries. These include flow in and out of adjacent basins and the ocean.

Initial Parameter Values

Once the model grid has been constructed, initial aquifer parameter values (hydraulic conductivity storage coefficient, etc.) will be assigned to each active cell in the model grid. These values will be estimated using available aquifer test data and the texture descriptions from the geologic model. Partial flow barriers and estimates of their hydraulic properties (conductance) will also be input during this step. Where possible, UWCD will seek opportunities to perform aquifer tests or collect other data that will help quantify the hydraulic properties of the different aquifers and flow barriers.

Following the successful construction and calibration of the groundwater flow model, the model can be utilized to evaluate specific water supply projects or broader pumping or precipitation changes within the watershed. The evaluation of individual projects requires the construction of model input files that define changes in pumping or recharge associated with the project under consideration. Model scenarios that include the new water project are typically compared to a "base case" scenario that characterizes how the basin or basins operate without the new project. United anticipates that the calibrated VRGWM will be used to assist cities or management agencies such as the FCGMA in evaluating large and/or complex water supply or water management proposals.

2.1.2 AB3030 GROUNDWATER MANAGEMENT PLAN UPDATE

The AB3030 Groundwater Management Plan (GMP), which is currently in draft form, is a cooperative effort of United Water, the City of Fillmore, and water companies/pumpers in the Piru and Fillmore Groundwater basins (Piru/Fillmore Groundwater Management Council, 2011). The original 1996 GMP was formulated with input gained from public information meetings and hearings. This 2011 GMP is an update of the original 1996 Plan (Piru/Fillmore Groundwater Planning Council, 1996).

The GMP uses the groundwater management plan authority contained in California Water Code Section 10750 et seq. initially enacted in 1992 through Assembly Bill 3030. An initial 1995 Memorandum of Understanding (MOU) between United, the City of Fillmore, and the water companies/pumpers, was incorporated in the plan and established the GMP as a cooperative groundwater management plan for the basins. The MOU outlines the roles of the various parties in implementing the Plan (M.O.U., 1995). The Piru and Fillmore basins are considered part of the Ventura Central Basin which is subject to critical conditions of overdraft (California Department of Water Resources, 1980).

United, as the lead agency, has formally adopted the GMP, which was formulated to ensure local control of groundwater management. It is the intent of the GMP to foster local control in as many aspects of the management of the basins as possible. The draft 2011 GMP update includes numeric Basin Management Objectives (BMO) for groundwater levels, groundwater quality, and surface water quality. Water Code Section 10753.7 now requires the inclusion of BMOs in a GMP for any local agency seeking state funds administered by the California Department of Water Resources for the construction of groundwater projects or groundwater quality projects. In addition

the update includes a formal groundwater export policy which was a requirement of the original GMP.

2.1.3 SANTA PAULA BASIN SPECIALTY STUDIES

In March 1996, the Superior Court of the State of California for the County of Ventura approved a stipulated Judgment for the Santa Paula Basin. (*United Water Conservation District vs. City of San Buenaventura etc, Ventura County Superior Court Case No. CIV115611,* Judgement entered March 7, 1996, and amended August 24, 2010) [hereinafter "Judgment"]). The Judgment recognized that all of the parties have an interest in the Santa Paula Basin, and in the proper management and protection of both the quantity and quality of this important groundwater supply. The basin is a significant water resource in the County of Ventura. Members of the Santa Paula Basin Pumpers Association and the City of San Buenaventura exercise rights to pump water from the basin for reasonable and beneficial uses. The United Water Conservation District does not produce water from the basin, but the basin is located within its boundaries and the District is authorized to engage in groundwater management activities and to commence actions to protect the water supplies which are of common benefit to the lands within the District or its inhabitants.

In 2010 the Judgment was amended to join various groundwater pumpers that were not previously joined as parties to the adjudication, and to clarify certain provisions pertaining to shortage conditions, the responsibilities of the Santa Paula Basin Pumpers Association and groundwater production by its members, and water rights transfer procedures.

The Judgment provides for the creation of a Technical Advisory Committee (TAC). The committee is charged with establishing a program to monitor conditions in the basin, including, but not necessarily limited to, verification of future pumping amounts; measurements of groundwater levels; estimates of inflow to and outflow from the basin; increases and decreases in groundwater storage; analyses of groundwater quality; studies relative to the basin; development of programs for its conjunctive use and operation; and other information useful in developing a management plan for the basin. The Judgment also authorizes the TAC to consider and attempt to agree on the safe yield of the basin.

The Judgment among other things requires the TAC to monitor and annually report individual and cumulative groundwater production from the basin. The Judgment further specifically provides that *"United Water Conservation District shall have the primary responsibility for collecting, collating, and verifying the data required under the monitoring program, and shall present the results thereof in annual reports to the Technical Advisory Committee*." The United Water Conservation District submits draft annual reports to the Santa Paula Basin TAC members for review, comment, and approval.

The 2008 Annual Report, filed with the Court in 2010, noted that the TAC has observed a long-term, but gradual, decline in basin groundwater elevations. The Annual Report stated that the TAC would over the following 12-24 months seek to determine the cause of the long-term gradual decline in the

groundwater elevations, and formulate remedial actions to reverse the problem should it persist (United Water Conservation District, 2009).

In 2011 the Santa Paula Basin TAC created a Santa Paula Basin Working Group to investigate the cause of the long-term gradual decline in groundwater elevations. The Working Group consists of technical experts from the United Water Conservation District, the Santa Paula Basin Pumpers Association and the City of San Buenaventura. The Working Group has initiated a series of studies that will address the cause of the long-term gradual decline in groundwater elevations.

In August 2011, the TAC issued a list of ten work items which were evaluations and studies to be completed for the Santa Paula Basin. These items are listed below:

- Investigation of Hydrologic Base Period.
- Investigation of groundwater and surface water inflow at Fillmore-Santa Paula Basins boundary.
- Evaluate groundwater confinement and differentiate measured wells by aquifer.
- Evaluate water level trends in both confined and unconfined parts of the Santa Paula Basin.
- Identify crop change over time.
- Investigation of groundwater storage change.
- Evaluate historical changes to the Santa Paula Creek channel and potential effects on basin recharge.
- Refine and finalize spatial and temporal Pumping Trends Report.
- Compilation of Santa Clara River infiltration data.
- Compilation of Santa Paula Creek infiltration data.

The technical evaluation of the spatial and temporal pumping trends within the basin has been completed (UWCD, 2011b), and the Technical Working Group of the TAC concluded that the long-term gradual decline of water levels in the basin are not due to shifts in pumping locations or magnitude over time.

2.1.4 DISTRICT-WIDE GROUNDWATER LEVEL MONITORING

United monitors groundwater elevations in all or portions of eight groundwater basins within the District boundaries. The regular monitoring of a large number of wells in the multiple aquifers throughout the District is necessary to adequately define the regional influences of groundwater extractions as well as natural and artificial groundwater recharge to the basins. Measurements are collected from both active production wells and dedicated monitoring wells. “Nests” of monitoring wells exist in some locations, allowing determination of heads in various aquifer units, and vertical gradients between aquifer zones at these locations.

In excess of 2,400 water level measurements were collected by District staff in 2011, on either a monthly, bimonthly, quarterly or semi-annual basis. The semi-annual runs are the most extensive runs and are scheduled to document annual high groundwater conditions in the spring and annual low groundwater conditions in the fall. The locations of wells measured by United at various frequencies are shown by basin in Figure 2.1-2. The locations of wells with groundwater elevation measurements are represented in various figures in Section 4 of this report.

In the Santa Paula basin, a more extensive groundwater elevation monitoring effort was initiated in 1998 and is continuing. The monthly, bimonthly and semi-annual monitoring of wells is conducted to assist technical work in progress to determine the perennial yield of the basin, and related to a March 1996 Court Settlement regarding pumping in the basin.

Beginning in the spring of 1999 the number of Upper and Lower Aquifer System wells monitored in the Oxnard Forebay, Oxnard Plain, Pleasant Valley and Mound basins was increased substantially. The increased frequency and distribution of groundwater elevation data in the coastal basins is intended to better define areas of groundwater abundance and deficit, and how these conditions relate to groundwater recharge and extraction in the basins, and geologic features within and between the basins. The implementation of an extensive semi-annual (spring and fall) water level measurement program in these basins is also intended to define the extremes of water levels throughout the year.

Beginning in 2009, United has increased its efforts to instrument additional wells in each groundwater basin with pressure transducers ("transducers"). These units consist of a compact pressure transducer and data logger, and are commonly suspended in a well by a special cable that allows records to be retrieved without removing the device from the well. The transducers are programmed to record water levels at frequent time intervals, allowing the acquisition of data sets that would be impossible or impractical to collect by hand. The automated collection of head measurements are very useful in evaluating transient events, such as tidal influences, the area of influence surrounding pumping wells, and water table responses to both natural and artificial recharge events. As of fall 2011, approximately 65 pressure transducers were deployed throughout the District (Figure 2.1-2).

A number of other Ventura County agencies routinely measure and record groundwater elevations in their wells, most commonly on a monthly or quarterly basis. Most cities and the larger mutual water companies measure water levels in their wells, often under both static and pumping conditions. Water levels are also routinely measured in monitoring wells at a number of environmental sites, such as landfills, large scale contaminant sites, or wastewater percolation ponds. United obtains water level records from these various sources and archives the records in a central database.

The Groundwater Section of the Water and Environmental Resources Division of the Ventura County Watershed Protection District also maintains a long-term groundwater elevation monitoring program (VCWPD, 2012). As with United's monitoring program, the lengthy water levels records

now associated with many of the wells in the County's program are valuable records for assessing long-term changes in water levels within area basins. United and the County of Ventura regularly exchange groundwater elevation records. The County of Ventura in turn reports groundwater elevation records to the California Department of Water Resources (DWR) as part of the California Statewide Groundwater Elevation Monitoring (CASGEM) program. This reporting program was authorized by the Legislature in 2009 as part of bill SBX7 6, and encourages local agencies to develop monitoring programs that adequately characterize groundwater conditions in their areas and regularly report the records to DWR for archiving and improved public accessibility.

2.1.5 DISTRICT-WIDE WATER QUALITY SAMPLING

United's water quality monitoring program integrates the District's sampling with sampling conducted by a variety of other organizations. Together, this monitoring serves the following varied purposes:

- For purveyors' wells, monitoring of a variety of regulated constituents ensures that groundwater is safe for potable use, and ensures taste and odor are within established guidelines.
- The saltwater intrusion monitoring network tracks the migration of saline water by direct seawater intrusion and the movement of chloride from clay layers between the aquifers. The network monitors the full series of aquifers from the Oxnard to the Grimes Canyon aquifer.
- Monitoring of wells allows documentation of both abrupt and long-term changes in water quality.

United staff samples numerous monitoring and production wells on a regular basis in order to evaluate the quality of groundwater within the District. Monitoring programs sometimes focus on specific areas within the District, typically for a specific type of degradation or improvement of water quality. In addition to United's regular sampling programs, water quality data are routinely acquired from other sources, most notably the California Department of Public Health (DPH) and the County of Ventura's Groundwater Section. Other sources of information include the California Department of Water Resources, cities, consultant reports and technical studies, landfill operators and individual well owners.

United routinely samples production wells and dedicated monitoring wells throughout the District, but monitoring is performed with increased frequency and density in two critical areas. One such area is the Oxnard Forebay basin, where United operates its main groundwater recharge facilities and the well field supplying the Oxnard-Hueneme potable water system. The monitoring serves to document both typical conditions and the variability of groundwater quality in areas of groundwater recharge and areas of groundwater production near specific land uses. Another area of frequent monitoring is the coastal area near and between the Hueneme and Mugu submarine canyons. Elevated chloride levels from the intrusion of saline waters continue to be a concern in this area,

especially in the area surrounding the naval base at Point Mugu. In recent years there has been interest in documenting increasing chloride conditions in the Piru basin. Water quality monitoring has increased in that basin, with much of the increased sampling being performed by the Groundwater Section of the Ventura County Watershed Protection District.

When water is delivered to the public, the California Department of Public Health enforces minimum monitoring requirements to assure that delivered water is free of chemical and biological contaminants. Testing requirements vary depending on the number of people served by the system and a system's vulnerability to contamination, as determined by the DPH. United regularly collects samples from the wells supplying the O-H potable water system, with sampling frequency exceeding the minimum DPH requirements. Water purveyors throughout California are required to report results of all water analyses to the DPH, and United regularly obtains these water quality records from the DPH for integration into United's water quality database.

United's groundwater staff regularly collects water quality samples from approximately 150 monitoring wells located throughout the District. Nearly all of these wells are PVC wells with a diameter of two inches. A portable submersible sampling pump is lowered into the well in order to purge the well prior to collecting a sample. Alternatively, an air compressor and long air line are used to purge other wells, where compressed air is released in the well below the water surface and water is "air lifted" to the surface by the air exiting the well. Most of the monitoring wells have a short screened interval, allowing the collection of water from a limited section of the aquifer. Many monitoring wells were installed as a nest or cluster of wells in a single borehole, allowing the collection of piezometric head and water quality samples from multiple depths at the same location. United measures field parameters during sampling, but all water quality analyses are performed by a commercial laboratory.

United also monitors a number of private domestic and irrigation wells throughout the District as part of its regional monitoring programs. The sampling of production wells spares the expense of drilling new monitoring wells, and provides examples of water quality pumped by groundwater users. However, the long screen intervals common to most production wells often draws water from multiple water-bearing zones, which can mask poor quality water that may source from specific aquifer zones. The Groundwater Section of the Ventura County Watershed Protection District also conducts annual sampling of a number of production wells in Ventura County, commonly in the fall of the year. The County sampled over 200 wells in 2011, and this sampling significantly contributed to the water quality sample coverage for several basins within United's district boundary.

The distribution of wells sampled by United is shown in Figure 2.1-3. As shown in the map, the Oxnard Forebay and the coastal areas of the southern Oxnard Plain have the highest density of monitoring wells. Production wells belonging to private parties and monitored by United are concentrated around the Oxnard Forebay and in the basins of the Santa Clara River Valley. The figure includes a table showing the number of wells monitored in each basin.

Special water quality studies are occasionally conducted within Ventura County. One significant recent study was the Groundwater Ambient Monitoring and Assessment (GAMA) program, conducted by the United States Geological Survey (USGS) in cooperation with the CA State Water Resources Control Board. This project sampled a number of "representative" wells throughout the Santa Clara River valley and the Oxnard Plain in order to assess the quality of local groundwaters commonly used for public supply. Many wells were sampled in spring 2007 for a broad suite of compounds at very low concentrations in order to document both the character of natural waters and the nature of contamination where it exists. While the identities of the wells sampled remain confidential, results from this sampling effort allowed characterization of groundwater in the study area. Contamination related to human activities was found to be relatively uncommon, and associated with shallow wells screens and younger waters when present. Older and deeper groundwater in some areas has somewhat elevated mineral content, and may have elevated iron and manganese concentrations related to reducing groundwater conditions (Burton el al, 2011). The geologic setting and nature of the area's aquifers are largely responsible for the high mineral content in the water, resulting in some aesthetic issues but not health concerns.

2.1.6 SALINE WATER INTRUSION MAPPING

The intrusion of saline waters remains the principal water quality threat to the groundwater resources of the Oxnard Plain and the Pleasant Valley basin. As described in Section 1.5.2, the movement of brines into fresh aquifer units remains a concern as long-term overdraft conditions persist in these basins, and chloride impacts are no longer limited to the coastal areas adjacent the Hueneme and Mugu submarine canyons. Water with elevated chloride concentration is not suitable for either potable use or for irrigation water. In recent years United has conducted several investigations to better define the extent of saline water in the coastal basins. Some of the subprojects of this effort include:

- Seismic reflection survey on south Oxnard Plain – this subproject focused on meso-scale geologic structures/features that were postulated to impact groundwater movement on the south Oxnard Plain;
- Time domain electromagnetic survey in the Port Hueneme and Point Mugu areas – this subproject was designed to reassess the areal extent of saline water intrusion and compare it to the USGS data from the early 1990s;
- Borehole electrical conductivity surveys in existing piezometers in the Port Hueneme and Point Mugu areas - conductivity profiling in existing wells/piezometers was performed to determine if the saline waters have begun to impact strata other than the screened intervals; and
- Collection of flow profile data and discrete-depth water quality samples - conduct flow profiling, depth-specific sampling with water quality analyses, and mass balance calculations are proposed on existing production wells to identify salinity changes for Mugu and Hueneme saline water impact areas that may be masked in a high capacity well.

To date, two of these subprojects have been completed and brief summaries of the project results are presented below.

2.1.6.1 SEISMIC REFLECTION SURVEY ON SOUTH OXNARD PLAIN

In 2010 United conducted an approximate 6 mile high-resolution seismic reflection survey in the southern Oxnard Plain that was supported by a California Department of Water Resources Grant (UWCD, 2011a). The overall purpose of the seismic reflection survey was to resolve the structural geology in the area east of Port Hueneme to provide additional subsurface data to assist with the design of the western portion of the proposed Seawater Intrusion Injection Barrier. A primary goal of the project was to better understand the structural geology and stratigraphy associated with the aquifers in the area. The seismic reflection data was obtained along four lines totaling about 6 miles in length. In spite of the semi-urban environment and the challenging site conditions, the seismic reflection survey successfully provided high-resolution images of the Plio-Pleistocene stratigraphy in the study area at depths ranging from as shallow as 60 feet to over 2,000 feet below ground surface. By correlating the stacked migrated reflection sections and data from nearby oil and water wells, United Water was able to establish an interpretation that approximates the depth, thickness, and configuration of the two major aquifer systems in the area; the Upper Aquifer System (UAS) and the Lower Aquifer System (LAS).

The base of the LAS is reported to represent the bottom of the sediments containing fresh water underlying the Oxnard Plain. United's interpretation also identified reflecting horizons within these systems that could represent the boundaries of their component aquifers such as the Oxnard and Mugu aquifers in the UAS and the Fox Canyon and Grimes Canyon aquifers in the LAS. In addition, the interpretation identified three unconformities associated with the aquifers, including a strong continuous reflector that correlates with the unconformity that forms the boundary between the UAS and LAS.

One of the objectives of the seismic reflection survey was to confirm or deny the existence of an igneous "dome" structure in the central portion of the field area (extending between the UAS and LAS). A sedimentary mound type structure was also considered to possibly occur at that location instead of the igneous dome. The existence of the structure(s) was based on conflicting data. The study concluded that no igneous dome was interpreted to exist and the subsurface materials were deemed to be sedimentary. United's interpretation of the seismic reflection data does confirm the existence of a mound of stratigraphic origin.

One significant localized thick section of low-permeability material was resolved in the data and interpretation. The body of low-permeability material is located northeast of Port Hueneme. The thick part of the body is approximately 1.8 miles (northeast-southwest direction) by 1.3 miles (northwest-southeast direction) in lateral extent and is approximately 600 feet thick. It is directly in line with the submarine canyon at Port Hueneme and is described in literature as "clay deposits Old Hueneme Canyon" (Hanson et al, 2003). It likely represents the landward extension of the submarine canyon by Port Hueneme during a transgression of the sea.

This body of low-permeability material will have an effect on the placement and design of a proposed LAS injection barrier well field to prevent further saline intrusion on the southern Oxnard

Plain. It is located directly adjacent to the saline water "plume" on the northeast side. Wells will need to avoid that area at the depths of the low-permeability material in order to be successful at injecting water. The lateral limits and thickness/depth of the materials is defined well enough for the design of the barrier injection wells. In addition the low-permeability body can be strategically used for saline water blockage in part of the injection barrier system.

2.1.6.2 TIME DOMAIN ELECTROMAGNETIC SURVEY IN THE PORT HUENEME AND POINT MUGU AREAS

United Water performed a Time Domain Electromagnetic (TDEM) geophysical survey on the southern Oxnard Plain to assess the lateral limits of saline water intrusion in the Upper Aquifer System (UAS) and Lower Aquifer System (LAS) at four different depth ranges (UWCD, 2012a). The survey was designed to replicate a study performed by the USGS in the early 1990s that provided information about the vertical and horizontal extent of saline water intrusion (Zohdy et al, 1993). The field survey area was approximately 35 square miles and extended along the coast between Port Hueneme and Point Mugu (approximately 7 miles) and inland for approximately 5 miles. One hundred twenty five (125) soundings (data points) were obtained in agricultural fields, open private land, open preservation land, game preserve land, and in open areas on the Mugu Naval Air Station. The data were forward and inverse modeled for each sounding. The model data were used to construct resistivity maps, at four depth ranges typical of the UAS and LAS.

The investigation was successful at delineating earth resistivity values that are typical of saline and brackish water in both aquifer systems. Resistivities typical of saline water occurred along the coast and extended farther inland near Point Mugu with brackish water inferred at various locations inland. The resistivity maps also exhibited configurations that are typical of geologic features which may be groundwater pathways for the migration of saline waters.

2.1.6.3 BOREHOLE ELECTRICAL CONDUCTIVITY SURVEYS IN EXISTING PIEZOMETERS IN PORT HUENEME AND POINT MUGU AREAS

United Water performed conductivity profiling in existing piezometers along the South Oxnard Plain in summer and fall 2011 to determine if the saline waters have begun to impact strata other than the screened intervals. United Water routinely records water levels and collects and analyzes water quality samples from several piezometer nests in the south Oxnard Plain. These piezometers provide much of the information about how chloride and TDS values have changed over time. The chloride concentrations are not constant with time or depth. These piezometer nests provide the opportunity to evaluate the vertical change in TDS over time. When the piezometer nests were initially constructed, borehole geophysical logs were performed in each borehole. Changes in the conductivity over time can be used to infer changes in the water chemistry. This technology works in PVC-cased piezometers (i.e., the conductivity tool can collect readings through the casing). By relogging these piezometers, the changes in the conductivity in the formation outside of the blank casing intervals can be assessed. Conductivity profiling of the piezometers, coupled with the production profiles from existing wells, will greatly increase our ability to evaluate how the vertical

distribution varies in the study area. Data from the conductivity profiling is currently being evaluated and findings have yet to be published.

2.1.6.4 COLLECTION OF FLOW PROFILE DATA AND DISCRETE-DEPTH WATER QUALITY SAMPLES

This proposed subproject includes conducting flow profiling, depth-specific sampling with water quality analyses, and mass balance calculations on production wells to identify salinity changes for Mugu and Hueneme saline water impact areas that may be masked in a high capacity well. United Water proposes to field verify the TDEM geophysical results by performing production profiles and discrete-depth water quality sampling from existing production wells located near the leading edge of the saline zones identified by the TDEM survey. Production profiles (also called flowmeter surveys) are performed on wells to determine the distribution of water entering the perforated intervals. The results of a production profile are often presented as gallons/minute (gpm) per ft of perforated interval or percentage of the total flow per perforated interval.

Inflow rates to a production well can be measured and typically the flow rates are not equal along the length of the perforations. By identifying the proportional flow rates, discrete-depth water samples can be collected from each flow interval and mass balance calculations can be used to determine the water chemistry in the aquifer surrounding the inflow zones. These techniques are in use by many water districts and the USGS to better understand the impact well hydraulics have on water quality sampling and evaluate variations in groundwater geochemistry with depth. For our study, we propose to use this technique to look for production intervals within existing wells that have elevated chloride values and determine the depths at which the well has been impacted by saline waters. Funding for this subproject has been included in United's draft budget for the 2012-13 fiscal year.

In 2002 United sponsored a similar study for a number of high-capacity production wells in the Pleasant Valley Basin. Researchers from the USGS performed flow profiling and collected water quality samples at specific depths within the screened interval of the wells under pumping conditions. The work demonstrated that deeper portions of these wells generally produced little water but tended to have higher chloride concentrations (Izbicki et al, 2005a and Izbicki et al, 2005b). This study was proposed by United and funded by DWR through an AB303 local groundwater assistance grant.

2.1.7 FOREBAY AQUIFER DELINEATION/MAPPING USING SURFACE GEOPHYSICS

Reconnaissance-level time domain surveys performed by UWCD in 2010 identified previously unrecognized geologic conditions (e.g., faults, thick clay sequences) underlying several of the District's recharge basins. Previous investigations (e.g., Daniel B. Stephens & Associates, 2008) depict the presence of clay units (aquitards) in the Oxnard Forebay, but the lateral continuity and presence/absence of faulting were not addressed. The Oxnard Forebay is a critical component of

the region's water supply system and is envisioned as a location for expansion of future groundwater pumping and the potential introduction of recycled water for aquifer recharge. As the groundwater resource utilization in the Forebay intensifies, a more refined understanding of the hydrogeologic conditions is needed to facilitate optimization of this resource.

The Fox Canyon Groundwater Management Agency (FCGMA) is assisting financially with a Forebay Basin surface geophysical survey being performed by United Water with a grant from their *Groundwater Supply Enhancement Assistance Program (GSEAP)*. This is an ongoing project with 50+ time domain electromagnetic (TDEM) geophysical soundings collected to date. Additional field work is planned in 2012. United Water field crews have enjoyed extensive cooperation from land owners who have readily provided access to their property.

2.1.8 PIEZOMETER INSTALLATION ALONG SANTA CLARA RIVER

In fall 2011 United contracted for the installation of eleven new monitoring wells in the Oxnard Forebay. Nine of the wells are located along either bank of the Santa Clara River, from the Saticoy area to the area near the RiverPark pits. Two wells were installed adjacent United's Noble Pit recharge basins. The boreholes were drilled by a hollow stem auger rig and most of the wells were screened from approximately 60 to 100 feet below the land surface. These new wells were installed in order to better characterize groundwater recharge sourcing from flows in the Forebay reach of the Santa Clara River, and to evaluate how recharge from United's recharge operations in areas near the river interact with groundwater mounding associated with natural recharge within the river channel. Matching funds of 50% were supplied by the Fox Canyon GMA as part of their Groundwater Supply Enhancement and Assessment Program (GSEAP). The locations of the eleven new wells are shown on Figure 2.1-2.

2.2 SURFACE WATER

The interaction of surface water and groundwater is complex and dynamic in the valley of the Santa Clara River. Surface water flows are often highly variable both between years and seasonally within single years. The water quality of stream flow also commonly varies throughout the year, with mineral content typically increasing as flows decrease. United's interest in surface water flows has historically centered on the Santa Clara River near Saticoy, where water is diverted from the river and routed to various facilities for either groundwater recharge or direct use as irrigation water. Because of various regulatory requirements imposed upon the District by the federal government, United has recently devoted more effort to the study and characterization of flow in the river and its major tributaries in order to better understand aquatic habitat within the lower watershed of the Santa Clara River. Of particular interest are seasonal migration opportunities for the endangered southern California steelhead and how United's activities affect flows in Piru Creek and the Santa Clara River.

2.2.1 STREAM FLOW

Flows in the Santa Clara Watershed are recorded by United, United States Geological Survey (USGS) and the Ventura County Watershed Protection District (VCWPD). Flows in the main stem of the Santa Clara River are recorded by the USGS at the Los Angeles/ Ventura County line (funded by United) and by the VCWPD downstream at Victoria Bridge near Oxnard. United also records continuous flows diverted at the Freeman Diversion. All of the major tributaries are monitored coming into the Ventura County portion of the watershed. United Water funds the USGS to monitor the flows above and below Lake Piru. The VCWPD funds the USGS to record Sespe and Santa Paula Creek while the VCWPD records Hopper and Pole Creek.

Additionally in 2011, over 150 manual discharge measurements were made in locations that are not at a continuous gauging location. These data provides the information needed to estimate benefits to each basin during the conservation/State Water release, discharge/percolation rates of each basin, and adjustment of environmental flows.

2.2.2 WATER QUALITY

United maintains a water quality monitoring program and samples from a number of locations (Figure 4.2-4) either seasonally, monthly or every two weeks. Sampling sites are generally located near groundwater basin boundaries or on major tributaries near their confluence with the Santa Clara River. Sampling of tributaries and the upstream reaches of the Santa Clara River assure that waters are acceptable for natural groundwater recharge. Sampling is conducted on a quarterly basis and consists of either a full general mineral suite or several key constituents. Water temperature and pH is documented at the time of sample collection. Sampling is conducted more frequently along the Santa Clara River near the Los Angeles County line (monthly) and at the Freeman Diversion (every two weeks).

Beginning in January 1999, United has sampled the Santa Clara River at Blue Cut near the Los Angeles County line each month. This monitoring is intended to improve understanding of how urbanization and community water supply decisions in the Santa Clarita area affect the quality and quantity of water flowing into Ventura County. From the late 1990s through 2003 discharges from the Valencia Water Reclamation Plant increased steadily in both volume and chloride concentration, with chloride concentrations exceeding 200 mg/l at the end of this period. Discharge rates continued to increase for several more years before diminishing slightly. Chloride concentrations in the discharges have fallen to levels common to the early 1990s (Figure 4.3-6), the result of lower chloride levels in State Water Project imports and a successful ban of self-regenerating water softeners in area homes.

Water quality monitoring of the river water diverted at the Freeman Diversion is performed every two weeks to confirm that the water is acceptable for use in both aquifer recharge and for irrigation deliveries. The mineral content of water in the river at this location exhibits a strong negative

correlation with flow, where higher flows are less mineralized. Nitrate concentrations are routinely low in the river and do not show a strong correlation with flow. The County of Ventura maintains and operates composite sampling device at the Freeman, and samples storm flow and dry weather base flows several times per year. These samples are analyzed for a broad suite of organic contaminants and metals as part of a storm water quality program required by the Los Angeles Regional Water Quality Control Board.

In recent years both the City of Fillmore and the City of Santa Paula have eliminated discharges of treated wastewater to the Santa Clara River upstream of the Freeman Diversion. Santa Paula's new treatment plant came on-line in 2010 and utilizes percolation basins for wastewater disposal. Fillmore completed a new plant in 2009 and now distributes reclaimed water to both percolation basins near the plant site and a network of subsurface irrigation systems constructed in parks and school fields throughout the city.

2.2.3 SANTA FELICIA DAM CONSERVATION RELEASES

United's conservation releases are designed to replenish the Piru, Fillmore and Santa Paula Basins by direct percolation from the Santa Clara River. The remaining portion of the release is diverted at the Freeman Diversion and is either spread for percolation into the Forebay, or is sent to the Oxnard Plain or Pleasant Valley Basins via the surface water delivery system. The conservation release can be adjusted in quantity (duration and magnitude) and timing to optimize benefits within the district. The quantity in most years is limited by the supply from the wet season runoff and the amount of State Water purchased. Lake Piru maintains a minimum pool of 20,000 AF of storage that is designed to keep the sediment deposits in the lake away from the outlet works. Releases beyond this point are only done when State Water released from Pyramid Lake is expected to fill the lake back to the minimum pool shortly after the conservation release.

In 2011 there was 56,400 AF of stored water available for the conservation release. The following factors were considered when deciding on how much of the stored water was to be released:

- Provide enough storage capacity in Lake Piru to minimize the chances of spilling in 2012;
- Meet the needs of the downstream basins;
- Meet the needs of the surface water deliveries to Pleasant Valley and the PTP system; and
- Hold over enough water in the lake in case 2012 was a dry year.

The analysis found that the optimal volume to be released was 31,700 AF leaving 46,100 AF (with minimum pool) in the lake for the following year in case it was dry. Figure 2.2-1 shows the basic hydrology of inflows and outflows of Lake Piru.

Because the water levels were relatively high in the Piru and Fillmore basins due to the wet year and a 11,000 AF release from Castaic Lake, the release was designed to concentrate more on the lower basins. A higher release rate normally accomplishes this goal. The release started at 400 cfs in order to cut a channel across the Piru Basin so that a higher percentage of the release would end up downstream in Santa Paula basin and the Coastal basins (the Oxnard Forebay, Oxnard Plain, Mound, West Las Posas and Pleasant Valley basins). Once the channel was cut, the release was tapered back so that the duration of the release could be extended using the same volume of water. This type of release is now called a tapered release and has been done several times in the past few years.

The timing of the release was designed to coincide with the maximum demand for the surface water deliveries out in the Oxnard Plain. Peak demand occurs with the planting of the strawberries that take place from mid September to the end of October. Heavy groundwater pumping at the end of the dry season would otherwise meet this demand. The release started on September 12 and ended on November 6. Consideration was also given to allow enough time to dry out and prepare the percolation ponds so that they are ready for the 2012 wet season.

Of the 31,700 AF released from Santa Felicia Dam in 2011, approximately 15,700 AF (50%) of the water directly percolated into the Piru and Fillmore basins (Upper basins). The remaining 16,000 AF either percolated into the Santa Paula basin or was diverted at the Freeman Diversion for groundwater recharge or surface water deliveries. Below is a table showing the estimates of the distribution of percolated flows in each basin during the conservation releases since 1999 with 2011 being near the 12 year average of the releases in terms of total quantity of the release and the direct benefit to each basin. Figure 2.2-2 shows the conservation release and the associated direct benefit to each basin. Discharge measurements were made near the Piru and Fillmore basin boundary to calculate the amount of water that percolated into the Piru Basin, and measurements were also made at Willard Rd. for the Fillmore Santa Paula basin boundary to calculate what percolated in the Fillmore Basin. The remaining discharge measured at Willard Rd. is assumed to either benefit the Santa Paula Basin or diverted at the Freeman Diversion ("Lower Basins" in following tables).

Table 2-1 Benefits of the SFD Conservation Release due to direct percolation

Year	Total Released from SFD AF	Direct Deliveries in AF. of SFD Release to:			
		Piru Basin	Fillmore Basin	Lower Basins (groundwater recharge)	Surface water Deliveries PTP and PV
1999	22,800	5,700	3,500	11,200	2,400
2000	47,200	13,800	6,100	24,150	3,150
2001	47,400	14,000	2,900	28,300	2,200
2002	20,200	8,000	5,100	6,530	570
2003	29,000	21,000	3,500	3,600	900
2004	12,200	8,000	2,150	1,600	550
2005	9,100	na	na	4,500**	0
2005	23,400	na	na	17,200**	150
2006	30,900	na	na	17,200**	1,600
2007	40,700	15,900	6,300	12,200	6,400
2008	44,400	15,400	5,700	17,400	5,800
2009	26,700	13,200	4,700	5,200	3,000
2010	33,000	14,500	4,800	10,700	3,200
2011	**31,700**	**12,400**	**3,300**	**14,100**	**1,600**
Average	29,907	12,900	4,368	12,420	2,251
13 yr. Total	448,607	154,800	52,418	186,300	33,771

*2005 had two conservation releases. Portion of the release includes spill water when the lake was full

** measured at the Freeman Diversion

2.2.4 IMPORTATION OF STATE WATER

Ventura County has a 20,000 AF allocation of State Water. United Water's share of the allocation is 5,000 AF. Port Hueneme Water agency uses 1,850 AF of the original 5,000 AF and takes delivery through Metropolitan Water District. The remaining 3,150 AF of water is permitted to be released from Pyramid Lake and sent to Lake Piru through the natural water course of Piru Creek. United may receive this water from November 1st through the end of February of each year. Typically the conservation release will end before the State Water has arrived in Lake Piru. In order to release the state water that year, United will continue the release below the lake's minimum pool to the volume of State Water that was purchased, knowing that state water will fill it back to the minimum pool by the end of November. The State Water allows the conservation release to be extended a

few extra days due to the extra volume of water. The volume of water that percolates into each basin on the extended days of the release was considered to be the direct benefit to each basin.

In 2011 the State Water Project made available 80% of water allocations held by subscribers to the system. United received its 80% or 2,520 AF by a release from Pyramid Lake in November and December of 2011. Due to the wetter than normal conditions United chose to store the State Water until 2012 when it can be delivered at the end of the conservation release, along with any other additional State Water purchased for 2012.

The table below is a summary of all the state water purchased by United Water along with the direct benefits to each basin from percolation. Detailed stream flow measurements are taken near the basin boundaries throughout the releases to determine where the state water is percolating.

Table 2-2 Summary of State Water Release from Santa Felicia Dam

	Summary of State Water Released From Santa Felicia Dam in 1991-2011 (Values in AF)				
Year State Water Purchased	From Santa Felicia Dam	Release to Upper Basins (Fillmore and Piru)	Releases to the Lower Basins (Santa Paula and Coastal Basins)	Delivered to PV. And PTP	Recharge To Lower Basins
1991	4,836	3,603	1,233	0	1,233
1992	988	84	904	0	904
2000	2,200	406	1,794	69	1,725
2002	3,150	1,455	1,695	192	1,503
2003	3,150	2,041	1,109	70	1,039
2004	4,047.5	3,348	700	228	472
2007	1890	844	1046	116	930
2008	1980	673	1307	306	1001
2009	3150	1045	2105	724	1381
2010	3150	917	2233	559	1674
2011	**2520***				
Total	28,542	14,416	14,126	2,264	11,862

* To be released in 2012 conservation release

The benefit of the conservation release along with the State Water released can be seen in Figure 2.2-3. Since November of 2007 a transducer has been monitoring water levels in a monitoring well near the river in the Piru Basin. The graph shows the immediate rise in water levels in a well during the releases (shown in red). Because the well is approximately 600 feet from the flow in the river, a mound will build rapidly when the release starts and dissipate a little more slowly at the end of the release. Water levels are always considerably higher following the release, compared to the projection of water levels trends before the release.

2.2.5 PIRU DIVERSION EVALUATION

The Piru Diversion has been historically operated to divert surface water into United's nearby spreading grounds for groundwater recharge however this facility has not been operated since September of 2008. The diversion is located on the western bank of lower Piru Creek just south of the old Center Street Bridge in the town of Piru. Part of the diversion dam is built under the two roadway bridges crossing lower Piru Creek at Center Street.

The existing diversion consists of an earthen berm that extends out across the river channel, a sluice channel that can accommodate approximately 200 cfs, and a diversion structure with a trash rack and four 24-inch inlets leading to a 48-inch diversion pipe that conveys diverted water to the 44- acre spreading grounds.

The structure is not in compliance with National Marine Fisheries Service standards for diverting water in a stream that is considered by NMFS to constitute anadromous waters for Southern California steelhead. Therefore the facilities have been included as parts of United's Habitat Conservation Plan (HCP) so that the facility will be covered for incidental take. The diversion will not be put back into operation until the take permit has been issued and the facility has been retrofitted.

2.2.6 SANTA CLARA RIVER FLOW DIVERSIONS

The Freeman Diversion diverted 92,600 AF in 2011. This represents about 150% of the historical average diversions since 1955. In wet years such as 2011 various operational strategies were implemented to assure maximum yield at the diversion. Such strategies included limiting turbidity turn-outs, shifting the locations to spread water to reduce mounding near the river, alternating ponds to insure the maximum possible percolation rates, and implementing new SCADA controls to optimize canal levels. Some of these strategies are discussed below.

High flows in the river are normally associated with high turbidity. During times when the river is at its peak, diversions stop so that the sediment-laden water is not diverted. A recently implemented more aggressive schedule to divert more turbid water allowed the facility to divert 2,000 to 3,000 acre feet more than it would have in prior years. This more aggressive turn in procedure increases the use of the desilting basin, resulting in the need for more frequent cleanouts.

United's aggressive wet season spreading at Saticoy and the Noble Basin increased water levels in the surrounding area to a point where groundwater from spreading in the Saticoy and Noble basins was discharging back to the river near the Highway 118 Bridge. Rising groundwater in this area reached around 50 cfs of discharge in the river in the month of April. The spreading ponds further away from the river were used to limit the amount of discharge back to the river. The discharging water is in large part due to the degradation in the riverbed near the Highway 118 Bridge. The riverbed is currently about 20 feet lower than it was in the early 1950's allowing for a larger elevation differential between the pond and the river. A portion of the discharging water will

percolate downstream of the discharging point. With the balance of the discharging river that breached the Forebay to become part of the environmental flows that were needed to maintain downstream passage for the Southern California steelhead.

Nearly 72,000 AF were spread for groundwater recharge at United's three recharge facilities. El Rio recharged nearly half of the water, with Saticoy and the Noble Basins making up the other half (Figure 2.2-4). The remaining 20,600 AF went to surface water deliveries discussed in Section 1.4.6.

2.2.6.1 EL RIO RECHARGE BASIN

Recharge to El Rio exceeded the 56 year average in all months except for August. The total volume recharged was approximately 160% of normal. El Rio became the preferred facility to recharge due to the mounding of water and discharge back to the river at the other facilities. Due to the active O-H well field surrounding the facility, the groundwater mounding does not reach the surface thereby reducing percolation rates.

Table 2-3 Recharge to El Rio for 2011 calendar year

Recharge to El Rio AF		
	2011 Year	average since 1955
Jan	3,776	2,691
Feb	3,617	3,123
Mar	5,283	3,473
Apr	6,070	2,709
May	2,188	2,035
Jun	2,594	1,053
Jul	1,459	871
Aug	224	1,144
Sep	2,283	1,604
Oct	4,370	1,705
Nov	3,520	1,548
Dec	2,461	2,138
Totals	37,845	24,096

2.2.6.2 NOBLE RECHARGE BASIN

The Noble Basin is normally the last of United's Forebay facilities to be used for groundwater recharge. It is difficult to maintain the ponds during the wet season due to greater water depths and proximity to groundwater. During 2011, water was spread into the basin for a portion of four months

during the natural runoff period, and two months during the conservation release. The average spreading at this facility was nearly double the average since it was built in 1994.

Table 2-4 Recharge to the Noble Basin for calendar year 2011

Recharge to Noble Basin AF		
	2011	average since 1994
Jan	766	275
Feb	2,507	808
Mar	2,259	1,279
Apr	4,305	1,385
May	0	614
Jun	0	435
Jul	0	210
Aug	0	108
Sep	0	150
Oct	137	153
Nov	705	160
Dec	0	175
Totals	10,679	5,754

2.2.6.3 SATICOY RECHARGE BASINS

The Saticoy facilities recharged 23,400 AF in 2011, which is about average for the 55-year period since construction of Lake Piru. As mentioned above, mounding was occurring under the ponds and recharged water was flowing back out to the river. Priority was given to the El Rio facility at this time to attempt to decrease the amount of rising groundwater going back to the river. Regardless of the mounding, United was able to divert its instantaneous surface water diversion license limits with consideration to the environmental bypass flows for the entire year.

Table 2-5 Recharge to Saticoy for calendar year 2011

Recharge to Saticoy AF		
	2011	average since 1955
Jan	7,608	2,229
Feb	1,946	2,504
Mar	2,208	3,361
Apr	4,478	3,074
May	265	2,377
Jun	164	1,461
Jul	0	1,233
Aug	0	1,076
Sep	816	1,453
Oct	5,041	1,927
Nov	909	1,270
Dec	0	1,662
Totals	23,435	23,627

2.2.7 SATICOY WELL FIELD USAGE AND CREDIT SYSTEM BALANCE

In conjunction with the conservation releases from Santa Felicia Dam, United temporarily stores surface water beneath the Saticoy Spreading Ground for later delivery to the overdrafted areas of the Pleasant Valley and Oxnard Plain basins. United constructed the Saticoy well field in 2004, allowing the pumping of mounded groundwater for delivery to the PV and PTP systems. The Fox Canyon Groundwater Management Agency adopted a resolution that created a pump- back storage program of the Saticoy spreading system and its well field usage. Recharged water from the conservation release at the Saticoy Facility to the surface water delivery system can be pumped back for a period of two years. At the end of the two years the storage credits expire. Below is a table showing the history of the credit/ balance of this system. To date an additional 24,900 AF have been stored during the conservation releases at Saticoy, with a total of 9,550 AF extracted for surface water deliveries. The credit system does not include the State Water that is part of the conservation release or the well field pumping when the water levels have “mounded”.

Table 2-6 Credit system for the Saticoy Well Field

	Total Available at the Start of year	Saticoy Well Field S.W. deliveries	Unused allocation	Recharged to Saticoy at end of year less state water
2006	0	0		7,846
2007	7,846	1,753	6,093	3,247
2008	9,340	3,845	5,495	5,695
2009	8,942	2,455	6,487	1,045
2010	6,740	759	5,981	1,821
2011	2,866	737	2,129	5,237

2.2.8 CASTAIC LAKE FLOODFLOW RELEASE

United is the lead member of a water conservation agreement between the California Department of Water Resources and the Downsteam Water Users (DWU). The DWUs consist of United, Los Angeles County, Newhall Land and Farming, and Valencia Water District. The program is designed to hold back flood flows in Castaic Lake and release them at a later date in a manner that allows the flows to percolate in the basins downstream of the dam, benefiting the DWU's. United takes the lead role for the DWUs in requesting the storage and releases, and by monitoring of the associated release to make sure that the flows are benefiting the basins. In 2011 approximately 11,000 AF of captured flood flows were released. Most of the released water percolated into the Piru Basin with some of it making it to the Fillmore Basin. Figure 2.2-5 shows the water level increase in a key well in Piru Basin during the associated release. Figure 2.2-6 shows the inflows/outflows from Castaic Lake in 2011.

2.2.9 BOUQUET RESERVOIR RELEASES

United has an agreement with the Los Angeles Department of Water and Power (LADWP) that provides for the release of flows from Bouquet Reservoir to recharge the aquifers of the Santa Clara River Valley to the extent that they were recharged from Bouquet Canyon outflows prior to construction of the reservoir. The agreement stipulates that LADWP release between 2,100 and 2,194 acre feet per year. This quantity is based on historical annual inflows to the reservoir. The agreement requires a continual release of 5 cfs between April 1st and September 30th; and 1 cfs between October 1st and March 31st of each year.

The prescribed flows were interrupted following an extreme weather event in 2005 that resulted in raising the streambed and pushing it toward Bouquet Canyon Road. In several locations the stream is higher than the road and on occasion stream flows have entered the road posing a threat to public safety. When water is observed on the road, flows from Bouquet Reservoir are reduced.

To complicate matters, this area of Bouquet Creek is designated critical habitat for unarmored three-spined stickleback, and flow changes require special consideration for this species. United has been participating in the stakeholders meetings to ensure that the deficit of water will eventually be released. By 2008 the deficit was approximately 4,400 AF. Since releases have at times been more than the required release, the overall deficit has been reduced to 3,328 AF.

3 HYDROGEOLOGY OF DISTRICT

United Water Conservation District overlies all or portions of eight groundwater basins in central and southern Ventura County. The geologic setting of the basins, the regional aquifers, and some characteristics of each basin are discussed in this section. Discussion related to 2011 conditions in the basins are included in Chapter 4 of this report.

3.1 GEOLOGIC SETTING

The United Water groundwater basins are part of the Transverse Ranges geologic province where the mountain ranges and basins are oriented east-west rather than the typical northwest-southeast trend of much of California. The geology associated with the Transverse Ranges is primarily east to west trending folds and faulting (fold axes trend east-west). This configuration creates the elongate mountains and valleys that dominate Santa Barbara County and Ventura County.

The boundaries of United Water Conservation District are located within the more regional Ventura Basin, which is an elongate east to west trending structurally complex syncline within the Transverse Range province (Yeats, et. al., 1981). The seven basins that underlie the District are the Piru, Fillmore, Santa Paula, Mound, Oxnard Forebay, Oxnard Plain, and Pleasant Valley basins (Figure 1-1). The western portion of the West Las Posas Basin also falls within the District boundary.

The Santa Clara River Valley occupies the Ventura Basin, which is one of the major sedimentary basins in the geomorphic province. The total stratigraphic thickness of upper Cretaceous, Tertiary, and Quaternary strata exceeds 55,000 feet (Sylvester and Brown, 1988).

Active thrust/reverse faults border the basins of the Santa Clara River Valley, contributing to the uplift of the adjacent mountains and down-dropping of the basins. The Piru, Fillmore, and Santa Paula basins are bounded by the Oak Ridge fault to the south and the San Cayetano fault system to the north. The Oxnard Plain and Mound basins extend across the offshore marine shelf to the shelf/slope break (the edge of the shelf).

The basins are filled with substantial amounts of Tertiary and Quaternary sediments that were deposited in both marine and terrestrial settings. The basins on the coast, including the Mound

basin, are filled with recent sediments deposited on a wide delta complex that formed at the terminus of the Santa Clara River. Figure 3.1-1 shows the local formations which form the mountain ranges, surface/subsurface geology, and the major faulting in relation to the United Water basins.

3.2 AQUIFERS

Most of the coastal basins within United Water Conservation District have a shallow perched aquifer zone, and the aquifers of all the basins can be classified as part of an Upper Aquifer System (UAS) and Lower Aquifer System (LAS) (e.g., Turner, 1975; Mukae and Turner, 1975). The UAS consists of the Oxnard and Mugu aquifers. The LAS consists of the Hueneme, Fox Canyon and Grimes Canyon aquifers. The aquifers contain gravel and sand deposited along the ancestral Santa Clara River, from alluvial fans along the flanks of the mountains, from a coastal plain/delta complex at the terminus of the Santa Clara River, and marine deposits from transgressional seas. The aquifers are recharged by infiltration of streamflow (primarily the Santa Clara River), artificial recharge of diverted streamflow, mountain-front recharge along the exterior boundary of the basins, direct infiltration of precipitation on the valley floors of the basins and on bedrock outcrops in adjacent mountain fronts, and irrigation return flow in some agricultural areas.

Figure 3.2-1 is a schematic of the UAS and LAS showing their subsurface sequence. The figure also shows general depths in feet. However, more recent work with geophysical logs has suggested that some of the aquifers are actually deeper than originally thought and indicated on this schematic. Also note that the clay layers (aquicludes) shown in the UAS are inter-fingering and in some places discontinuous.

3.2.1 PERCHED/SEMI-PERCHED

On the Oxnard Plain, the uppermost silt and clay deposits of the Oxnard aquifer are overlain by sand layers of the “semi-perched zone,” which generally contains poor-quality water. This zone extends from the surface to no more than 100 ft in depth. The confining clay of the upper Oxnard aquifer generally protects the underlying aquifers from contamination from surface land uses. Deep percolation of rainfall and irrigation return flows are the major components of recharge to the semi-perched zone. The semi-perched zone is rarely used for water supply on the Oxnard Plain.

3.2.2 UPPER SYSTEM

The Upper Aquifer System (UAS) consists of the Oxnard and Mugu aquifers. These aquifers are characterized by recent alluvium (Oxnard aquifer) of Holocene age and older alluvium (Mugu aquifer) of late Pleistocene age. The Oxnard aquifer rests unconformably on the Mugu aquifer. A clay layer occurs between the aquifers.

Recent river channel deposits comprise the uppermost water-bearing units along portions of the Santa Clara River basins. These deposits are generally up to 100 ft in thickness. In the Santa Paula basin, nested monitoring wells indicate that this upper alluvial aquifer is somewhat isolated from the underlying aquifers of the San Pedro formation. The alluvial unit, from which there is considerable water production in the Santa Clara River basins, may be time-equivalent to portions of the UAS on the Oxnard Plain, but has not been assigned to the UAS in the literature.

3.2.2.1 OXNARD

The Oxnard aquifer materials generally consist of lagoonal, beach, river, floodplain and alluvial fan deposits (Turner, 1975). The Oxnard aquifer is present throughout the Oxnard Plain and other basins. The Oxnard aquifer is the primary aquifer used for groundwater supply on the Oxnard Plain. This highly-permeable assemblage of sand and gravel is generally found at a depth of approximately 100 ft to 250 ft below land surface elevation.

3.2.2.2 MUGU

The Mugu aquifer materials generally consist of lagoonal, beach, river, floodplain, alluvial fan terrace and marine terrace deposits. The Mugu aquifer rests unconformably on the LAS. Basal conglomerates occur in many areas (Hanson et al, 2003). In the Oxnard Plain, these coarse-grained basal deposits comprise the Mugu aquifer (Turner, 1975). The Mugu aquifer is generally penetrated at a depth of 255 ft to 500 ft below land surface.

3.2.3 LOWER SYSTEM

The Lower Aquifer System (LAS) consists of the Grimes Canyon, Fox Canyon, and Hueneme aquifers (Figure 3.2-1). The LAS is part of the Santa Barbara, San Pedro, and Saugus formations of Plio-Pleistocene age (Mukae and Turner, 1975).

In any of the basins, the aquifers of the LAS may be isolated from each other vertically by low-permeability units and horizontally by regional fault systems. The LAS is folded and tilted in many areas, and has been eroded along an unconformity that separates the upper and lower aquifer systems.

3.2.3.1 HUENEME

The Hueneme aquifer is considered to underlie the Oxnard Plain basin (Hanson et al, 2003). The Hueneme aquifer materials generally consist of terrestrial fluvial sediments, and marine clays and sands. In the basins along the Santa Clara River, the deeper aquifer system is generally considered to be the San Pedro Formation (Mann, 1959) or the time-equivalent Saugus Formation, although the U.S. Geological Survey considers this deeper aquifer to be equivalent to the Hueneme aquifer (Hanson et al, 2003).

3.2.3.2 FOX CANYON

The Fox Canyon aquifer underlies the Las Posas, Pleasant Valley, Oxnard Forebay and Oxnard Plain basins. The Fox Canyon aquifer materials generally consist of marine shallow regressive sands and some clays. The Fox Canyon aquifer is the lower unit in the San Pedro formation. This same unit also extends north into the Mound basin, but the character of the sediments change to more finely-bedded deposits (UWCD, 2012).

3.2.3.3 GRIMES

The lowest water-bearing unit of the East Las Posas and Pleasant Valley basins is commonly referred to as the Grimes Canyon aquifer (CA DWR, 1954; Turner, 1975). The Grimes Canyon aquifer materials generally consist of marine shallow regressive sands.

3.3 GROUNDWATER BASINS

The groundwater basins within the District vary in their water production and ability to be recharged rapidly. The groundwater basins detailed here are really sub-basins of the larger basin of the Santa Clara River Valley (CA DWR, 2003). Hydraulic connection exists between all basins within the District boundaries. The Fillmore basin receives recharge as underflow from the Piru basin, and the Santa Paula basin receives significant recharge from the Fillmore basin. The Mound basin receives recharge from the Santa Paula basin and from the Oxnard Plain and Oxnard Forebay basins, although head differentials across the western Santa Paula basin boundary are greater than those between the other sub-basins of the Santa Clara River valley. The Oxnard Forebay basin is widely recognized as the primary recharge area for aquifers in the Oxnard Plain. Many of the confining clays present in the aquifer systems of the Oxnard Plain are absent or discontinuous in the Oxnard Forebay basin, creating a window for recharge to other down-gradient aquifers. High groundwater elevations in and near the Oxnard Forebay promote groundwater flow to the nearby Mound and West Las Posas basins. The Pleasant Valley basin is more distant from the Oxnard Forebay and receives less direct benefit from United's recharge operations, but pipelines have been constructed to convey irrigation water directly to water users in Pleasant Valley and on the southern Oxnard Plain.

3.3.1 PIRU

The Piru basin consists of recent and older alluvium underlain by San Pedro (Saugus) Formation. The recent and older alluvium is made up of coarse sand and gravel that are present to a depth of approximately 60 to 80 feet throughout the basin. The San Pedro Formation consists of permeable sand and gravel and extends to a depth of approximately 8,000 feet. Two faults bound the Piru basin, the Oak Ridge fault to the south and the San Cayetano fault to the north (UWCD, 1996b).

Groundwater flow in the alluvium of the Piru basin tends to be westerly, parallel to the river channel. Similarly, the flow gradient in the San Pedro Formation is westerly with a small north/south component as the groundwater moves parallel to the axis of the syncline that forms the basin. The basin is considered to be an unconfined groundwater basin. The Santa Clara River and Piru Creek are major sources of recharge to the Piru basin, with minor sources from smaller streams, from outcrops to the north of the basin, and from percolation of rainfall. United occasionally operates the Piru Spreading Grounds, a 44-acre recharge basin which diverts water from Piru Creek for groundwater recharge. The Piru basin readily accepts large volumes of recharge as surface water percolates to groundwater in the channel of the river. During United's conservation releases from Lake Piru a significant percentage of flow infiltrates through the river channel and serves to recharge the Piru basin.

Under low-flow conditions (up to approximately 100 cfs), all of the surface flow of the Santa Clara River coming from Los Angeles County commonly infiltrates into the Piru basin above the confluence of Piru Creek, so that there is no continuity of river flow across the basin. Continuous surface flow may extend the length of the basin following large winter storms, during large releases from Castaic Lake, and in the winter and early spring of exceptionally wet years. A lengthy "dry gap" of approximately five miles commonly exists in the central portion of the Piru basin, extending from the point of complete percolation of surface water east of Piru Creek to areas near the downstream end of the basin. During United's conservation releases flows ranging from 100-200 cfs are often required to establish surface flow between Piru Creek and the west end of the basin. In the area west of Hopper Creek groundwater flow is constricted as the basin narrows and shallow groundwater intersects the river channel. This "rising groundwater" contributes or restores surface flow in the river near the west end of the basin. When groundwater levels in the Piru basin are high, the area of rising groundwater extends farther east than in drier times, and the total flow of the discharge to surface water is greater. At the lower end of the Piru basin, a significant amount of groundwater flows into the Fillmore basin as underflow (Mann, 1959).

The channel of the Santa Clara River stays along the basin's southern edge over the length of the basin, likely secured in that position by the alluvial fans of Piru and Hopper Creeks entering the basin from the north. Chloride impacts associated with wastewater discharges sourcing from Los Angeles County over the past decade are now observed in wells along the northern portions of the middle of the basin. The northerly extent of these chloride impacts suggests the primary groundwater flow paths down the basin are north of the modern river channel. Groundwater flow paths are likely influenced by both geologic structure within the basin and the extraction of groundwater in the northern portions of the basin.

3.3.2 FILLMORE

The Fillmore basin consists of varying alluvial deposits resting on the San Pedro Formation. The younger alluvial deposits comprise recent sands and gravels of the Santa Clara River and Sespe Creek in the southern and eastern parts of the basin. Southward-sloping alluvial fan material forms

the Sespe uplands in the north-central portion of the basin, and alluvial fan material of the Pole Creek Fan underlies the City of Fillmore (UWCD, 1996b). Alluvial thickness varies from 60 to 120 ft. The San Pedro Formation, folded into an east-west syncline, underlies most of the Fillmore basin. Along the main axis of the syncline, the San Pedro Formation reaches a depth of 8,430 feet. At the western basin boundary, the San Pedro Formation extends to a depth of 5,000 to 6,000 feet.

The groundwater flow gradient in the Fillmore basin generally creates an east to west movement of groundwater through the alluvium. Groundwater that infiltrates from Sespe Creek generally flows towards the southwest. In the San Pedro Formation, the movement of groundwater is believed to be southerly beneath the Sespe fan, changing to westerly near the axis of the syncline. The basin is considered an unconfined groundwater basin. The Santa Clara River and Sespe Creek are two major sources of recharge to the Fillmore basin, as is underflow from Piru basin. As with the Piru basin to the east, the Fillmore basin readily recharges in years of abundant rainfall and streamflow.

The Fillmore basin narrows at the downstream end, resulting in an extensive area of rising groundwater and gaining flow in the Santa Clara River. Extensive wetlands exist in this area, and are easily visible on aerial photographs. Groundwater underflow into the Santa Paula basin is likely significant, although some suggest surface flow related to rising groundwater comprises a larger component of the discharge from the basin (Mann, 1959).

3.3.3 SANTA PAULA

The Santa Paula Basin is located along the Santa Clara River, extending from approximately Kimball Road and the town of Saticoy in the west to Santa Paula Creek in the east. The basin is bounded by the Sulphur Mountain foothills on the north and South Mountain on the south. The basin is elongated in a northeast-southwest direction, about 10 miles long and as much as 3.5 miles wide. The surface area of the basin is approximately 13,000 acres, and ranges in elevation from 130 feet above sea level near Saticoy to 270 feet above sea level near the City of Santa Paula. Ongoing uplift along the Oak Ridge and other faults has created a deep basin, with Plio-Pleistocene deposits exceeding 10,000 feet in thickness.

The principal fresh water-bearing strata of the Santa Paula Basin are the Pleistocene San Pedro Formation, Pleistocene river deposits of the ancient Santa Clara River, alluvial fan deposits shed from the uplifted mountain blocks, and recent river and stream sediments deposited locally along the Santa Clara River and its tributaries. These water-bearing sediments are underlain by relatively impermeable Pliocene and older units. The sediments of the basin have been warped into a syncline that is oriented in a northeast-southwest direction along the center of the basin. To the east, the Santa Paula Basin is considered to be in hydraulic connection with the Fillmore Basin. To the south, the Oak Ridge fault forms a partial barrier to groundwater movement. On the north, the portion of the aquifer represented by the San Pedro Formation is exposed in an outcrop along the Sulphur Mountain foothills. The Santa Paula basin borders the Oxnard Forebay and Mound basins on the west. The western boundary of the Santa Paula Basin is more complex, with local uplift and

faults mapped by some investigators. Although there is general agreement that there is some hydraulic connection between Santa Paula Basin and the Mound Basin, the degree of connection is uncertain.

Long-term records of groundwater elevations within the Santa Paula basin demonstrate that the basin has a more muted recharge response to wet years than the Piru and Fillmore basins to the east. Much of the recharge likely occurs in the eastern portion of the basin (Santa Paula Basin Experts Group, 2003). Groundwater levels in many wells in the central and western portions of the basin show significant seasonal variability, suggesting some degree of confinement. During high rainfall years, monitor wells in the southern portion of the basin near the Freeman Diversion, and historically some other wells near Saticoy, have shown artesian flow. The complex subsurface geology in the western portion of the basin complicates interpretations of groundwater flow in this area.

3.3.4 MOUND

The principal fresh water-bearing strata of the Mound basin are the upper units of the San Pedro Formation and overlying Pleistocene deposits that are interpreted to be correlative with the Mugu aquifer of the Oxnard Plain basin. There is an upper confining layer of Pleistocene clay approximately 300 feet in thickness. The basin extends several miles into the offshore.

The sediments of the basin have been warped into a syncline that is oriented in an east-west direction that roughly follows Highway 126. Structural disruption along the Oak Ridge fault in the southern portion of the basin has resulted in considerable uplift and erosion of the San Pedro and younger sediments. This disruption is the cause of the topographic “mounds” near the intersection of Victoria Avenue and U.S. 101, for which the basin is named. The Montalvo anticline has traditionally been used to define the southern extent of the basin. These structural features generally offset only the deeper LAS units of the adjacent Oxnard Plain. The deposits of the Upper Aquifer System overlie the faults and folds along the southern margins of the basin, but the character of the deposits change as they extend to the north, becoming more finely bedded and fine-grained (UWCD, 2012b).

The limited number of wells in the Mound basin, especially in the northern half of the basin, complicates efforts to ascertain the primary sources of recharge to the basin. There likely is some component of recharge from precipitation falling on aquifer units that outcrop in the hills along the northern margin of the Mound basin (Figure 3.1-1), but no wells exist to provide evidence of this occurrence. There is general agreement that the basin benefits from recharge from the Oxnard Forebay and Oxnard Plain to the south, especially during periods of high water level on the Plain (GTC, 1972; Fugro, 1996; UWCD 2012b). The hydrogeologic boundaries of the Mound basin are not coincident with the structural boundaries of the basin, so there is hydrologic connection between the Mound basin and adjoining groundwater basins (UWCD, 2012b). The amount of recharge from the Santa Paula basin to the east is also unclear, but high heads in some wells in the eastern

Mound basin suggests some degree of connection and recharge. Mann (1959) suggested that there is little underflow from the Santa Paula basin to the Mound basin, although more recent studies suggest it may be significant (Fugro, 1996; UWCD, 2012b).

Groundwater flow in the Mound basin is generally to the west and southwest with modest to weak gradients, especially in times of drought. The poor distribution and limited number of wells with water level records complicates efforts to contour groundwater elevations in the basin. During periods of drought and increased pumping, a pumping trough forms along the southern portion of the basin that significantly modifies groundwater gradients.

3.3.5 OXNARD FOREBAY

Both UAS and LAS aquifers are present in the Oxnard Forebay and Oxnard Plain basins. The Oxnard Forebay maintains direct hydraulic connection with confined aquifers of the Oxnard Plain basin, which extends several miles offshore beneath the marine shelf where outer edges of the aquifer are in direct contact with seawater. In areas near Port Hueneme and Pt. Mugu where submarine canyons extend nearly to the coastline, the fresh-water aquifers may be in direct contact with seawater a short distance offshore.

The Forebay is the main source of recharge to the Oxnard Plain basin. Recharge to the Forebay benefits other coastal basins (Mound, West Las Posas, Pleasant Valley) but a majority of the water recharged to the Forebay flows downgradient to the confined aquifers of the Oxnard Plain. The shallow sediments of the basin are dominated by coarse alluvial deposits of the ancestral Santa Clara River. The absence of low-permeability confining layers between surface recharge sources and the underlying aquifers in the Forebay allow rapid groundwater recharge in the Forebay. The recharge to the Forebay comes from percolation of Santa Clara River flows, artificial recharge from United's spreading basins, irrigation return flows, percolation of rainfall, and likely lesser amounts of underflow from the Santa Paula basin and mountain-front recharge from the nose of South Mountain. In the area of the Forebay between the El Rio and Saticoy spreading grounds, the LAS has been uplifted and truncated along its contact with the UAS. In this area recharge from surface sources may enter both the UAS and the underlying LAS. The U.S. Geological Survey estimates that about 20% of the water recharged to this area reaches the LAS, with the remainder recharging the UAS. In some areas of the Forebay significant clays are present among the deposits of the LAS.

3.3.6 OXNARD PLAIN

The Oxnard Forebay is hydraulically connected with the aquifers of the Oxnard Plain basin, which is overlain by an extensive confining clay layer. Thus, the primary recharge to the Oxnard Plain basin is from underflow from the Forebay rather than the deep percolation of water from surface sources on the Plain. Natural and artificial recharge to the Forebay serves to raise groundwater elevations in this up-gradient area of the groundwater flow system for the Oxnard Plain. High water levels in

the Forebay increase the hydrostatic pressure in the confined aquifers extending from the margins of the Forebay to the coastal and offshore portions of these continuous aquifer units. While the physical movement of groundwater out of the Forebay is fairly slow, the pressure response in the confined aquifers distant from the Forebay responds more rapidly to significant recharge events in the Forebay. When groundwater levels are below sea level along the coastline, there may also be significant recharge by seawater flowing into the aquifers.

Vertical gradients also commonly exist between aquifer units on the Oxnard Plain, resulting in some degree of water movement through low-permeability units that occur between most of the major aquifers. When LAS water levels are substantially lower than UAS water levels (creating a downward gradient), there may be substantial leakage of UAS water into the LAS through the confining clays. Likewise, a downward pressure gradient can exist between the Semi-perched aquifer and the Oxnard aquifer when heads in the shallow confined Oxnard aquifer are lowered (either regionally by drought conditions or locally by pumping wells). The movement of poor quality water from the semi-perched zone to the Oxnard aquifer has been documented in some locations, with abandoned or improperly constructed wells being a notable pathway for this downward flow (Izbicki, 1992; Stamos et al, 1992).

The highly-permeable deposits of the UAS are relatively flat lying across approximately the upper 400 feet of the Oxnard Plain. In the northern Oxnard Plain heads are often similar in the Oxnard and Mugu aquifers, but heads in the Mugu are considerably deeper in the greater area surrounding Mugu Lagoon. Deposits of the LAS are generally finer-grained and have been deformed by folding and faulting in many areas. An uneven distribution of pumping, along with structural and stratigraphic changes within the deposits of the LAS result in varied heads among the deep wells across the Oxnard Plain and Pleasant Valley.

3.3.7 PLEASANT VALLEY

Pleasant Valley is bounded to the south by the Santa Monica Mountains, to the north by the Camarillo Hills, and to the west by the Oxnard Plain. The Bailey fault runs along the base of the Santa Monica Mountains, and the Camarillo fault along the Camarillo Hills to the north.

The Pleasant Valley basin is differentiated from the Oxnard Plain basin by a general lack of UAS aquifers (Turner, 1975). The UAS is composed of alluvial deposits about 400 feet thick. In Pleasant Valley much of the UAS is fine grained and not extensively pumped for water supply (Turner, 1975; Hanson et al, 2003). Although where coarse-grained deposits are present, wells in the UAS underlying Pleasant Valley can yield large quantities of water to wells.

The LAS is composed of the Hueneme, Fox Canyon, and Grimes Canyon aquifers to a depth of about 1,400 feet. The Hueneme aquifer is composed of alternating layers of sand and finer grained deposits. The Fox Canyon and Grimes Canyon aquifers are composed of thick sequences of relatively uniform marine sand. The Fox Canyon aquifer is the major water-bearing unit in the basin.

In Pleasant Valley the LAS is surrounded and underlain by partly consolidated marine deposits and volcanic rocks. Marine deposits are present in the Camarillo Hills and in the western edge of the Santa Monica Mountains near the coast. As a result of faulting and uplift of the underlying marine deposits near Mugu Lagoon the LAS is not hydraulically connected to the Pacific Ocean in this area (Izbicki, 1996a; Hanson et al., 2003). Volcanic rocks consisting of basalts, submarine volcanic flows, and debris flows are present in the Santa Monica Mountains along the southern edge of the valley (Weber et al., 1976). The underlying marine deposits and volcanic rocks both contain high-chloride water.

Under predevelopment conditions groundwater movement in the UAS and LAS was likely from recharge areas in the eastern part of Pleasant Valley toward the Oxnard Plain to the southwest. The LAS in Pleasant Valley appears to be fairly isolated from sources of recharge, and the time since recharge of the ground water ranges from 3,000 to more than 6,000 years before present (Izbicki, 1996b). Groundwater age increases with depth and water within deeper aquifers has contacted aquifer material longer, reacting to a greater extent with these materials than water in overlying aquifers. Over the past two decades water levels in two wells in northern Pleasant Valley have recovered more than 250 feet. The re-establishment of surface flow in Arroyo Las Posas that subsequently percolates at the northern margin of the basin is now recognized as a source of recharge to the basin.

High-chloride concentrations are present in water from wells throughout Pleasant Valley, especially along the southern edge of the valley near the Bailey Fault. Wells yielding high-chloride water in this area may have been drilled too deep and directly penetrated deposits having high-chloride water, or high-chloride water may have invaded deeper freshwater aquifers from surrounding and underlying deposits as a result of pumping. However, despite their isolation from sources of ground water recharge, chloride concentrations in water from deep wells in Pleasant Valley increase during dry periods when ground-water pumping increases. Conversely, chloride concentrations decrease during wetter periods when alternative sources of irrigation water are available from surface supplies and groundwater pumping decreases. Regardless of the source, changing hydraulic pressure as water levels within the lower aquifer system decline as a result of pumping wells, especially during dry periods, may increase chloride concentrations in water produced from deeper wells if the proportion of high-chloride water yielded to the well from underlying deposits increases (Izbicki et al., 2005a). In addition to water from surrounding and underlying rocks, irrigation return also may contribute to high chloride concentrations in deep wells that are partly screened in the upper aquifer system. More recently, groundwater recharge from Arroyo Las Posas in the northern portion of the basin has been recognized as an additional source of salt in the basin.

3.3.8 LAS POSAS

The West Las Posas basin lies adjacent the northeast Oxnard Plain in the area south of South Mountain and north of the Camarillo Hills. The basins generally consists of a broad alluvial plain sloping to the south, and is drained by Beardsley Wash which flows west around the Camarillo Hills.

Only the western portion of the West Las Posas basin lies within United's District boundary. Tree crops are the dominant land use in this agricultural area. Much of this area is served by groundwater imports from the Oxnard Plain, but some agricultural pumping is reported from deep wells near Beardsley Wash and the South Mountain foothills.

Most groundwater production in the West Las Posas basin is from deposits of the San Pedro Formation. Beneath most of the Las Posas Valley, the upper San Pedro Formation consists of low permeability sediments with lenses of permeable sediments which are age-equivalent to Hueneme Aquifer on Oxnard Plain (DWR, 1975). The permeable lenses form isolated, yet, locally important water sources. The water-bearing zones in the upper San Pedro Formation are not well connected. Some recharge to the deeper Fox Canyon aquifer may source from downward leakage from the upper San Pedro Formation. Many wells in the Las Posas Basin are perforated in the Fox Canyon aquifer, making it the principal water-bearing unit (Mukae, 1988). The FCA is exposed almost continuously along the southern flank of South Mountain. South of the outcrop, beds of the Fox Canyon aquifer dip below the valley and are folded into a series of anticlines and synclines. Groundwater in the Fox Canyon aquifer exists under confined conditions beneath the valley and unconfined conditions at the valley margins where the aquifer is folded upward and exposed at the surface. Much of the groundwater recharge to the western portion of the West Las Posas basin is believed to source from the Oxnard Plain. Minor amounts of recharge are derived likely from infiltration of precipitation and runoff in the outcrop areas.

4 ANNUAL HYDROLOGIC CONDITIONS

This section details the range of hydrologic conditions observed throughout United's district boundaries in the year 2011. While the emphasis is placed on surface water and groundwater conditions over the past year, some discussion is devoted to the comparison of recent conditions to conditions documented in the historical record. Recorded rainfall totals were commonly several inches greater than average, but significant storm events occurring in December 2010 and March 2011 resulted in high base flows in the Santa Clara River and its major tributaries. The groundwater response to the above-average flow in stream channels, increased surface water deliveries and reduced pumping associated with the wet conditions was favorable.

4.1 PRECIPITATION AND EVAPOTRANSPIRATION

United participates in data collection in partnership with the Ventura County Watershed Protection District's three rainfall gauges, two of which are also evaporation stations. The VCWPD maintains approximately 125 gauges around the county (Figure 4.1-1). United's gauges are located at the field offices in Saticoy, El Rio, and at the guard station at the Lake Piru. United also maintains records from the gauge at the office in Santa Paula for its own use. United's monitoring stations showed that precipitation was about 136% of normal for the water year, with December and March

accounting for 65% of the rainfall. Lake Piru recorded 28.48 inches of rainfall, approximately 8.6 inches more that the average received at that location, and in the top 20% in terms of rainfall totals for this station.

Table 4-1 Monthly Precipitation for water year 2011

Monthly Precipitation Data - 2010-11 Water Year													
Gauge Location	**Gauge no.**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
El Rio	**231**	1.87	1.01	8.43	0.53	2.34	4.58	0.00	0.55	0.10	0.00	0.00	0.00
Lake Piru	**160**	2.04	1.54	11.92	0.62	5.27	6.22	0.06	0.80	0.01	0.00	0.00	0.00
Santa Paula	**245**	2.11	1.07	9.61	0.30	3.64	6.03	0.00	0.89	0.14	0.00	0.00	0.00

4.2 SURFACE WATER

The Santa Clara River Watershed is extensively monitored by multiple agencies for rainfall, daily stream discharge and flood flows. Data for many of the monitoring sites goes back to the early 1900s giving a long period of record for comparison purposes. The year 2011 overall would fall in the normal to wet category in terms of both precipitation and run-off. Below is a brief discussion of how 2011 compares to the historical record. Daily and monthly data for all the sites discussed can be obtained on-line at websites maintained by the USGS and VCWPD.

4.2.1 SANTA CLARA RIVER SYSTEM

The Santa Clara River is the largest river system in southern California remaining in a relatively natural state. The headwaters start on the northern slopes of the San Gabriel Mountains and the river flows approximately 84 miles to an estuary and river mouth at the Pacific Ocean near Ventura Harbor on the northern Oxnard Plain. The major tributaries include Castaic Creek and San Francisquito Creek in Los Angeles County, and Sespe, Piru and Santa Paula creeks in Ventura County. While the Los Angeles portion of the watershed accounts for 40% of the total area, it only produces about 20% of the total river flow, with dry-season base flows sustained by discharges from wastewater treatment plants and rising groundwater from the Eastern groundwater basin. As mentioned in other sections of this report, even though 2011 was wetter than most years, large sections of the main stem of the Santa Clara River remained dry for most of the year.

4.2.1.1 FLOW IN THE SANTA CLARA RIVER WATERSHED

Surface water flows in the Santa Clara River system were well above normal for the 2011 calendar year. The season started out wet with an early storm in December 2010, before the reporting period for this report. Figure 4.2-1 shows monthly flows in each of the tributaries. The storm peaked Sespe flows over 3,000 cfs a couple of times before runoff subsided in late February. Two

smaller storms were then followed by a large March storm where the Sespe's peak flow exceeded 35,000 cfs. Flows in the Sespe were over 1,000 cfs for the next 10 days. Figure 4.2-2 shows the monthly flows in the Sespe compared to the monthly average flows. The response to the March storm was much different in the Piru watershed due to the elevation difference between the two watersheds. The higher elevations in the Piru watershed accumulated several feet of snow. The storm resulted in flows peaking at about 600 cfs in Piru Creek at Pyramid Lake. The runoff then subsided to less than 200 cfs over the next couple of days. A warm period then melted the snow, creating diurnal fluctuations in runoff of up to 600 cfs in Piru Creek (Figure 4.2-3).

The USGS station 111090000, Santa Clara River near Piru, measures the entire contribution from Los Angeles County's portion of the watershed that flows into Ventura County. This station recorded a peak flow of nearly 9,000 cfs in the March storm. Flows subsided to a little over 300 cfs within a couple of days after the peak. A large release from Castaic Lake in the month of April brought the average flow up to 11,000 AF that month.

Table 4-2 Total Discharge for various stream flow stations

USGS/VCWPD Stream flow Stations	Total Discharge for 2011
	AF
Santa Clara River Near Piru USGS Sta. 11109000	61,824
Piru Creek Above Santa Felicia Dam USGS Sta. 11109600	61,787
Piru Creek Below Santa Felicia Dam USGS Sta. 1110900	36,175
Sespe Near Fillmore USGS Sta. 1111300	124,500
Santa Paula Creek VCWPD 709	29,700
Santa Clara River at Victoria VCWPD 723	121,052

The natural runoff in most of the tributary watersheds was about 130% to 140% of average. The main exceptions were flows coming from Los Angeles County which were 156% of the average, and flows below Santa Felicia Dam which were near normal. Los Angeles County's flows may have been proportionally higher than the other watersheds for two reasons. Wastewater discharge to the river has been gradually increasing since the late 1970s, and the DWR did not appropriate any storm inflow into Castaic Lake in 2011 because all stored inflows could be beneficially used downstream in April and May. See Section 2.2.8 for discussion concerning the Castaic flood flow release.

4.2.1.2 WATER QUALITY

United maintains a surface water quality monitoring program and collects samples from a number locations at frequencies ranging from quarterly to every two weeks. Sampling sites are generally located on the Santa Clara River near groundwater basin boundaries and at the major tributaries near the confluence with the river. Additional water quality sampling sites include the Santa Clara River at the Freeman Diversion and the weir where surface water arrives at United's El Rio

recharge basins. Sample analysis commonly consists of either a full inorganic general mineral suite or several key constituents such as TDS, chloride and nitrate. This surface water quality monitoring provides documentation of variations in surface water quality and information on the quality of water that is recharging the groundwater basins of the District. Sampling is conducted every three month at most of the sites, but more frequently at some key locations (Santa Clara River: every month near County Line and every two weeks at Freeman Diversion).

Water quality at the various sampling sites throughout the District tends to vary seasonally, with the lowest annual mineral concentrations commonly recorded in the winter and spring when flow is higher. Results from United's 2011 surface water sampling are shown on Figures 4.2-4 and 4.2-5, where the annual recorded maximum concentrations of chloride and TDS, respectively, are displayed over the annual minimum values. The range in values is from four seasonal samples at most locations, so the true range in quality in the water bodies is likely greater than what is documented.

Water quality in Piru Creek is influenced by Pyramid Lake located higher in the Piru Creek watershed, which receives large volumes of water from the State Water Project. Water in middle Piru Creek is a blend of State Water and local runoff from the upper Piru Creek watershed. When chloride concentrations in State Water are high, the chloride in middle Piru Creek and Lake Piru can be much higher than what would occur naturally. In 2011 the maximum-recorded chloride above Lake Piru was 57 mg/l, a value lower than many recent years due to lower State Water chloride concentrations and above-average precipitation in the watershed.

Chloride concentrations in the Santa Clara River near the Los Angeles County line are also influenced by chloride in imported State Water, as Castaic Lake Water Agency delivers State Water to water retailers in the greater Santa Clarita area. Nearly 50% of the chloride load in wastewater discharges is from the chloride load in delivered water (LACSD, 2008). Additional chloride loading occurs during beneficial use of the delivered water, but loading has been significantly reduced in recent years as the Los Angeles County Sanitation District has managed a successful campaign to remove thousands of self-regenerating water softeners from the community. The Sanitation Districts are trying to satisfy regulatory requirements for the quality of their effluent, but the approach to be taken is not yet clear as community residents have resisted funding a chloride TMDL proposed by the Sanitation Districts and approved by the Los Angeles Regional Water Quality Control Board in December 2008.

Over the past decade chloride concentrations in the Santa Clara River have varied considerably near the Los Angeles County line as water quality at this location is heavily influenced by discharges from the Valencia Water Reclamation Plant. From the late 1990s through 2003 the discharges from the Valencia plant increased steadily in both volume and chloride, with chloride concentrations exceeding 200 mg/l near the end of this period. Since 2003 chloride concentrations in the discharges have fallen somewhat: however, chloride in the river commonly exceeds the 100 mg/l surface water objective during months without significant rainfall (Figure 4.2-6). The lower chloride concentrations in the Santa Clara River in recent years are largely related to lower chloride

in wastewater discharges from the Valencia WRP (Figure 4.3-6). This is likely the result of lower chloride levels in State Water Project imports and a successful ban of self-regenerating water softeners in City of Santa Clarita area homes. Prior to 1970 the discharge of oilfield brines significantly impaired water quality in the river at this location, but flows associated with this poor water quality were likely minor.

Beginning in January 1999, United has sampled the Santa Clara River near the Los Angeles County line each month for chloride and other analytes. Sampling in 2011 documented chloride concentrations ranging from 79 to 132 mg/l. Chloride concentrations in the water released from Lake Piru ranged from 47 to 59 mg/l over the same time period (Figure 4.2-4). All surface water sample locations recorded lower-than-average chloride in 2011 following the abundant rainfall in the winter and spring.

In recent years both the City of Fillmore and the City of Santa Paula have eliminated discharges of treated wastewater to the Santa Clara River. Santa Paula's new treatment plant came on line in 2010 and now utilizes percolation basins for wastewater disposal. Fillmore completed a new plant in 2009 and now distributes reclaimed water to both percolation basins near the plant site and a network of subsurface irrigation systems constructed in parks and school fields throughout the City. The City of Fillmore has banned installation of self-regenerating water softeners as part of its efforts to reduce chloride loading to the watershed. There are now no Ventura County water reclamation plants discharging flow to the Santa Clara River. Continuous river flow from Los Angeles County to the Freeman Diversion is uncommon, but when there is connection flows are usually high in the lower watershed and the recycled water component sourcing from Los Angeles County is very minor. The maximum-recorded chloride concentration in the Santa Clara River at Freeman Diversion in 2011 was 69 mg/l (Figure 4.2-4).

United frequently monitors water quality in the Santa Clara River at the Freeman Diversion, the point where water is diverted from the river for either direct deliveries to agricultural users or groundwater recharge in the Oxnard Forebay. Samples are collected at the Freeman Diversion approximately every two weeks to confirm that the water is acceptable for use in both aquifer recharge and for irrigation deliveries. The TDS and chloride content of water in the river at this location exhibits a strong negative correlation with flow, with higher flows being less mineralized (Figure 4.2-7 and Figure 4.2-8). Under dry conditions groundwater discharge from the Fillmore basin comprises a large portion of the river flow at the Freeman Diversion. Under wetter conditions tributary flow, most notably from Sespe and Santa Paula Creeks, contribute flow to the lower river and improves water quality compared to low-flow conditions. High river flows resulting from the direct runoff of precipitation commonly has the lowest dissolved mineral content, as does the recession limb of hydrographs from large flow events (Figure 4.2-7). United commonly diverts large volumes of water from the river for groundwater recharge during these periods of high flow and good water quality. Recorded TDS concentrations at the Freeman Diversion ranged from 570 to 1150 mg/l in 2011 (Figure 4.2-5).

Nitrate concentrations in the Santa Clara River at Freeman Diversion show some negative correlation with flow but concentrations are routinely low in the river during both high and low flows (Figure 4.2-9). A weak seasonal signature has been observed, with nitrate concentrations rising slightly in the fall (UWCD, 2008). For the 26 samples collected at Freeman Diversion in 2011 the maximum-recorded nitrate concentration was 8.4 mg/l, well below the CA DPH health standard of 45 mg/l.

The County of Ventura maintains and operates composite sampling device at the Freeman Diversion, and samples storm flow and dry weather base flows several times per year. These samples are analyzed for a broad suite of organic contaminants and metals as part of a storm water quality program required by the Los Angeles Regional Water Quality Control Board. Detections of organic contaminants such as pesticides are uncommon and generally of low concentration (VCWPD, 2010)

4.2.2 CALLEGUAS CREEK

United does not actively gauge or sample surface water in the Calleguas Creek watershed. Much of the monitoring activity in the Calleguas Creek watershed is currently associated with the Salts TMDL under development for the watershed.

4.3 GROUNDWATER

Groundwater is utilized extensively for municipal and agricultural use throughout the boundaries of United Water Conservation District, as imported water supplies are unavailable over much of this area. United has a responsibility to monitor conditions in the basins throughout the District so that the basins are understood and managed as needed. Many small water supply projects are completed without United's direct involvement, but proponents of most large water projects engage United's support in some way (e.g., data sets, technical support, financial assistance, etc.).

The following sections detail 2011 basin conditions within the eight groundwater basins which fall wholly or partially within United's District boundaries. Following the favorable recharge conditions in the watershed in the winter and spring of the year, and large releases from Lake Piru and Castaic Lake, groundwater conditions were generally good compared to other recent years. Some discussion in the following section is devoted to comparing current conditions to past periods of drought, or periods pre-dating some major water supply projects within the District.

4.3.1 PIRU BASIN

The Piru basin has the capacity to rapidly accept water from the channel of the Santa Clara River and tributary streams. Some component of the water stored in the basin is slowly discharged to the downstream Fillmore basin, so that in some ways the Piru basin acts as a "forebay" to downstream groundwater basins in the Santa Clara River Valley. Surface water discharge of rising groundwater

at the west end of the basin is greater when water levels are higher in the downstream portions of the basin. Groundwater elevations tend to remain well above historic lows, but over the past decade chloride impacts sourcing from Los Angeles County have migrated down past the midpoint of the basin.

4.3.1.1 WATER LEVELS

Historical groundwater elevations for United's Piru basin key well, located northwest of the confluence of Piru Creek and the Santa Clara River are shown on the hydrograph in Figure 4.3-1. The historical record for this well shows that groundwater elevations in the Piru basin fluctuate dramatically, and that the basin is capable of rapid recovery of water levels following drought periods. Water level recovery at this location is largely related to channel recharge associated with high and prolonged flow in the Santa Clara River and in Piru Creek, such as that which occurs during reservoir releases or large winter storms.

The basin fills in wet years such as 1998 and 2005, as shown by the flat-topping of groundwater elevations at 620 feet. Although 2011 was a moderately wet year the basin did not fill to historical highs. The 2011 recorded high groundwater elevation at United's key well is approximately 12 feet lower than recorded high groundwater elevations. The groundwater elevation recorded in this well in 1991 was 510 feet above sea level, at the end of a period of drought.

Piru basin groundwater levels have benefited from the recharge of recycled water discharged to the Santa Clara River by water reclamation plants in Los Angeles County. Historically the Santa Clara River has maintained perennial flow in the vicinity of Blue Cut and the County line, with the flow sustained by groundwater discharge from the Eastern groundwater basin. The City of Santa Clarita began importing State Water in 1980, and steady growth in that community resulted in steady increases in wastewater discharges until recent years, when discharge has diminished slightly. United's fall conservation releases from Lake Piru provide an additional source of recharge to the basin. Release volumes vary year-to-year, and variable channel conditions affect the percentage of the released water that percolates in the Piru basin. Recharge through the channel of Hopper Creek is likely another source of significant recharge during wet years like 2011.

Groundwater elevation contours were interpreted from measured groundwater elevation highs from the spring of 2011 and groundwater elevation lows from the fall of 2011, and are shown in Figures 4.3-2 and 4.3-3 respectively. Groundwater flow is consistently from east to west, roughly following the land surface gradient of the river channel. Depths to water are greater along the northern portions of the basin where alluvial fan deposits elevate the land surface. Groundwater elevations were similar in the spring and fall of 2011, in part due to a large fall release from Lake Piru and a late spring release of stored runoff from Castaic Lake.

The tight contours shown in the eastern Piru Basin, just west of United's District boundary, indicate that this eastern portion of the basin is an area of significant recharge. This is the area where surface water sourcing from Los Angeles County infiltrates to groundwater and the river often goes

dry. Spring 2011 groundwater elevations are approximately 20 feet higher than in fall 2011 in this area.

Groundwater rises near the constriction at the downstream west end of the basin, contributing flow to the Santa Clara River. Groundwater elevations near the constriction at the west end of the basin are historically more stable than those in the central and eastern portions of the basin. Recorded groundwater elevations are approximately the same in this area in the spring and fall of 2011. The contours also show groundwater flow to the Fillmore basin to the west.

4.3.1.2 GROUNDWATER EXTRACTIONS

Reported groundwater extractions from 101 active wells in the Piru Basin totaled 11,700 acre-feet for the 2011 calendar year. This is 720 acre-feet less than the historical average for the period 1980 to 2011, the period of available records. A portion of the Piru basin extends east of United's District boundary and any pumping from this portion of the basin is not reported to United. The historical annual extractions for the Piru basin are shown in the histogram in Figure 4.3-4. Only a small percentage of groundwater pumping in the Piru basin is for municipal and industrial use, consistent with agriculture being the dominant land use within the basin.

Figure 4.3-5 is a map showing reported groundwater extractions from individual wells in the Piru Basin for the 2011 calendar year. Pumping magnitude is indicated by dot size and color. Agriculture is the predominant land use within the Piru basin, and pumping is shown to be distributed throughout the basin. Few active wells exist along the southeastern margin of the basin, and some crops here are irrigated with water piped in from other areas. Two private mutual water companies operate within the basin. The Piru Mutual Water Company diverts water from Piru Creek for agricultural use in the north-central portion of the basin, and Warring Water Company pumps water primarily for domestic use in the town of Piru.

In some canyon and upland areas, orchards are irrigated with groundwater pumped from lower areas of the basin and piped to higher elevations. In recent years a large number of orange orchards have been removed and replaced by row crops or box tree nurseries.

The primary losses of groundwater from the Piru basin are the result of discharge of groundwater to the Santa Clara River at the western boundary of the basin, the subsurface outflow of groundwater at the western boundary of the basin and extraction of groundwater by wells.

4.3.1.3 WATER QUALITY

Over the past decade the main water quality concern in the Piru basin has been impacts associated with high chloride concentrations in the Santa Clara River flows sourcing from Los Angeles County. Discharge from the Valencia Water Reclamation Plant located next to the river at Interstate 5 significantly influences the flow and water quality of this reach of the river, which normally percolates completely in the eastern Piru basin (UWCD, 2006; CH2M Hill, 2006). The chloride

concentration of plant discharges began to increase in the late 1990s and peaked at over 210 mg/l in 2003 (Figure 4.3-6). The chloride plume associated with these discharges has made a steady advance with groundwater flow down the Piru basin. The extent of chloride impacts is now approaching Hopper Creek in the western third of the basin (Figure 4.3-7). Irrigation of salt-sensitive crops such as strawberries and avocado with water over 100 mg/l chloride is generally not recommended, and growers in Ventura County remain concerned about the westward progression of these impacts. More recently, chloride concentrations in Los Angeles County wastewater discharges are improving, the result of a successful campaign to remove self-regenerating water softeners from Santa Clarita residences and lower chloride concentrations in imported State Water Project deliveries. In the western portion of the basin chloride concentrations are generally less than 70 mg/l, indicative of background levels within the basin (DWR, 1989).

The Piru basin generally does not have problems with nitrate contamination, and samples collected in 2011 show only one well exceeding the MCL of 45 mg/l (VCWPD, 2012). Many wells record TDS concentrations of 1,200 mg/l or less, but some wells record TDS concentration twice this value (VCWPD, 2012). Water quality of the Piru basin is characterized more thoroughly in the revised Groundwater Management Plan for the Piru and Fillmore basins (Piru/Fillmore Groundwater Management Council, 2011).

4.3.2 FILLMORE BASIN

The City of Fillmore overlies the northeast portion of the Fillmore basin, and relies entirely on groundwater for water supply. Sespe Creek is the largest tributary to the Santa Clara River and enters the basin from the north. Sespe Creek is an important source of recharge to the basin, providing high-quality water from a largely undeveloped watershed draining the southern slopes of the Pine Mountain complex in the Los Padres National Forest. Groundwater supports extensive acreage of agriculture in the basin, ranging from row crops and nursery stock near the valley floor to citrus and avocado plantings at both low and high elevations. Discharge to the downstream Santa Paula basin is thought to be significant, especially during high groundwater conditions such as those observed in 2011.

4.3.2.1 WATER LEVELS

Many water levels in the Fillmore basin behave in a manner similar to the Piru basin. Water levels from a key well in the Bardsdale area shows that water levels rise to a threshold elevation in significant wet years, as evidenced by the flat topping of groundwater elevations in 1998 and 2005 (Figure 4.3-8). In this vicinity south of the confluence of Sespe Creek and the Santa Clara River, groundwater elevations do not fluctuate as dramatically as those in the Piru basin.

Groundwater elevations at United's key well for the basin show that in 2011, a moderately wet year, the basin did not fill completely. The 2011 recorded high groundwater elevation at United's key well is approximately 3.1 feet lower that the 1998 recorded high groundwater elevation, and

approximately 26 feet higher than the recorded low groundwater elevation during the 1987 to 1991 drought.

Fillmore basin groundwater levels likely benefit from increased discharge from the Piru basin as that basin has sustained fairly high water levels in recent decades. The Fillmore basin also benefits from United's fall conservation release from Lake Piru which helps stabilize groundwater elevations. The Fillmore basin receives most of its recharge from the Santa Clara River and Sespe Creek.

Groundwater elevation contours are shown for spring and fall 2011 in Figures 4.3-2 and 4.3-3. Groundwater flow is predominantly east to west in the area of the Santa Clara River alluvium. In the Pole Creek fan area underlying the City of Fillmore, groundwater flow is generally westerly, but few wells exist here, which constrains interpretations of groundwater flow. Well control in the Sespe Upland area is also poor, but groundwater flow here is thought to be predominantly north to south. Along the valley floor groundwater gradients are quite uniform and are similar for the spring and fall of 2011. The contours merge at the west end of the basin where the groundwater flow is east to west. Groundwater elevations in wells located in the Sespe Upland area and in the Pole Creek fan area of the basin generally exhibit more variability than well wells along the valley floor.

The relatively tight contours shown in the eastern Fillmore Basin near the basin boundary show a steeper gradient as groundwater moves from the constriction of the Piru narrows and moves into the basin. In this area surface water commonly infiltrates to groundwater, resulting in diminished surface flow and a greater component of flow as groundwater. As in Piru basin, groundwater is forced to the surface near the downstream end of the Fillmore basin as geologic structure constricts the main aquifer units of the Fillmore basin. In this area groundwater elevations are more stable than elsewhere in the basin. At this discharge area of the basin contouring shows that spring and fall 2011 groundwater elevations are approximately the same (Figures 4.3-2 and 4.3-3). Extensive wetlands in this area are clearly visible on aerial imagery.

4.3.2.2 GROUNDWATER EXTRACTIONS

Reported groundwater extractions from 266 wells in the Fillmore Basin totaled approximately 40,855 acre-feet for the 2011 calendar year. This is 3,337 acre-feet less than the historical average from 1980 to 2011. The historical annual extractions for the Fillmore basin are shown in the histogram in Figure 4.3-9. Recently and historically, agriculture has been the predominant user of groundwater in the basin.

Figure 4.3-5 is a map depicting reported groundwater extractions from individual wells in the Fillmore Basin for the 2011 calendar year. This graphic shows that: 1) the City of Fillmore pumps from three wells located in the north Pole Creek fan area near Sespe Creek and no longer pumps from wells located near the Santa Clara River; 2) there are numerous wells in the Bardsdale area pumping small volumes of water, as there is no mutual water company distributing potable water in this area; 3) few active wells in the Sespe Upland area and most active wells are located at lower elevations; and 4) Groundwater extractions from wells at the Fillmore Fish Hatchery located at the

eastern boundary of the basin accounts for a significant portion of the groundwater extractions of the basin. In 2011 Fillmore Fish Hatchery wells reported pumping of 9,146 acre-feet (22% of the total groundwater extractions from the basin).

Twelve mutual water companies operate in the Fillmore Basin, serving water primarily for irrigated agriculture. Fillmore Irrigation operates a surface water diversion on Sespe Creek, supplying water to nearby agricultural lands. Several water companies operate wells near the valley floor and pump water to higher elevation where groundwater is not as plentiful. Plantings in Timber Canyon and many areas of the Sespe Uplands are served by such arrangements. In recent years many orange orchards at lower elevations have been removed and replaced by row crops or box tree nurseries. Plantings of citrus and avocado remain the primary agricultural land use at higher elevations.

Discharge of groundwater to the Santa Clara River at the western boundary of the basin, subsurface outflow of groundwater to the Santa Paula Basin and extraction of groundwater by wells are the three primary losses of groundwater from the basin. The extensive wetlands and stands of *Arundo donax* (an invasive giant cane) at the west end of basin likely transpire large volumes of water. By some estimates *Arundo donax* may transpire up to six times the amount of water as native vegetation (CA Invasive Plant Council, 2011)

4.3.2.3 WATER QUALITY

The Fillmore basin is not known for having any pervasive water quality problems. TDS concentrations can be somewhat elevated in some locations, as in other groundwater basins along the Santa Clara River Valley. The City of Fillmore no longer uses wells near the Santa Clara River, favoring locations near Sespe Creek where TDS tends to be lower. Deeper aquifer units may have elevated concentrations of iron and manganese, a common occurrence throughout Ventura County.

Chloride concentrations from samples collected in 2011 are shown on Figure 4.3-7. Recorded concentrations exceeding 70 mg/l are uncommon, and limited to the area located south of the Santa Clara River. Concentrations in the 40s and 50s in the downstream/discharge portion of the basin are likely indicative of background chloride concentrations in the basin.

4.3.3 SANTA PAULA BASIN

Groundwater storage in the Santa Paula basin is generally less dynamic than in surrounding basins. Pumping in the Santa Paula basin is managed by a stipulated Judgment which assigns pumping allocations to each basin pumper that restricts the amount or groundwater each pumper can extract (within a seven-year rolling average). The City of Santa Paula occupies the eastern portion of the basin and relies entirely on groundwater for its water supply. Extensive water delivery systems have long existed in the basin, delivering water to areas with poor water quality or areas of the basin that are not readily recharged.

4.3.3.1 WATER LEVELS

Long-term records of groundwater elevations in the Santa Paula Basin indicate that water levels do not recover as readily as in the Piru and Fillmore basins. The channel of the Santa Clara River is located south of the Oakridge fault in the central portion of the basin, and overlies sediments of low permeability. The basin likely receives significant recharge as underflow from the Fillmore basin. Recent gauging of Santa Paula Creek and the Santa Clara River suggests the amount of recharge the basin receives from these sources, at least during low-flow conditions, is limited. An extensive flood control project on lower Santa Paula Creek, completed in the late 1990s, may have negatively affected the amount of recharge derived from this source.

Historical groundwater elevations dating from 1923 to present are shown in a hydrograph for United's key well for the basin (Figure 4.3-10). The well is located near Peck Road and Highway 126 in the eastern portion of the basin. The hydrograph shows that groundwater elevations in spring 2011, a moderately wet year, were higher than in spring 2010, a year of nearly average precipitation. The hydrograph also shows that the recorded high groundwater elevation for 2011 was approximately 8 feet lower than the recorded high groundwater elevation in 1998, and approximately 30 feet higher than the recorded low groundwater elevation during the 1987 to 1991 drought.

Evaluation of the key well hydrograph and other the hydrographs for other wells located throughout the basin show that water levels in many of the wells (43 of 57 wells) in both the eastern and western portions of the Santa Paula basin failed to fully recover to 1998 levels after near-record precipitation in 2005. This lack of complete recovery is consistent with an observed long-term, gradual decline in basin groundwater elevations (UWCD, 2009; Santa Paula Basin Technical Advisory Committee, 2011).

Figure 4.3-11 and Figure 4.3-12 show groundwater elevation contours in the Santa Paula Basin for spring and fall 2011, respectively. The spring contours represent the annual basin high groundwater elevations and the fall contours represent the annual basin low groundwater elevations. The difference between the spring high groundwater elevations and the fall low groundwater elevations is approximately 10 feet throughout the basin.

The contours show a general east to west flow direction with groundwater underflow from the Fillmore basin to the Santa Paula Basin and groundwater underflow from the Santa Paula Basin to the Mound basin. The relatively tight contours just west of the Santa Paula-Fillmore boundary show an area of recharge to the basin. The complex subsurface geology related to extensive faulting in the most western portion of the basin complicates the interpretation of groundwater flow in this area.

4.3.3.2 GROUNDWATER EXTRACTIONS

A histogram of reported basin pumping from 1980 to 2011 is shown in Figure 4.3-13. In recent years municipal pumping has accounted for more than 20% of the total pumping from the basin. The total reported groundwater extractions from 124 active wells in the Santa Paula Basin totaled 24,265 acre-feet for the 2011 calendar year. This is 1,432 acre-feet below the long-term average of 25,697 acre-feet. A 2003 basin study titled "Investigation of Santa Paula Basin Yield" was conducted by experts from the City of Ventura, Santa Paula Basin Pumpers Association and United. The study suggested that the yield of Santa Paula basin is probably near the historic average pumping of about 26,000 acre-feet per year.

Figure 4.3-14 is a map showing groundwater extractions by wells in the Santa Paula Basin in year 2011. The map shows significant pumping within the Santa Paula city limits and near the Fillmore basin boundary. Numerous wells report pumping in agricultural areas in the central portion of the basin. Few active wells exist north, west and south of this vicinity. In the western third of the basin, significant pumping is reported south of Highway 126 and west of Ellsworth Barranca, and in the area north of Highway 126 and west of Brown Barranca.

Several private irrigation companies are active in the Santa Paula basin, operating wells and delivery pipelines that distribute large quantities of water around the basin. Farmers Irrigation Company pumps groundwater primarily from the eastern portion of the basin and distributes the water by pipeline for agricultural use in areas of the central and western basin. Also affiliated with Farmers Irrigation Company are Canyon Irrigation Company and Thermal Belt Mutual Water Company. Canyon Irrigation operates the Harvey Diversion on Santa Paula Creek, and some wells in the eastern basin, delivering water to agriculture in the area of Santa Paula Canyon. Thermal Belt Mutual pumps groundwater from the east basin for pipeline distribution for agriculture in the Foothill Road area and upland area of the north central basin. Alta Mutual Water Company extracts water from the Saticoy area in the west basin, and delivers water primarily to agricultural areas north of Telegraph Road. These extensive water delivery systems were largely established to deliver water to areas of the Santa Paula basin having poor quality groundwater. In the canyons and foothills along the northern flank of the basin, both well production and water quality are generally poor.

Farmers Irrigation Company, Thermal Belt Mutual Water Company and Canyon Irrigation Company pumped a combined total of 9,125 acre-feet in 2011. This pumping totaled approximately 38% of all groundwater extracted from the basin in 2011.

4.3.3.3 WATER QUALITY

Water quality is fairly variable throughout the Santa Paula basin, but water quality is generally worse in the western portion of the basin. The maximum recorded TDS concentrations for Santa Paula basin wells in calendar year 2011 are shown in Figure 4.3-15, with the highest concentrations recorded in the west. In these wells sulfate is commonly a large contributor to TDS. Deeper wells

in the basin tend to have elevated iron and manganese concentrations, and both the City of Santa Paula and City of Ventura operate treatment facilities to reduce these constituents in delivered municipal water. Recorded nitrate concentrations from wells within the basin are generally low, with one well measuring nitrate over the MCL of 45 mg/l in 2011.

United conducts groundwater quality monitoring at the two nested monitoring well sites in the Santa Paula Basin, and in several production wells in the basin. Mineral concentrations are observed to vary with groundwater elevation in some wells. More thorough characterizations of groundwater quality in the Santa Paula basin can be found in other publications (DWR, 1989; Santa Paula Basin TAC, 2011).

4.3.4 MOUND BASIN

The Mound Basin is located in the westerly portion of the District and has experienced over time a progression of groundwater use that was historically dominated by agriculture, followed by a period of time when municipal and industrial pumping was dominant, and most recently a return to greater pumping by agriculture than by municipal and industrial users.

4.3.4.1 WATER LEVELS

Historical groundwater levels for a key monitoring well in the Mound Basin are shown in Figure 4.3-16. Measured water levels have varied over about a 90-foot range over the period of record for this well, located in the eastern portion of the basin near Kimball Road. An extended period of low water levels was recorded in the late 1980s and early 1990s when water levels declined to below sea level. Water levels recovered in the 1990s and generally have remained more than 15 feet above sea level over the past decade, except when falling below sea level in 2004.

Recharge of the aquifers in this basin comes from multiple sources such as direct precipitation, mountain-front recharge, and subsurface flow from adjoining basins (e.g., Santa Paula, Oxnard Forebay, and Oxnard Plain). Recharge from the Oxnard Forebay and Oxnard Plain is thought to be significant, most notably during periods of high water levels in these adjacent basins (GTC, 1972; UWCD, 2012b).

Groundwater elevation records exist for nearly 60 active and historic wells located within the Mound Basin. A number of important wells have water levels dating to the late 1920s, allowing an evaluation of long-term water level trends within the basin. However, the distribution of wells is heavily skewed towards the southern half of the basin, with relatively few wells existing north of Telephone Road. In the western portion of the basin wells are concentrated along Olivas Park Drive and near the railroad tracks south of Highway 101. This poor distribution of active and historic wells complicates the assessment of potential mountain-front recharge to the basin from the north. The southern and eastern boundaries of the basin are defined by structural features, and water level records from adjacent areas help assess the nature of the basin boundaries in these

areas. Water level trends for many wells within the basin are similar, with evidence of recharge from adjacent basins to the east and south (UWCD, 2012b). The main groundwater flow pattern is down the axis of the basin from east to west. The slope of the potentiometric surface within the basin is quite flat during dry periods and the gradient increases somewhat following periods of above-average rainfall. During dry periods, groundwater elevations in many wells fall below sea level.

The contouring of past water level conditions is complicated at times by sparse data. Available groundwater elevation data for the spring and fall of 2011 are presented in Figures 4.3-17 and 4.3-18. Increased collection of water level records is recommended in this basin to better define groundwater gradients between this basin and adjacent basins. The recent installation of monitoring wells north of the Santa Clara River near the northwestern margin of the Forebay should be helpful in better defining the flow of groundwater from the Oxnard Forebay to areas north of the Montalvo anticline (see Section 2.1.8). Relatively few wells, however, exist along the southeastern portion of the Mound basin, an area of sparse well records and known structural complexity.

4.3.4.2 GROUNDWATER EXTRACTIONS

The City of Ventura is the major municipal and industrial groundwater pumper in the Mound basin, with its wells concentrated in the area near the Ventura County Government Center. Agricultural pumping was historically the majority use of groundwater in the Mound Basin, but municipal and industrial use exceeded or approximately equaled agricultural use for the period 1999 through about 2006 (Figure 4.3-19). Municipal pumping peaked in 2003 and has declined fairly steadily in recent years, with agricultural use predominating since 2007. Since the mid-1980s agricultural pumping has averaged nearly 4,200 acre-feet per year with a peak annual production of 5,850 acre-feet recorded in 1990. In 2011 reported agricultural pumping totaled 3,120 acre-feet with municipal and industrial pumping reaching 1,525 acre-feet.

4.3.4.3 WATER QUALITY

While the quality of the groundwater produced by most wells within the Mound Basin is suitable for municipal and agricultural uses, the basin is not known for the high quality of its groundwater. Water quality is variable between wells, and many records indicate somewhat elevated concentrations of TDS, sulfate, hardness and other analytes. Water quality appears to be relatively stable among many of the Mound basin wells having long-term water quality records, although some municipal production wells (e.g., Victoria 1 and 2) in the central portion of the basin have been experiencing declining water quality (i.e., increasing TDS values) that currently reach about 1,800 mg/L. Available records from wells nearest the coast do not show evidence of saline intrusion.

A map showing recorded TDS concentrations in Mound basin wells from 2011 is shown as Figure 4.3-20. The map plots TDS (by summation) from production well samples collected by the

Groundwater Section of the Ventura County Watershed Protection District, as well as TDS (by residue) as sampled by United Water and the City of Ventura. Without the sampling by the County's Groundwater Section, coverage in the basin would be very poor. The distribution of sampled wells within the basin for 2011 is better than in most prior years. TDS in the production wells ranged from 1,150 to over 2,200 mg/l. Sulfate commonly contributes roughly half the TDS in these samples, and water quality results are often variable among nearby wells.

4.3.5 OXNARD FOREBAY

The Oxnard Forebay basin is an area of critical importance to the water resources of the Oxnard Plain. This is the unconfined portion of the Oxnard Plain where units of low permeability are generally absent or discontinuous, allowing water to percolate deep into the ground and recharge the underlying aquifers. The basin readily accepts large volumes of recharge water under wet hydrologic conditions. A time series of estimated changes in available groundwater storage within the Forebay is shown in Figure 4.3-21. The graphic shows that storage in the basin can change rapidly, especially when the basin is filling.

Coarse gravel deposits deposited by high flows of the ancestral Santa Clara River are common in the Oxnard Forebay. These gravels have historically been extensively mined, both within the river channel and in nearby upland areas. The high permeability of these coarse alluvial deposits also comprise an ideal substrate for groundwater recharge. Groundwater recharge occurs naturally where water percolates through the bed of the Santa Clara River, and in upland areas near the river where United distributes diverted river water to a series of recharge basins. United's recharge activities are sometimes termed "artificial recharge" because the activities augment the recharge that would naturally occur in this area. The term "managed aquifer recharge" has become more popular in recent years.

Groundwater recharge to the Forebay serves to raise groundwater elevations in this upgradient area of the groundwater flow system for the Oxnard Plain. High water levels in the Forebay increase the hydrostatic pressure in the confined aquifers extending from the margins of the Forebay to the coastal and offshore portions of these continuous aquifer units. While the physical movement of groundwater out of the Forebay is fairly slow, the pressure response in the confined aquifers distant from the Forebay responds more rapidly to significant recharge events in the Forebay. During wet climatic years the Forebay has the ability to quickly accept large volumes of water, allowing storage of surface water that otherwise would be lost from the system. Water stored in the Forebay slowly bleeds out to the outlying areas, flowing naturally from areas of high elevation to areas of lower elevation on the Oxnard Plain and near the coast, and serves to raise or sustain groundwater elevations in wells in downgradient areas. Groundwater extraction by wells, both in the Forebay and in the confined aquifers of the Oxnard Plain, hastens the decline of Forebay water levels as water is removed from the system. Under drought conditions, groundwater elevations in the Forebay may approach sea level, resulting in flattened groundwater gradients and only minor groundwater flow out of the Forebay. Ventura County has not experienced a prolonged

drought since completion of the Freeman Diversion in 1991, and estimates of available storage show the basin has filled to historic highs in subsequent years with above-average precipitation (Figure 4.3-21). Storage estimates suggest little available storage existed in the basin in spring 2011.

4.3.5.1 WATER LEVELS

Groundwater elevation contours for the Upper Aquifer System (UAS) in the spring of 2011 are shown in Figure 4.3-22. An area of closely-spaced contours is shown beneath the Saticoy and Noble recharge basins in the up-gradient portion of the basin. This is an area of groundwater mounding due to United's recharge activities. A fairly uniform groundwater gradient is interpreted to exist beneath the channel of the Santa Clara River. The groundwater elevation contours deflect around the El Rio Spreading Grounds, where in the spring the volume of water recharged at this location greatly exceeded that pumped and delivered to the southern Oxnard Plain. Overall, natural and artificial recharge to the Forebay was abundant in winter and spring 2011, largely related to two large storm events and other lesser storms that resulted in sustained high flows in the Santa Clara River.

Figure 4.3-23 displays UAS groundwater elevation contours for the Oxnard Plain in fall 2011. Groundwater mounding is again apparent beneath the Saticoy Spreading Grounds, as a portion of the water from the fall conservation release from Lake Piru is routed here for groundwater recharge. Southwest of this location groundwater elevation contours show greater spacing than in the spring of the year, and are more consistent with the regional gradient across the Oxnard Plain to the south. Adjacent to the Forebay in the northeast Oxnard Plain groundwater elevations are similar or slightly higher than elevations were in the spring. Water stored in the winter mounding of groundwater within the basin is now flowing to down-gradient areas, and in this year counters the effects of groundwater extractions which normally result in annual water level lows in the fall when pumping exceeds local recharge. The general direction of groundwater flow in the basin remains similar throughout the year. Water level records show a slight pumping depression in the fall beneath the El Rio Spreading Grounds.

Historical water level hydrographs from selected wells in the Forebay are shown in Figure 4.3-24. UAS water levels in the Forebay fluctuate by as much as 100 feet, with groundwater elevations dropping below sea level in drought periods and recovering during wet periods. Historic highs were recorded in a number of wells in recent years, following a number of consecutive wet years and the expansion of United's recharge facilities.

4.3.5.2 GROUNDWATER EXTRACTIONS

Reported 2011 groundwater extractions from the Forebay totaled nearly 18,500 acre-feet. Figure 4.3-25 shows reported extractions for the basin since 1980. Pumping in the Forebay has decreased for five consecutive years, with pumping totals from the past two years being below the

average annual extraction rate of 25,000 AF. Pumping from the Forebay is often more variable than in other basins within the District, caused by the variable amount of groundwater pumping for delivery to the Oxnard Plain and Pleasant Valley basins. Agricultural pumping in 2011 was similar to that in 2010, but the big change from the prior year was a reduction in municipal pumping at the O-H well field at United's El Rio Spreading Grounds. O-H customers used nearly 5,000 AF less water in 2011 compared to the prior year. The reduction in use was partially related to a large construction project which required a realignment of the O-H supply pipeline.

In the 2011 calendar year some 37,800 AF of water were spread for groundwater recharge at the El Rio Spreading grounds. Over this same period 10,740 AF was pumped from UAS wells at El Rio for deliveries to the O-H system.

The distribution of UAS pumping for calendar year 2011 is shown in Figure 4.3-26. Significant pumping is apparent surrounding the El Rio Spreading Grounds, where municipal pumping in the basin is centered. The majority of the pumping in the up-gradient areas of the Forebay is for irrigation purposes, including the pumping on the south side of United's Saticoy Spreading Grounds. Wells screened in units of the Lower Aquifer System are uncommon in the Forebay, and 2011 pumping from LAS wells is shown in Figure 4.3-27.

4.3.5.3 WATER QUALITY

Water quality records from Forebay basin wells near the Santa Clara River and United's recharge facilities show that groundwater quality in these areas is similar to that of the Santa Clara River. The most recharge from the river takes place when flows are high, which is generally when water quality in the river is best. Some characterization of Santa Clara River water quality is included in Section 4.2 of this report. During the dry season when river flows are lower and mineral content is generally higher, much of the diverted surface water is blended with well water and used for irrigation in areas served by the PTP and Pleasant Valley pipelines.

Occasional high nitrate concentrations in UAS wells has historically been the water quality issue causing concern in the Forebay. A definitive evaluation of sources of nitrate and flow paths to area wells has proven difficult, but septic systems and fertilizer from irrigated agriculture are commonly believed to be major contributors of nitrate to the groundwater flow system (UWCD, 1998). The highest nitrate concentrations are often observed during drought periods, when nitrogen inputs continue but the diluting influence of natural and artificial recharge is reduced. High nitrate has also been documented in wells as water levels rise following periods of drought, as nitrogen stored in the vadose zones is mobilized as sediments become saturated by a rising water table. Installation of additional monitoring wells in the Forebay has contributed to the understanding that the highest nitrate concentrations are often observed in the shallowest wells (UWCD, 2008). Once high-nitrate water enters the groundwater flow system its movement is likely very complex. An incomplete understanding of nitrate inputs to the Forebay basin and the complexity of water movement in the unsaturated and saturated zones of the subsurface make predictions of future nitrate impacts to area wells impractical.

Maximum-recorded nitrate concentrations from wells in the Forebay and northern Oxnard Plain in 2011 are shown in Figure 4.3-28. Few samples exceed 23 mg/l, a value half the nitrate MCL of 45 mg/l. A single Forebay well recorded very high nitrate, a shallow monitoring well in the south-central portion of the basin. Near United's Saticoy Spreading Grounds UAS nitrate concentrations ranged from three to eight mg/l, values that match the range of nitrate concentrations recorded for diverted Santa Clara River water spread nearby. The public supply wells in the El Rio community and at the El Rio Spreading Grounds also recorded relatively low nitrate concentrations in 2011.

A major effort to sewer the El Rio community was recently completed, significantly reducing nitrate loading in this areas of shallow unconfined groundwater. Residents and regulators are hopeful that significant nitrate impacts will be avoided in future droughts, but a cautionary statement from a recent UC Davis report on nitrate contamination is repeated here as a reminder that flow paths to production wells are often not well understood, and may be longer and more complex than many might imagine: "Travel times of nitrate from source to wells range from a few years to decades in domestic wells, and from years to many decades and even centuries in deeper production wells. This means that nitrate source reduction actions made today may not affect sources of drinking water for years to many decades" (Harter and Lund, 2012).

4.3.6 OXNARD PLAIN BASIN

Early newspaper accounts suggest that the confined aquifers of the Oxnard Plain were first drilled for water supply wells in the early 1870s. Artesian conditions existed on the Oxnard Plain at this time, and the well installations that received press coverage were wells providing impressive flow at the land surface without a pump in the well. Artesian conditions are believed to have persisted through the late 1800s. The town of Oxnard was established in 1897, and in 1899 a large sugar beet processing facility began operations. The large water demands associated with irrigation of beets and other crops on the Oxnard Plain, along with the growing population and industrial uses, lowered the pressure in the Oxnard aquifer. By the turn of the century widespread artesian conditions were generally absent, requiring wells to be fitted with pumps to lift water from elevations below the land surface (Freeman, 1968).

Over the approximately 110 years since the initial depressuring of the Oxnard Aquifer in the late 1800s, artesian conditions have periodically returned to the Oxnard Plain during wet climatic cycles. Documentation of water levels in the aquifers of the Oxnard Plain are sparse until the early 1930s, but artesian conditions were documented in Oxnard City well #9 in the winters of 1917, 1919, 1922 and 1923 (CA Division of Water Rights, 1928). The early 1940s was a wet period, and widespread artesian conditions likely existed at that time. The year 1945 marked the beginning of a long dry period during which water levels fell across the plain and problems with saline intrusion intensified in coastal areas. These alarming developments at a time of urban and economic growth in Ventura County prompted significant investments in water resource projects, including the O-H well field at El Rio and a pipeline delivery system to urban areas on the coastal plain. In subsequent years pumping patterns continued to change as the City of Oxnard grew. The city once had water supply

wells distributed throughout its service area, but now pumping is centralized in two primary well fields. As farmland around the city margins has converted to urban areas, pumping has generally been transferred to the City of Oxnard's main well field in the northern Oxnard Plain. Much of the population growth in the cities of Oxnard and Port Hueneme has been supported by State Water Project supplies, imported and delivered by Calleguas Municipal Water District.

Widespread artesian conditions were again present on the Oxnard Plain in the late 1990s following the completion of the Freeman Diversion and high precipitation totals in 1993, 1995 and 1998. More recently, artesian conditions periodically existed in coastal areas surrounding Port Hueneme, and are more common in UAS wells than in wells with deeper screened intervals.

Following a period of drought in the 1970s and expansion of the areas impacted by saline intrusion, the Fox Canyon Groundwater Management Agency (FCGMA) was established in 1982 as a local agency with regulatory authority to bring overdraft conditions under control in southern Ventura County. The agency has successfully implemented a number of mandatory cutbacks for production from public supply wells, and agricultural pumpers are required to demonstrate the use of efficient irrigation practices. One early strategy was a shift of pumping from the Upper Aquifer System to the Lower Aquifer System on the Oxnard Plain. This shift in pumping resulted in improved conditions in the UAS but considerable overdraft of deeper aquifers. An update to the FCGMA's management plan was completed in 2007, and describes a number of projects and strategies that might be employed to bring pumping in the Oxnard Plain, Pleasant Valley and Las Posas basins into balance with recharge to the aquifers of these highly-developed basins (FCGMA, 2007).

The primary water quality concern on the Oxnard Plain is degradation associated with the intrusion of saline waters. The direct lateral intrusion of seawater remains the primary threat in coastal areas, with the near-shore submarine canyons at Port Hueneme and Point Mugu exposing aquifer beds to the sea. The vertical movement of deep brines and shallow water of poor quality has also been documented. This movement of poor-quality groundwater is also related to overdraft conditions, but is not limited to coastal areas. Nitrate problems have been documented periodically in specific Oxnard Plain wells. In some cases this degradation is related to the downward movement of poor-quality water, in other locations it may be related to nitrate contamination sourcing from the Oxnard Forebay (UWCD, 2008).

4.3.6.1 WATER LEVELS

As discussed in the groundwater basin descriptions of the Oxnard Forebay and Oxnard Plain, large volumes of groundwater flow from the Oxnard Forebay to the Oxnard Plain. Contouring of recorded UAS water levels from wells shows that groundwater flows radially from recharge areas in the Forebay to surrounding areas (Figures 4.3-22 and 4.3-23). Recharge from the Forebay serves to raise or sustain water levels in wells on the Oxnard Plain, countering the decline in groundwater elevations resulting from groundwater extractions. When water levels are high across the basin groundwater may flow past the coastline to the offshore extension of the aquifers of the plain, or exit the system at near-shore canyons as discharge to the sea.

Precipitation totals in 2011 were higher than average, and a large storm event in March helped sustain above-average flows in the Santa Clara River through the spring of the year. Significant natural and artificial recharge occurred in the Forebay, and mounded groundwater conditions are evident in Figure 4.3-22. A sizable storm hit the area in December 2010, allowing an early start to wet-season recharge to the basins. Artesian conditions existed in coastal areas of the north and central Oxnard Plain by March and April 2011, the period when water levels were collected for contouring spring conditions.

In fall 2011 UAS groundwater elevations in most areas of the Oxnard Plain were similar to what they were in the spring, suggesting that between spring and fall the amount of groundwater pumped on the Plain was similar to the amount of water moving from the Forebay to the Plain. It is more typical for water levels in the confined aquifers of the Oxnard Plain to exhibit a distinct annual signature, with increased pumping stresses and reduced recharge in the summer and fall resulting in water level declines of ten feet or more (Figure 4.3-29). In the southern Oxnard Plain the sea level (0 feet) contour is mapped more than two miles inland from the coast in fall 2011. In this area south of Hueneme Road, piezometric heads in the Mugu aquifer of the UAS are commonly at least 20 feet lower than in the Oxnard aquifer. The selected hydrographs shown in Figure 4.3-29 show spring 2011 heads were often about ten feet below historic highs, but in some cases 60 feet higher than historic lows.

LAS heads are contoured for the spring and fall of 2011 for the Oxnard Forebay, Oxnard Plain and Pleasant Valley basins (Figures 4.3-30 and 4.3-31). These contours show a new interpretation for LAS groundwater flow. Evaluation of well construction, interpretation of geophysical well logs and construction of stratigraphic cross-sections for the area indicate that a number of wells in the Oxnard Forebay and north Oxnard Plain, utilized in the past construction of LAS contours, and previously classified as LAS wells, are likely influenced by heads in the UAS. Some of these wells may be screened in both the LAS and UAS. South of a certain point these “shallow LAS” wells are absent, and wells are screened much deeper due to structural and stratigraphic changes in the subsurface.

A better understanding of UAS and LAS stratigraphy and the structural deformation of the LAS has allowed United staff to better interpret water levels recorded in the Oxnard Forebay. Groundwater elevations recorded in the deep monitoring wells at the El Rio Spreading Grounds, utilized in this new interpretation, better conform to groundwater elevations of LAS wells in the central and south Oxnard Plain.

The inclusion of the “shallow LAS” wells in earlier contouring resulted in a steep break in groundwater elevations that was thought to be indicative of a structural barrier to groundwater flow. This revised interpretation of LAS groundwater elevations functionally expands the pumping depression seen along the eastern Oxnard Plain and western portions of the Pleasant Valley Basin north into the Forebay. Above sea level LAS groundwater elevations near the Saticoy Spreading Grounds, however, indicates that the LAS pumping depression does not extend north to this area of the Forebay. Water level records and associated contouring shows that in the aquifers of the LAS,

groundwater flows from the Oxnard Forebay to the large pumping depression in the eastern Oxnard Plain and the Pleasant Valley basin.

Also notable in this interpretation (of deeper LAS wells) is higher LAS heads along the coast in the western Oxnard Plain than in most other areas of the basin. Maps showing LAS pumping locations within the basin (next section) are consistent with the contouring. The LAS contouring presented here is somewhat preliminary and subject to modification in the future as work on the hydrogeology in this area is ongoing.

In the northwestern Oxnard Plain, LAS groundwater flow is likely from the Oxnard Forebay towards the coast. Few LAS wells exist in this area (Figure 4.3-27), as recharge to the Oxnard Forebay is very effective in sustaining groundwater elevations in this area (UWCD, 2010). LAS wells near Victoria Avenue and the northern boundary of the Oxnard Plain record groundwater elevations similar to nearby UAS wells (UWCD, 2010), and artesian conditions were observed in a LAS monitoring well near the coast in spring 2011 (Figure 4.3-30.). The exclusion of "shallow LAS" groundwater elevations from Figures 4.3-30 and 4.3-31 provides an incomplete representation of LAS heads in the northwestern Oxnard Plain.

Historical water level records from selected LAS wells on the Oxnard Plain are shown on Figure 4.3-32. Periods of drought are clearly evident in some of the wells, with measured water level declines exceeding 100 feet in some wells. Annual water level fluctuations of greater than thirty feet are common in the confined conditions of the LAS. Water levels in wells near the coast are more muted, as recharge by seawater prevents heads from falling as low as they do in inland areas.

4.3.6.2 GROUNDWATER EXTRACTIONS

The groundwater resources of the Oxnard Plain are heavily utilized to support overlying land uses. The area is famous for its highly productive agriculture, supporting year-round production of a wide variety of agricultural products. Groundwater supports much of the agriculture on the Plain, but surface water is available in some areas. The area also supports an extensive urban population. The Cities of Oxnard and Ventura maintain active wells on the Oxnard Plain, but also rely on other sources of water. The City of Port Hueneme and other coastal communities generally maintain wells in reserve status and import water from inland areas given their location near the coast and vulnerabilities with respect to seawater intrusion.

The distribution of reported UAS pumping shown in Figure 4.3-26 is typical of pumping patterns in recent years. The City of Oxnard operates several wells at its main well field near Third Street and Oxnard Blvd., and at a smaller facility some distance to the northeast. Aside from these locations UAS pumping is uncommon in the urban areas of the Oxnard Plain. Agricultural interests pump extensively from the UAS in the northwest Oxnard Plain, as well as in the northeastern portion of the basin near the Oxnard Forebay. Additional pumping is scattered across the central Plain east

of the City of Oxnard, where a number of wells reporting minor pumping are small domestic wells. Few UAS wells are active south of Hueneme Road on the southern Oxnard Plain.

The distribution of LAS pumping on the Oxnard Plain is concentrated in the eastern half of the basin, as shown in Figure 4.3-27. Near the basin boundary in the northwestern Oxnard Plain the City of Ventura operates two wells at the Ventura Municipal Golf Course, and exports water for municipal use in the Mound basin. LAS extractions are common for irrigation in the northeastern Oxnard Plain, as they are in the east-central portion of the basin. South of Hueneme Road LAS aquifers are pumped extensively for irrigation, in contrast to the UAS which is pumped very little in this area. Also notable is the near-absence of LAS pumping in the northwest portion of the basin.

A histogram of historical extractions from the Oxnard Plain and the portions of the Pleasant Valley and West Las Posas basins within United's District boundary are shown in Figure 4.3-33. Pumping in the portions of the West Las Posas and Pleasant Valley basins within United's district boundary are included with the Oxnard Plain due to the way records are processed within United's Finance Department. Reported pumping for both agricultural and municipal uses were slightly higher in 2011 than in 2010. Despite 2011 rainfall totals being slightly higher than 2010, the timing and rainfall totals for 2010 storms may have been more favorable for avoiding pumping for irrigation on the Oxnard Plain and surrounding areas.

The 60,300 acre-feet of pumping reported for the Oxnard Plain in 2011 was considerably less than reported pumping in 1990, when a record 105,000 acre-feet of pumping was reported. The Freeman Diversion was completed the following year, which improved the quantity and reliability of surface water delivered to the Oxnard Plain. Completion of the Conejo Creek Diversion in 2002 brought additional surface water to the Pleasant Valley area. Municipal and Industrial (M&I) pumping has been subject to cutbacks mandated by the FCGMA, beginning with 5% in 1992 and currently at 25%. Municipal pumping has not actually been reduced by this amount: pumping allocations have been transferred to the Cities of Oxnard and Camarillo, as these cities have expanded into agricultural areas. As noted in earlier sections, large volumes of potable water are imported from both the Oxnard Forebay and from northern California, so the extraction totals represented in Figure 4.3-33 are less than the total demand for agricultural and M&I water in the area.

4.3.6.3 WATER QUALITY

Seawater intrusion was first recognized on the Oxnard Plain in the 1930s and since that time this issue has dominated water quality concerns in southern Ventura County (CA DWR, 1971; FCGMA, 2007). In areas not impacted by saline intrusion, groundwater quality is somewhat variable among wells but generally is adequate for most agricultural and municipal/industrial uses. Water in the confined aquifers of the Oxnard Plain tends to be somewhat mineralized due the marine deposition of many of the aquifers (TDS, sulfate, iron, manganese), but contamination by organic contaminants is uncommon (Burton et al, 2011). Nuisance concentrations of iron and manganese are most commonly associated with LAS wells where reducing conditions are present.

In the northern portion of the Oxnard Plain samples for some wells in 2011 show elevated concentrations of nitrate. The provenance of the high nitrate detected in these wells is generally difficult to determine, but high and variable concentrations are likely related to the downward leakage of near-surface waters (Izbicki, 1992, Zohdy et al, 1993). On the southern Oxnard Plain nitrate concentrations in wells are not commonly detected, and the rare detects are related to damaged or improperly constructed wells.

Recorded chloride concentrations across the central Oxnard Plain were consistently low in 2011, as shown in Figure 3.4-34. These values are similar to native chloride concentrations in the basins of the Santa Clara River Valley. South of Hueneme Road some wells record chloride concentrations of greater than 16,000 mg/l, concentrations similar to seawater.

4.3.6.3.1 SALINE INTRUSION

Since the 1930s the southern Oxnard Plain in Ventura County has been subject to seawater intrusion. The Oxnard, Mugu, Fox Canyon, and Grimes Canyon aquifers are believed to be geologically vulnerable, to varying degrees, to seawater intrusion by their exposure in offshore submarine outcrop in the walls of submarine canyons and along the broader offshore shelf. Concerns related to the expansion of intruded areas in the 1970s and 1980s helped motivate the funding of cooperative studies with the U.S. Geological Survey.

In 1989 the U.S. Geological Survey initiated the Regional Aquifer-System Analysis (RASA) study in the Santa Clara-Calleguas groundwater basin. As part of this project a series of fourteen nested monitoring well sites were installed in coastal areas. Extensive sampling was conducted, and a number of advanced analytical techniques were used to provide a much better understanding of the nature and extent of saline intrusion on the Oxnard Plain. The USGS studies concluded that some areas classified as seawater intrusion in the past were in fact subject to increased chloride concentrations from connate saline water squeezed from fine-grained sediments within and separating the aquifers (Izbicki, 1992). The USGS mapped areas of high salinity in the major aquifer units of the southern Oxnard Plain, and classified sources of salinity as either seawater intrusion or saline intrusion from local sediments. A major product of the RASA study for the Santa Clara-Calleguas study area was a calibrated groundwater flow model. A solute transport component of the model was proposed in the scoping of the study, but this component was later abandoned after initial efforts proved unsuccessful.

United continues to sample the network of monitoring wells on the southern Oxnard Plain. In all of the recent samples from the southern Oxnard Plain, calcium or sodium are the dominant cations. Among samples not affected by high salinity, sulfate and bicarbonate are the dominant anions. For most samples impacted by saline waters, sodium and chloride are the dominant ions (UWCD, 2007). Major ion analysis is helpful in determining chemical conditions and changes over time, but not necessarily the source of brine causing water quality degradation. Researchers from the USGS have advanced methods for determining whether high chloride is sourcing from direct seawater intrusion or rather from deep or stranded brines (Izbicki, 1992 and Izbicki et al, 2005a). The minor

ions iodide and bromide, along with the trace elements boron and barium, are useful indicators for delineating the source of brines impacting fresh aquifers. Analysis of minor ion concentrations and trace element ratios from coastal monitoring wells suggest that some wells are impacted by the recent intrusion of seawater via the near-shore submarine canyons at Port Hueneme and Point Mugu. Other wells are likely impacted by inland brines, such as those expelled from buried fine-grained marine deposits. Clays within these deposits compact over time in response to regional pumping stresses, allowing the brines to enter adjacent permeable beds within the aquifer system (UWCD, 2007).

Over the past decade the sampling of coastal monitoring wells has indicated that near Port Hueneme chloride conditions have generally improved as heads in most aquifers have remained near or above sea level. United's sampling of wells and contouring of groundwater elevations in this area suggest the chloride plumes associated with past periods of drought are now migrating southeast towards the Mugu area, most notably in the UAS (UWCD, 2004). Figure 4.3-35 displays chloride records for selected UAS monitoring wells in coastal areas of the southern Oxnard Plain. The figure shows well A1-195 located north of Port Hueneme has totally recovered from chloride impacts in the early 1990s. The chloride plume shown east of Hueneme Harbor likely extended north from Hueneme Canyon during the drought (chloride spike in well A1-195), and since that time the plume has slowly shifted towards the southeast (groundwater flow is perpendicular to the groundwater elevation contours shown on Figure 4.3-23). Within the plume of displaced seawater, samples from well CM4-275 remain above 6,000 mg/l, and chloride continues to rise in well CM7-190 some 20 years after the drought ended. In the Mugu area, however, saline groundwater would likely flow out from the groundwater basin if a significant seaward groundwater gradient could be maintained, but such conditions have not existed for many years. In inland areas surrounding Mugu Lagoon aquifers of the UAS remain impaired by high chloride. One well in the western portion of this area has shown some improvement in recent years, but chloride is still over 2,000 mg/l (Figure 4.3-35). Other UAS wells show continued degradation by either brines or direct intrusion of seawater (UWCD, 2007).

Selected chloride time series for Lower Aquifer System monitoring wells on the southern Oxnard Plain are shown in Figure 4.3-36. Near Hueneme Canyon few wells show chloride impacts, but well CM2-760 shows increasing chloride at concentrations greater than 10,000 mg/l. In the greater Mugu area chloride degradation is severe in a number of wells, and chloride is trending upwards in many wells. Degradation by brines continues unabated in LAS monitoring wells at the Q2 well site, located about two miles north of Mugu Canyon. Degradation in these wells is related to chronically depressed water levels in the area, allowing brines to migrate into the aquifers from surrounding sediments or deeper zones hosting poor-quality groundwater (UWCD, 2007).

Given the chronic groundwater depression existing north and northeast of the Mugu area, basin managers wish to better understand the extent of existing chloride impacts and the potential for further degradation. While additional monitoring wells allow the ability to sample discrete zones within an aquifer and identify vertical head gradients, expansion of the network of monitoring wells

is an expensive endeavor. United received California DWR grant funding in 2006 for an additional nested monitoring well installation located about a mile north of and between the existing DP and Q2 well sites, and samples from these new wells do not have high chloride concentrations (UWCD, 2007). A better understanding of the extent of saline water impacts and the rate of change in recent years will help both pumpers and water managers plan and prepare for water quality changes that may make groundwater unsuitable for beneficial uses in specific areas.

United has recently sponsored geophysical studies on the southern Oxnard Plain to assess conditions over a broad area in this productive agricultural region (see Section 2.1.6). One such project was a Time Domain Electromagnetic (TDEM) geophysical survey on the southern Oxnard Plain to assess the lateral extent of saline water intrusion over four different depth ranges (UWCD, 2012a). The survey was designed to replicate a study performed by the USGS in the early 1990s, conducted as part of the RASA project (Zohdy et al, 1993). United's field survey area was approximately 35 square miles and extended along the coast between Port Hueneme and Point Mugu (approximately 7 miles) and inland for approximately 5 miles. One hundred twenty five soundings were collected throughout the study area and the data were forward and inverse modeled for each sounding. The model data were used to construct resistivity maps, at four depth ranges typical of the UAS and LAS.

United's TDEM investigation was successful at delineating earth resistivity values that are typical of saline and brackish water in both the Upper and Lower Aquifer Systems. Resistivities typical of saline water occurred along the coast and extended farther inland near Point Mugu with brackish water inferred at various locations inland. An image of contoured resistivity values at depths approximating the lower portions of the UAS are shown in Figure 4.3-37. A second image of contoured resistivity values for the shallower portions of the LAS are shown in Figure 4.3-38. Groundwater salinity estimates from the TDEM surveys generally correlated well samples from areas monitoring wells. The work suggested that geologic features such as paleochannels may affect groundwater flow and the migration of chloride, particularly in deposits of the UAS (UWCD, 2012a).

Local water managers share a common desire to better understand the extent of saline water impacts on the southern Oxnard Plain and how rapidly it might be migrating toward the more large scale pumping to the north. There exists relative few monitoring wells in the coastal areas of the southern Oxnard Plain and the extent of saline impacts is not precisely known, but it is well understood that elimination of groundwater overdraft conditions will largely mitigate the worsening of chloride impacts on the southern Oxnard Plain. Prevention of additional water quality degradation is a common goal for all stakeholders as degraded aquifers can negatively affect land values. Restoration of degraded aquifers is a difficult prospect, especially in areas already suffering from groundwater overdraft.

4.3.7 PLEASANT VALLEY BASIN

The Pleasant Valley basin lies adjacent and east of the Oxnard Plain, occupying the area south of the Camarillo Hills. Aquifers of the Upper Aquifer System are poorly developed in this basin and dominated by fine-grained deposits. This change in UAS deposits forms the basis for the basin boundary with the Oxnard Plain. Aquifers of the Lower Aquifer System are continuous with areas to the west on the Oxnard Plain. The City of Camarillo occupies the northern portion of the basin. Agriculture is the predominant land use in the remainder of the basin, where the Pleasant Valley County Water District operates an extensive water delivery system. The entire area of the basin falls within the Calleguas Creek watershed.

4.3.7.1 WATER LEVELS

Most wells in the Pleasant Valley basin area are completed in units of the Lower Aquifer System. Some wells are perforated in coarse basal units of the UAS, but pumping and water level measurements from UAS wells are uncommon as the UAS in the Pleasant Valley basin is predominantly comprised of fine-grained sediments (UWCD, 2003). United does not attempt to contour UAS water levels in the Pleasant Valley basin.

Groundwater elevation hydrographs for selected LAS wells are shown in Figure 4.3-39. The LAS well located in the northeast corner of the Pleasant Valley basin near Las Posas Road and Lewis Road recorded groundwater elevations approximately 140 feet below sea level in the early 1990s. Since the early 1990s water levels in this well have increased dramatically, reaching levels of nearly 120 feet above sea-level in 2011. This recovery is related to increased surface water flow in Arroyo Las Posas and the associated groundwater recharge in the northern portion of the basin. Since the 1990s flow in the Arroyo Las Posas has increased dramatically, largely due to population growth in upstream areas and related water imports and wastewater discharges (LPUG, 2011). This recharge in recent years has lead to the recognition that the basin is unconfined in this area and may be considered a forebay area for the Pleasant Valley basin (Hopkins, 2008). Some recovery in this well is likely related to the relatively wet period the area has experienced since the drought period ending in 1991. The degree to which this recharge has influenced water levels in the central portion of the basin is a topic of current study.

The groundwater elevation hydrograph for the LAS well located at the intersection of Las Posas Road and Pleasant Valley Road shows a clear response to drought conditions in the late 1980s, with water levels reaching approximately 180 feet below sea level in 1991. Since that time, with the onset of a relatively wet period, groundwater elevations have increased steadily except for a slight decline during a dry period from 2002 to 2004. Since 2004, however, groundwater elevations have increased considerably above the water levels recorded in the late 1980s and early 1990s. This recent recovery is most likely related to the utilization of surface water diverted from Conejo Creek and delivered to agricultural users in the basin. Camrosa Water District constructed the Conejo Creek Diversion in 2002 and has negotiated agreements to provide water to Pleasant Valley County

Water District (PVCWD), a major supplier of agricultural water in the Pleasant Valley basin. From 2004 to 2011, diversions from Conejo Creek have averaged approximately 5,600 acre-feet per year. Use of this water for irrigation has reduced pumping demands in the basin. Despite the water level recovery in this well over the past twenty years, recent records show levels remain 26 feet below sea level.

The groundwater elevation hydrograph for a well in the southern Pleasant Valley area, located along Laguna Road, shows a 1991 drought groundwater elevation of 174 feet below sea level. Since 1993, groundwater levels have returned to pre-drought levels and annual high water levels have remained fairly stable. Annual variability in groundwater elevation appears to be greater following the drought, which could be the influence of a nearby well. Unlike some wells in the northern portion of the basin, spring high water levels recorded in this well are not appreciably higher than they were in the 1980s. The highest recorded groundwater elevation for this well is approximately twenty feet below sea level.

Groundwater elevation contours for LAS wells measured in spring and fall 2011 are shown in Figures 4.3-30 and 4.3-31. The LAS contours on the maps show the significant pumping depression that exists in west Pleasant Valley and the eastern Oxnard Plain, where groundwater elevations are well below sea level over a broad area. The fall maps show groundwater elevations in the pumping depression in excess of sixty feet below sea level, and approximately twenty feet lower than water levels recorded in the spring of 2011. The contours for both spring and fall indicate groundwater flow from the west Oxnard Plain and from the Oxnard Forebay to the north. A better understanding of the stratigraphy in the area between the Oxnard Forebay and the Pleasant Valley pumping depression has resulted in a change in the way water levels are contoured in this area (see discussion in Section 4.3.6.1). A steep groundwater gradient likely exists between the pumping depression and the recharge area along Calleguas Creek in the northern part of the basin, but this area is not contoured due to sparse well control and the unknown influence of faulting in the northern basin.

4.3.7.2 GROUNDWATER EXTRACTIONS

Maps showing reported groundwater pumping from LAS wells in the Pleasant Valley basin and on the Oxnard Plain are shown in Figure 4.3-27. The northern and eastern portions of the basin fall outside of United's district boundary, and pumping in those areas is not shown on figures in this report. Pumping from the LAS is concentrated along the western portion of the basin, and aligns with the areas where water levels are deepest in the basin. Pumping of the UAS is limited, and skewed towards the eastern portion of the basin that lies within United's boundary (Figure 4.3-26). A majority of the UAS wells report minor pumping and are likely used for domestic supply.

A majority of the pumping in the Pleasant Valley Basin occurs within United's boundaries. In 2011 5,684 acre-feet of groundwater was pumped from LAS wells, and 881 acre-feet of water was pumped from UAS wells in the Pleasant Valley Basin within United's boundary.

4.3.7.3 WATER QUALITY

The map showing the maximum groundwater chloride concentrations recorded in 2011 is shown as Figure 4.3-34. Samples from wells in the Pleasant Valley basin are distinctly higher than those from the Oxnard Plain to the west. Many wells in the Pleasant Valley Basin had chloride concentrations well over 100 mg/l, a common advisory chloride level for sensitive agricultural crops. A number of the samples are from wells operated by Pleasant Valley County Water District, which blends well water with surface water diverted from Conejo Creek and the Santa Clara River before delivery to areas growers.

During the RASA study in the early 1990s USGS investigators recognized high chloride in some Pleasant Valley basin wells. Innovative techniques were employed to profile flow and chloride concentrations in deep production wells. It was recognized that the highest chloride and TDS was commonly sourcing from the deepest portions of these deep LAS wells, but these zones contributed little water to the well. In 2001 United sought and was awarded an AB303 grant from the California Department of Water Resources to study the nature of the inland saline intrusion problem in the Pleasant Valley basin (UWCD, 2003). A major part of this study was depth dependent sampling and flow profiling of eight deep production wells in the basin. The USGS was contracted to perform this work, which included chemical analysis of major ions and trace elements as well as specific isotopes and chemical tracers. United staff characterized overdraft in the basin and performed groundwater modeling to assess how much additional water might be needed to bring the basin into balance. Geochemical analysis by the USGS was not complete before the project due date, and United's report titled *"Inland Saline Intrusion Assessment Project*" was submitted without the geochemical analysis. The report concluded that chloride increased with pumping during past period of drought, and that increased delivery of surface water to the area of the Pleasant Valley Basin pumping depression would help groundwater levels recover and likely decrease chloride concentrations in water produced from deep wells in the basin.

In 2005 the USGS published technical papers detailing the results of their sampling of Pleasant Valley wells, which included depth-dependent groundwater sampling, flow profiling, and analysis of isotopic and chemical tracers (Izbicki et al, 2005a; Izbicki et al, 2005b). The results detailed by the USGS included that: 1) high chlorides were entering wells from various sources at different depths; 2) concentrations of chlorides in the upper portion of some wells influenced by irrigation return flow were as high as 220 mg/L; 3) concentrations of chlorides in wells with depths greater than 1400 feet were as high as 500 mg/L and had the chemical and isotopic composition trending toward oil field production water in the area; 4) higher chloride concentrations occurred in deep wells near faults that bound the valley such as the Camarillo fault in the north basin and the Bailey Fault on the south side of the basin; and 5) chlorides increase with increased pumping during droughts.

A recommendation by the USGS was that the sealing of the low-yield and poor-quality lower portions of some deep wells would act to improve water quality in many production wells without sacrificing appreciable yield. The 2011 chloride concentrations shown in Figure 4.3-34 suggests that a majority of the wells in the basin are impacted by elevated chloride concentrations. These

impacts are likely to continue as chronic overdraft conditions persist in the basin and deep brines migrate upward in response to the hydraulic gradients produced by over-pumping. Figure 4.3-40 displays maximum chloride concentrations from calendar year 1990, a year when extensive sampling was conducted by the USGS as part of the RASA study. In this drought year few wells recorded chloride less than 100 mg/l. Comparison of chloride records from 1990 to 2011 reveals that recent samples from a number of wells record higher chloride now than they did in a past period of drought.

Recharge water sourcing from Arroyo Las Posas in the northern portion of the Pleasant Valley basin is another significant chloride input to the basin. Chloride loading associated with this recharge is currently under evaluation as part of a proposed desalter project for this area. The effort is being lead by the City of Camarillo in partnership with other parties.

4.3.8 WEST LAS POSAS BASIN

The West Las Posas basin is the western most of a series of three sub-basins that are referred to collectively as the Las Posas Basin. The other sub-basins of the Las Posas Basin are the East Las Posas Basin and South Las Posas Basin. The West Las Posas Basin is bounded to the north by South Mountain, to the south by the Camarillo Hills, to the west by the Oxnard Plain and to the east by the East Las Posas Basin. Only approximately the western one-third of the West Las Posas basin is included within the boundaries of United Water Conservation District (Figure 1-1).

The Los Posas Basin Users Group (LPUG) is currently in the process of formulating a Basin Specific Groundwater Management Plan for the Las Posas Basin. The portion of the basin within the District, however, is excluded from the Plan. Del Norte Mutual Water Company made a formal request of the LPUG to be excluded from the Las Posas Basin Plan on the basis of groundwater conditions, groundwater source, and political jurisdiction. LPUG agreed that the District's portion of the Las Posas Basin should not be managed under the Las Posas basin plan, because groundwater users pay pump charges for groundwater recharge and management activities conducted by United (LPUG, 2011). Although the United portion of the West Las Posas Basin will not be managed by the LPUG plan, it will be monitored because it is hydraulically connected to the remainder of the West Las Posas sub-basin.

4.3.8.1 WATER LEVELS

Groundwater levels have been monitored for nearly a century in the Las Posas Valley. Groundwater elevations in the West Las Posas Basin are monitored by UWCD and Ventura County Watershed Protection District (VCWPD) with private entities also providing data. Fewer wells are monitored in this basin than for most other basins within the District.

In the West Las Posas basin, piezometric heads range from approximately 100 feet below mean sea level (msl) near the Central Las Posas fault to approximately 50 feet above msl near the

Oxnard Plain, indicating a general northwest to southeast flow direction (LPUG, 2011). The flow pattern in the West Las Posas basin suggests the aquifer is receiving inflow from the Oxnard Plain and recharge along the northern flank of the valley. Groundwater moves across the sub-basin toward an area of focused pumping near Bradley Road where there has been a long history of depressed water levels (LPUG, 2011).

4.3.8.2 GROUNDWATER EXTRACTIONS

During calendar year 2011, a reported 3,536 acre-feet of groundwater were pumped from the portion of West Las Posas basin that lies within United's boundaries. The areal distribution of pumping in the UAS and LAS in 2011 is shown in Figures 4.3-26 and 4.3-27. In addition Del Norte Water Company pumps water from its well yard, located near Highway 118 and Santa Clara Avenue on the Oxnard Plain, for agricultural use in northern portions of the West Las Posas Basin within United's District boundary. In 2011 Del Norte pumped and exported 1,455 acre-feet from the Oxnard Plain to the West Las Posas Basin.

Pumping for domestic or potable supply is minimal in the western portion of the West Las Posas basin, as agriculture remains the predominant land use in this area.

4.3.8.3 WATER QUALITY

Water quality samples from wells in the West Las Posas basin indicate groundwater quality is generally adequate for agricultural and municipal use, however, localized exceedances of the MCL for TDS, nitrates, and sulfates have been reported.

Ventura County Watershed Protection District (2012) reports that six wells in the basin exceeded the MCL for TDS (average of 966 mg/L) with two wells having concentrations above the MCL for nitrate, and three wells having concentrations above the MCL for sulfate. Groundwater with this degree of mineralization is common throughout United's service area, and slightly elevated salt content does not pose a health risk. In the West Las Posas basin TDS and chloride concentrations tend to be higher in the northern and western portions of this basin compared to other areas, suggesting that mountain front recharge along the southern flank of South Mountain and inflow from the Oxnard Plain Basin are the sources of higher TDS and chloride concentrations (LPUG, 2011).

5 SUMMARY

United Water continues to evaluate various strategies to best manage and protect the surface and groundwater resources within the District. Current and on-going considerations include: the characterization of groundwater conditions, the most-efficient use of existing infrastructure and the need for additional or modified facilities, current and future water demands, current and anticipated water quality issues, and effective utilization of existing allocations of imported State Water Project water. United Water's goal is to identify the best use of local water resources and infrastructure, and to work with other agencies to implement these strategies, while honoring a coherent strategy and set of priorities that guides all future infrastructure and water management decisions.

The District's groundwater and surface water projects and programs are keyed to the issues and concerns that impact or potentially impact the water resources of the region. These issues and concerns evolve over time and United Water strives to adjust, modify, or devise new projects or programs in response to changing water resource challenges. Many of the projects and programs undertaken by United Water have long-term implementation schedules (e.g., District-wide groundwater level measurements, conservation releases), however, these types of efforts provide the critical data needed to make sound water resource management decisions that provide for the maintenance of reliable, sustainable, local water resources for the benefit of both agricultural and municipal and industrial water users in central and southern Ventura County.

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7 FIGURES AND TABLES

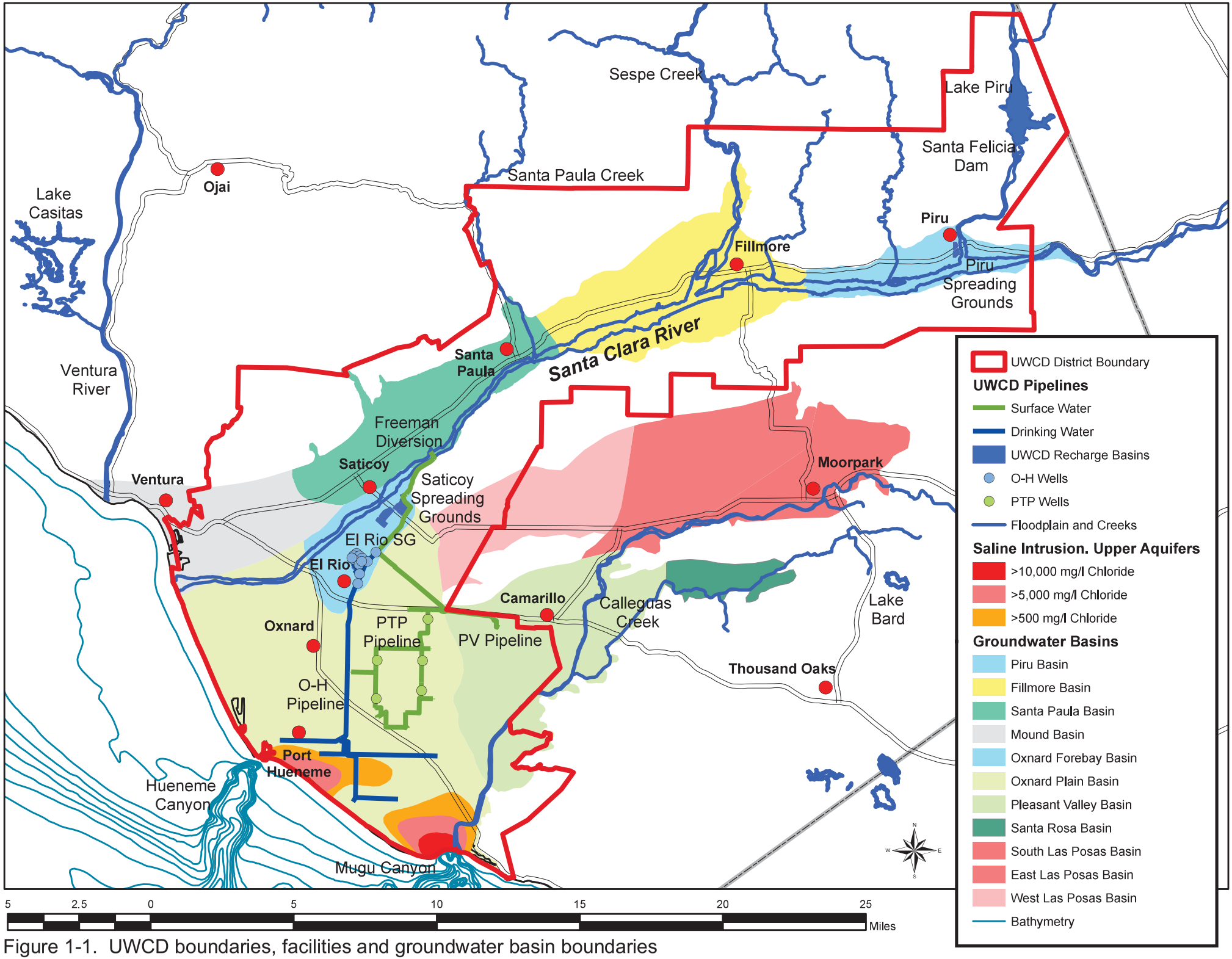


Figure 1-1. UWCD boundaries, facilities and groundwater basin boundaries

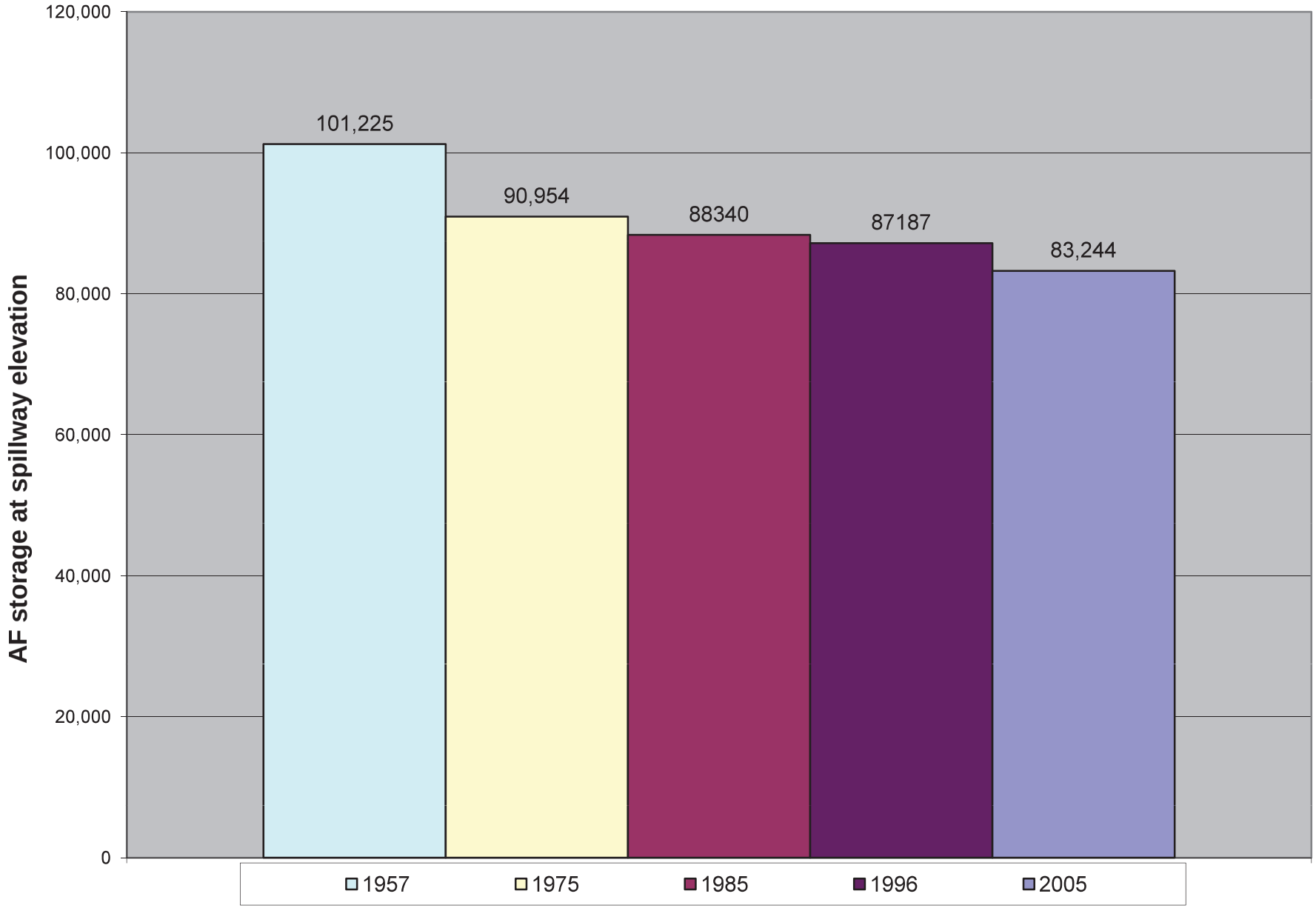


Figure 1.4-1. Silt surveys showing historic storage capacity in Lake Piru

Agricultural Water Deliveries			
	Surface water deliveries to the PTP (AF)	Ground water deliveries to the PTP (AF)	Surface water deliveries to Pleasant Valley Water District (AF)
JAN	346	160.6	385
FEB	362	85.8	453
MAR	376	0.1	643
APR	776	45.6	1,352
MAY	932	63.6	1,433
JUN	776	41.0	1,143
JUL	839	22.1	1,102
AUG	952	60.0	880
SEP	622	79.2	1,255
OCT	1,392	221.4	1,603.4
NOV	544	35.1	849.7
DEC	527	0.8	1,091.7

Figure 1.4-2. (Table showing) surface water deliveries to agriculture, 2011

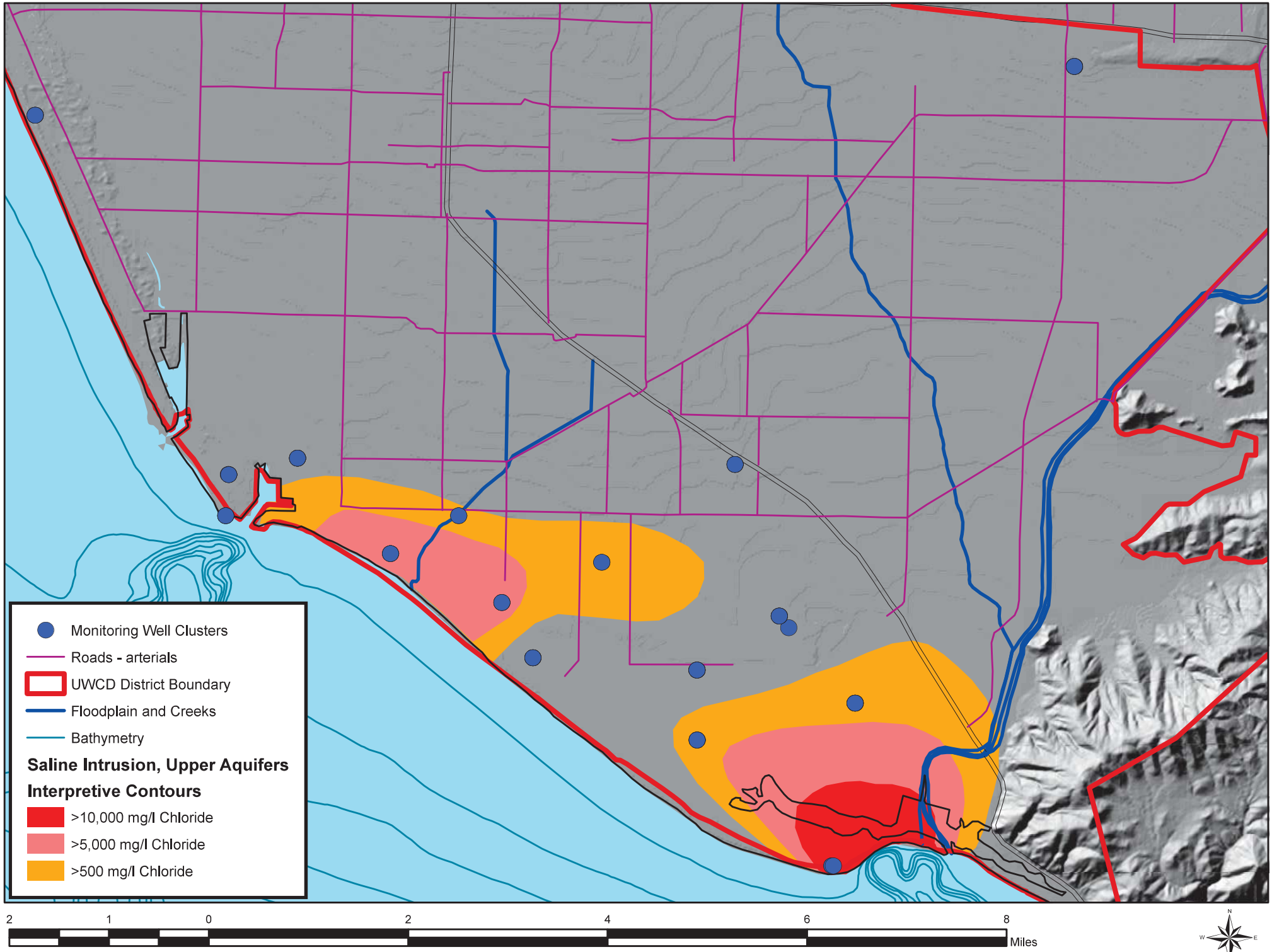


Figure 1.5-1. Locations of RASA coastal monitoring well clusters

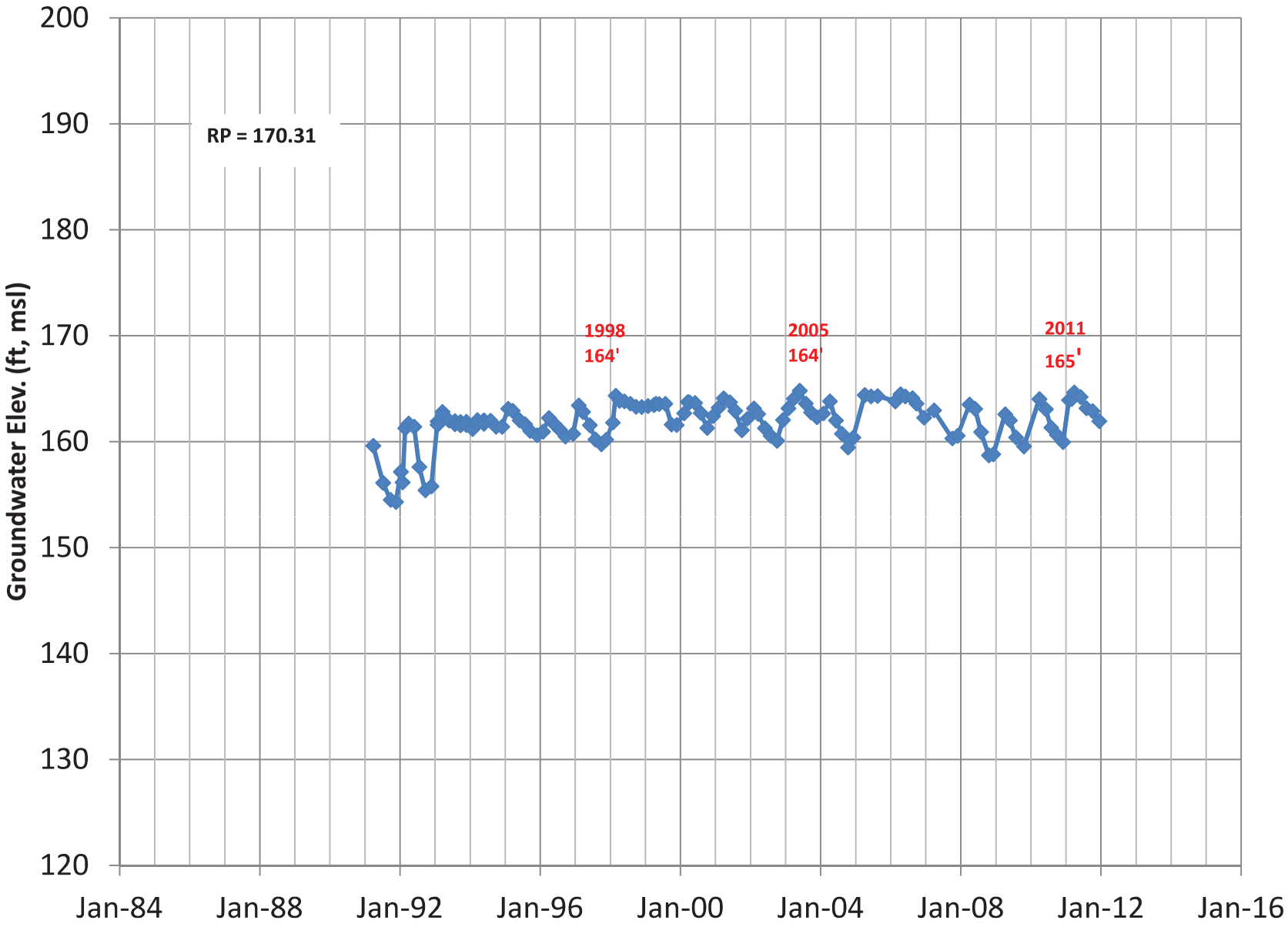


Figure 1.6-1. Groundwater elevations near the Freeman Diversion

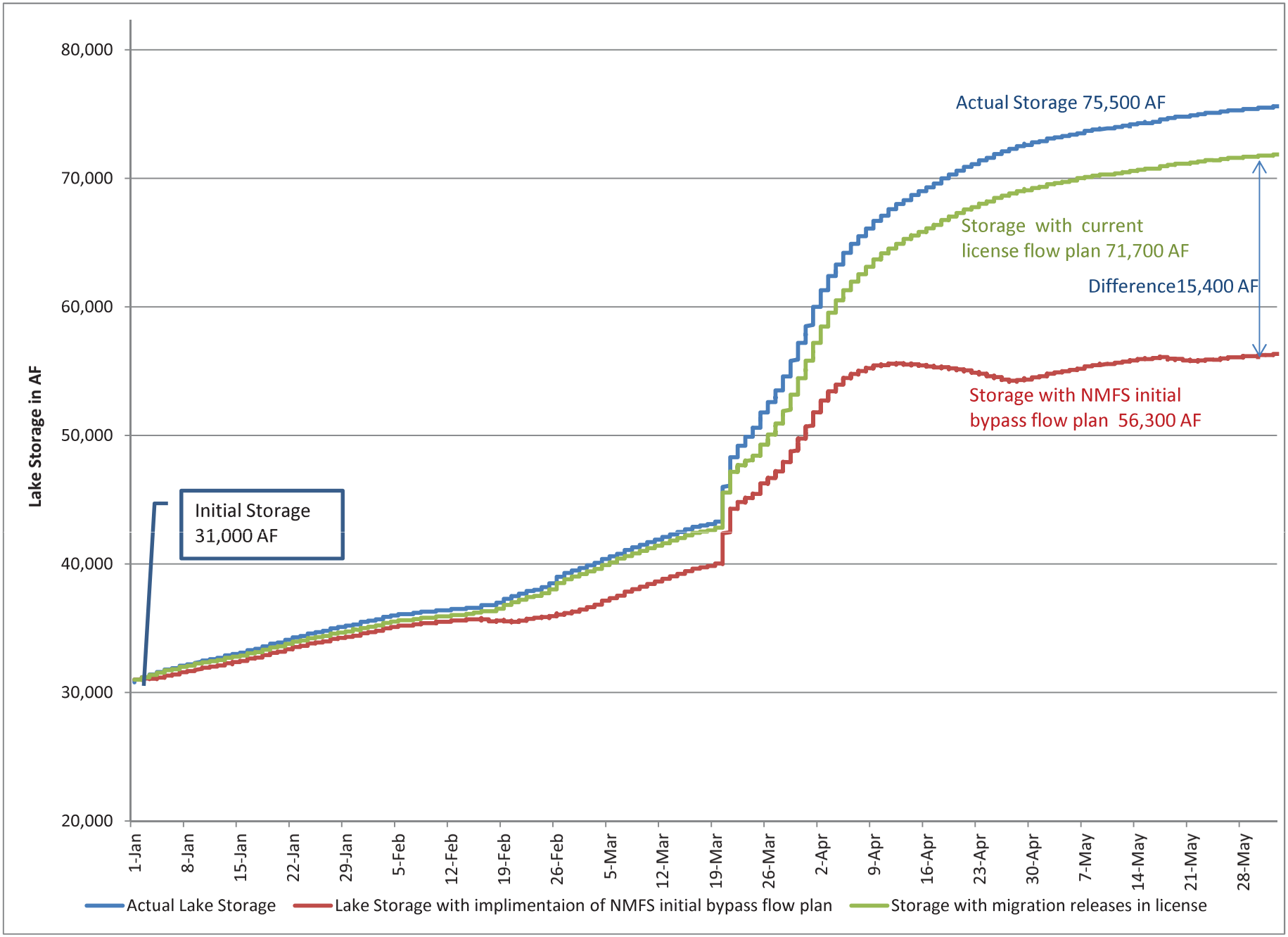


Figure 1.6-2. Possible lake levels with the current FERC license and NMFS recommended flows

Project	Overdraft Conditions	Declining Water Levels	Groundwater Exports	Saline Water Intrusion	Upwelling Saline Water	Riverbed Stabilization	Biological Opinion-SFD	Biological Opinion-VFD	VFD Operation	Aquifer Mapping	Recharge Optimization	Water Quality Degradation
Update Regional GW Flow Model	X	X	X	X	X	X				X	X	X
AB3030 Piru/Fillmore GW Management Plan Update			X								X	X
Santa Paula Basin TAC and Specialty Studies		X	X			X			X	X	X	
District-Wide GW Level Measurements / Piezometers	X	X	X	X	X	X	X	X	X		X	X
District-Wide Water Quality Sampling & Analyses	X	X	X	X	X						X	X
District-Wide Stream Gauging	X	X				X	X	X	X		X	X
Surface Geophysical Studies (Seismic Reflection, TDEM)	X	X		X						X	X	
SCR/Forebay Piezometer Installation		X					X	X	X		X	

Figure 2.1-1. Groundwater issues and concerns versus projects

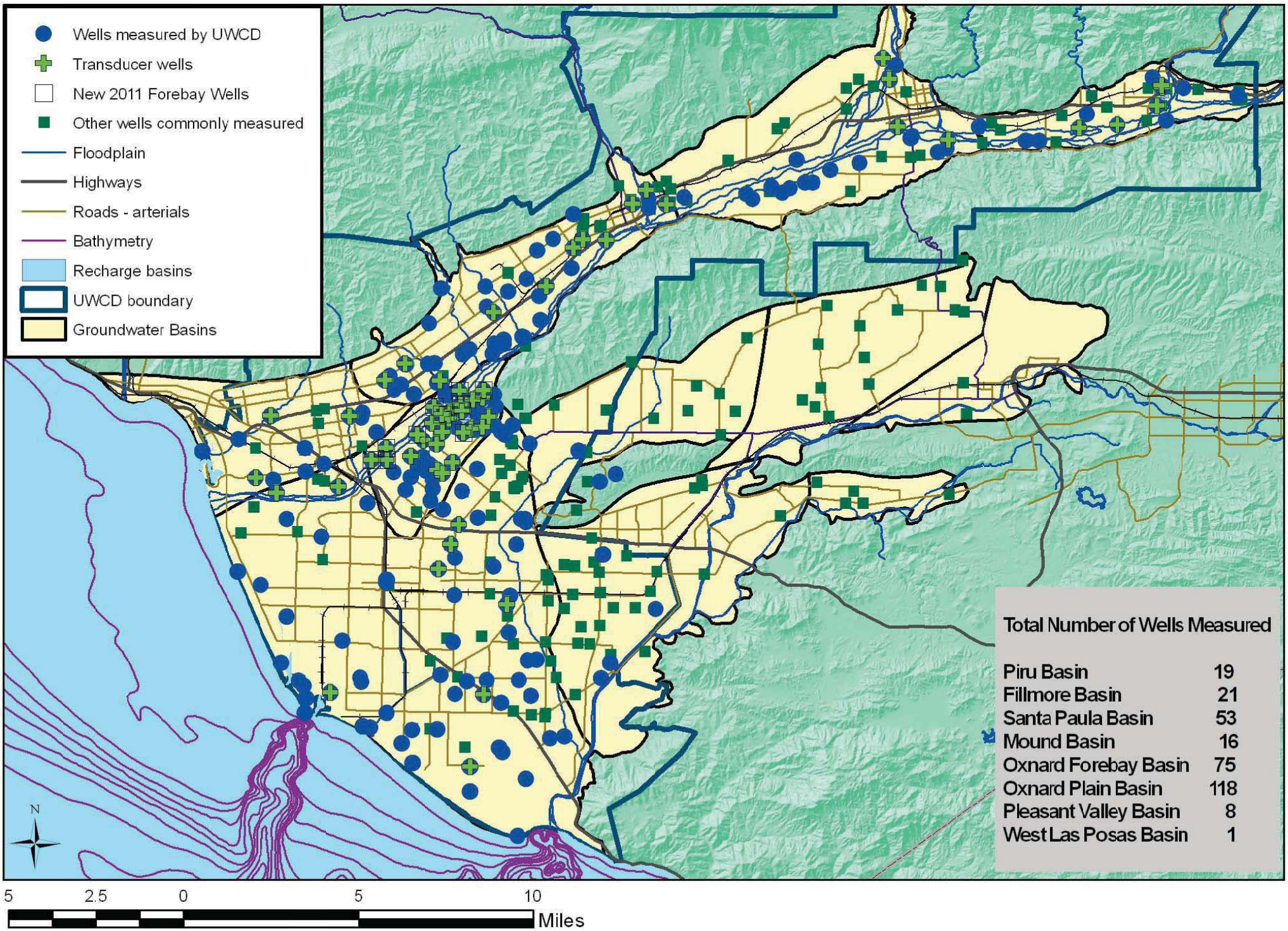


Figure 2.1-2. Wells monitored by United for water levels

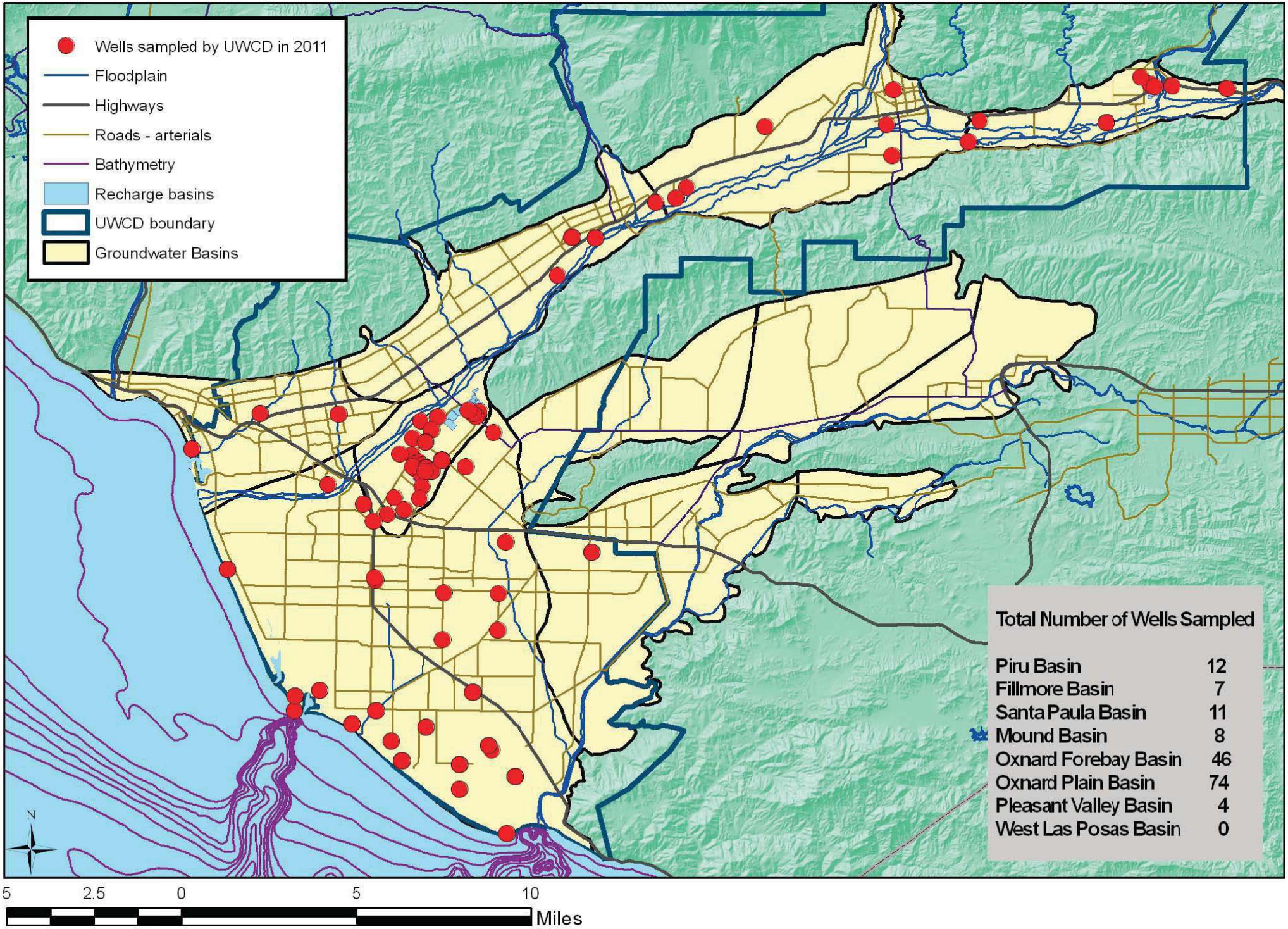


Figure 2.1-3. Wells sampled by United for water quality

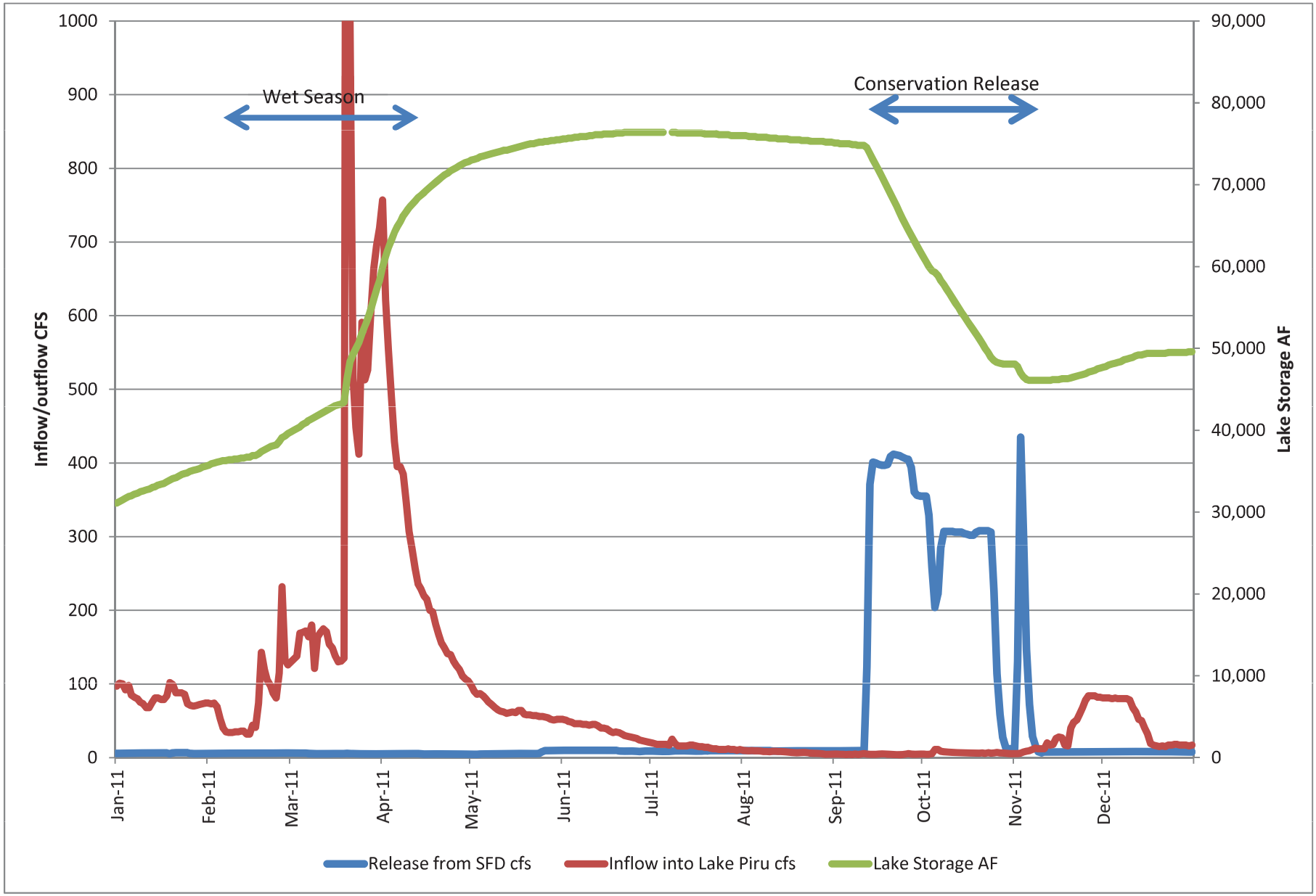


Figure 2.2-1. Basic hydrology for 2011 at Lake Piru

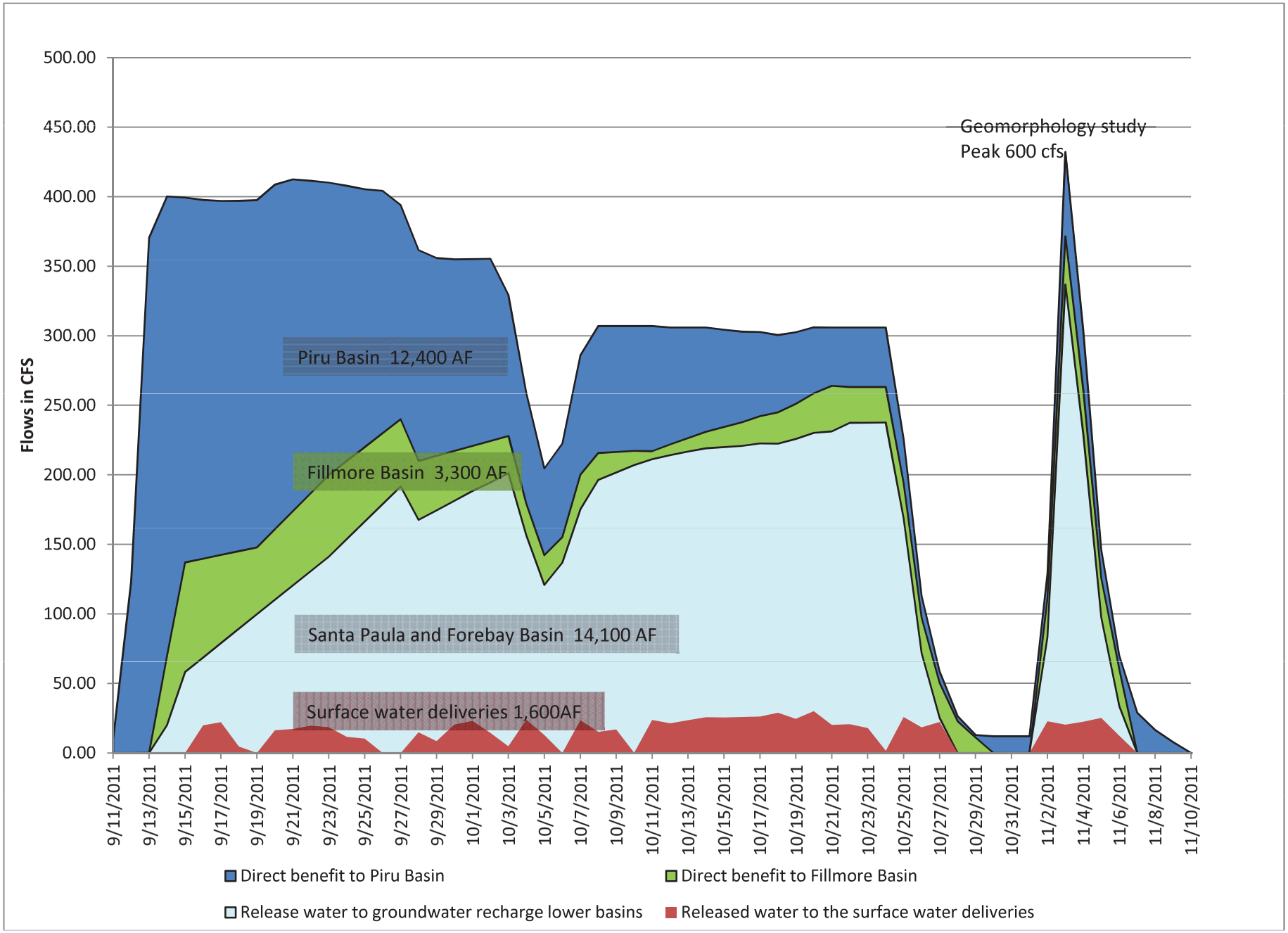


Figure 2.2-2. Benefit to each basin from direct percolation during 2011 conservation release

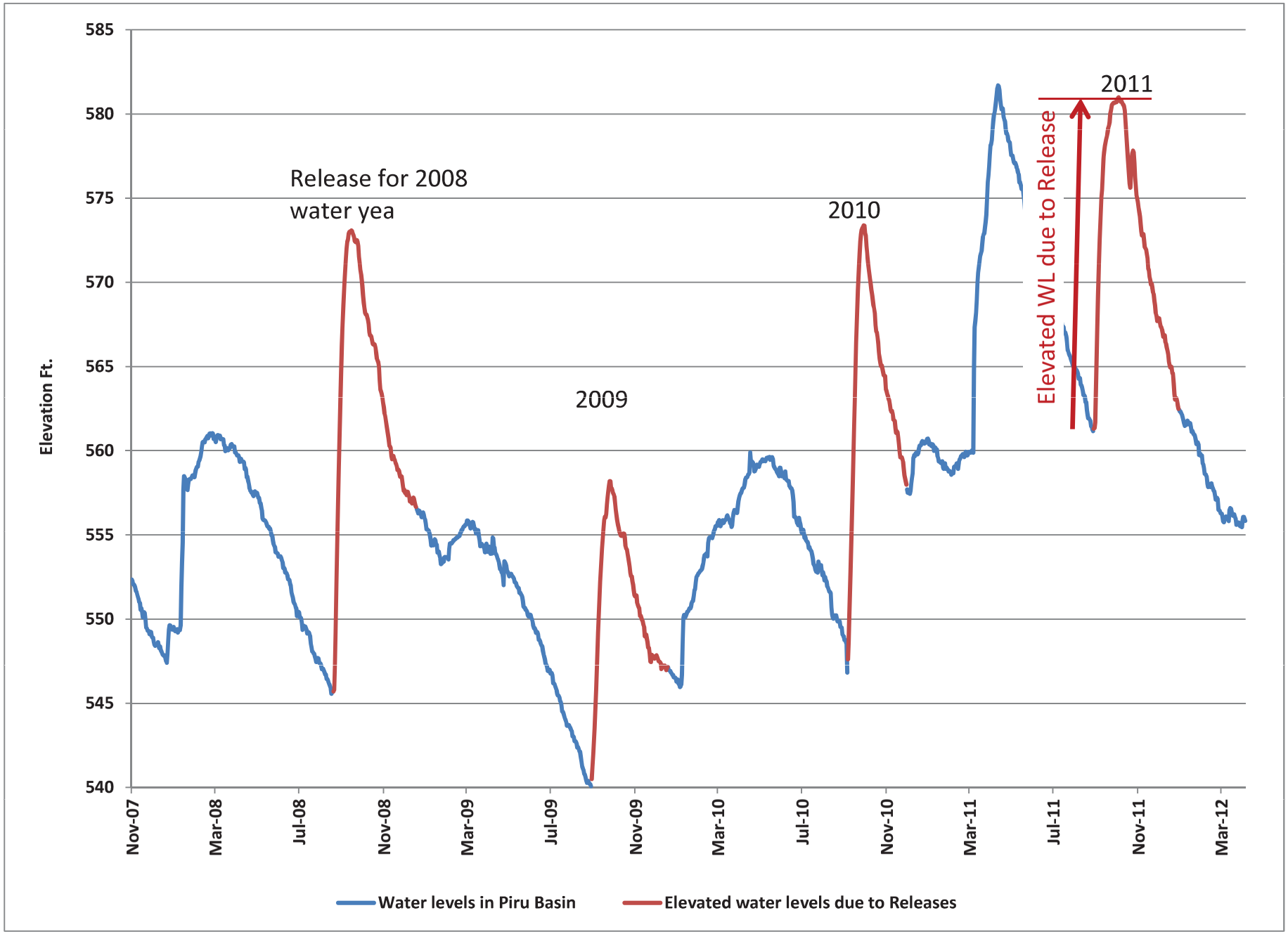


Figure 2.2-3. Groundwater response in the Piru Basin to conservation release from Santa Felicia Dam (well 04N18W31D07S)

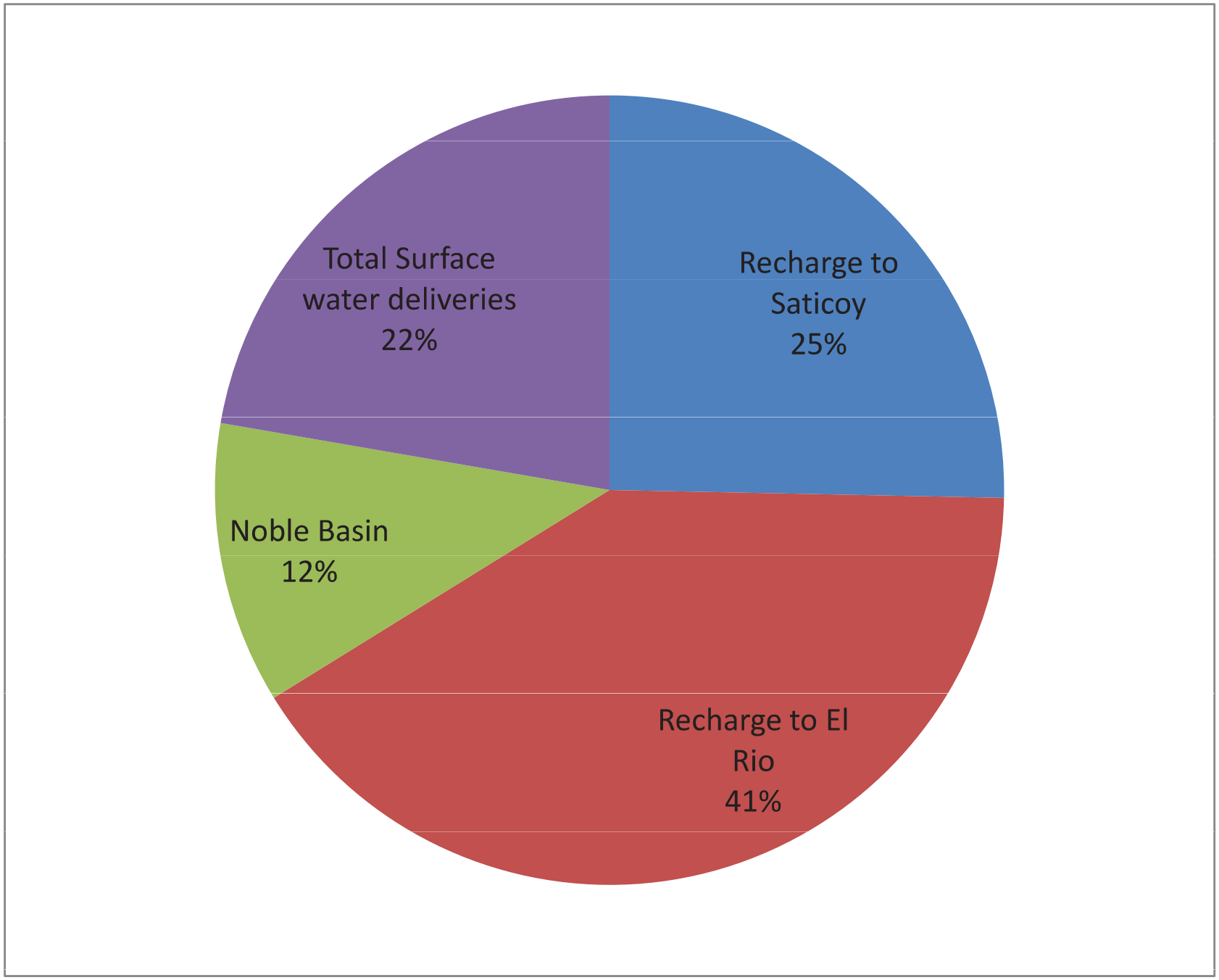


Figure 2.2-4. Distribution of water diverted at Freeman Diversion, 2011

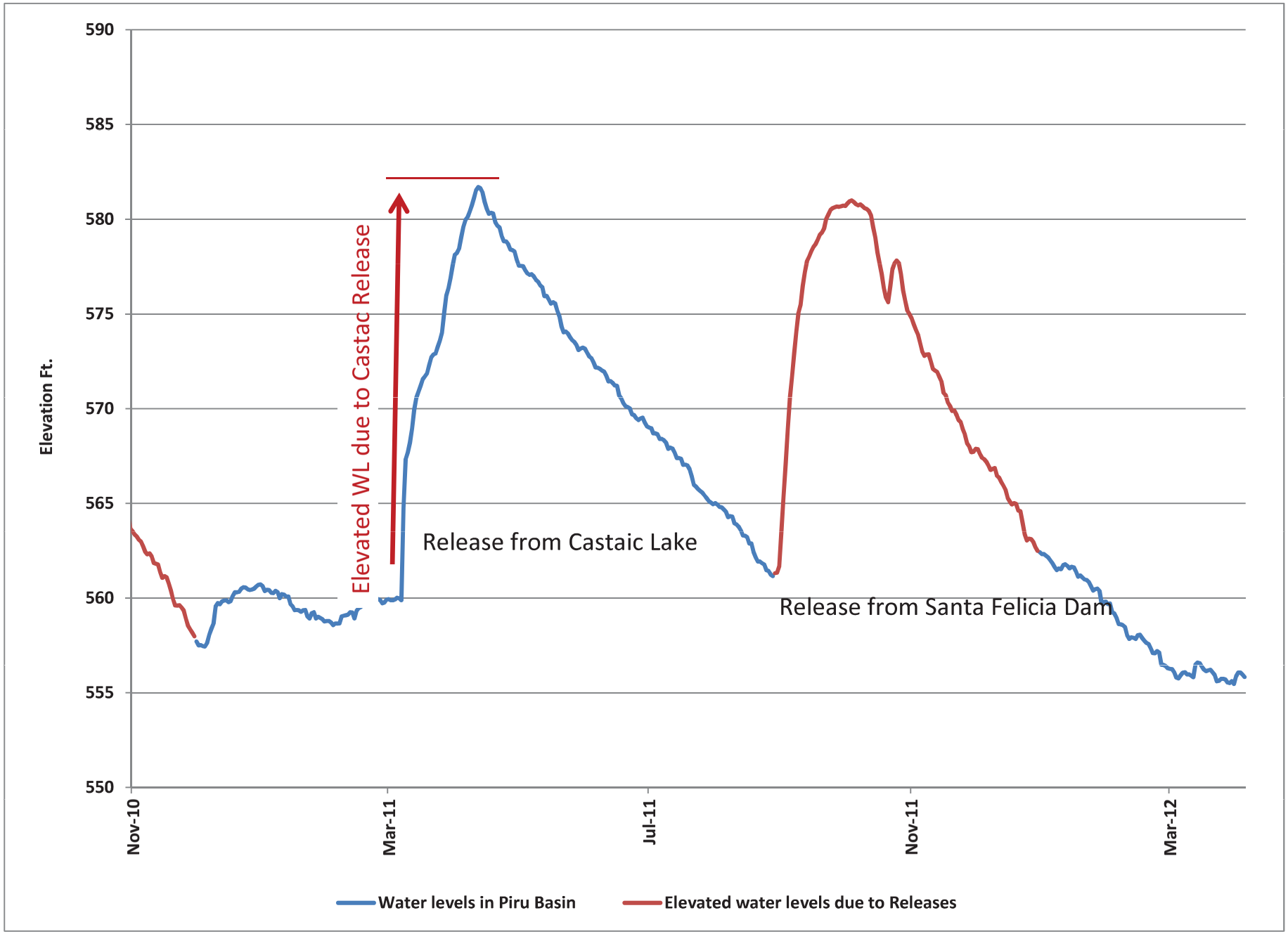


Figure 2.2-5. Groundwater response in the Piru Basin to Castaic floodflow release (well 04N18W31D07S)

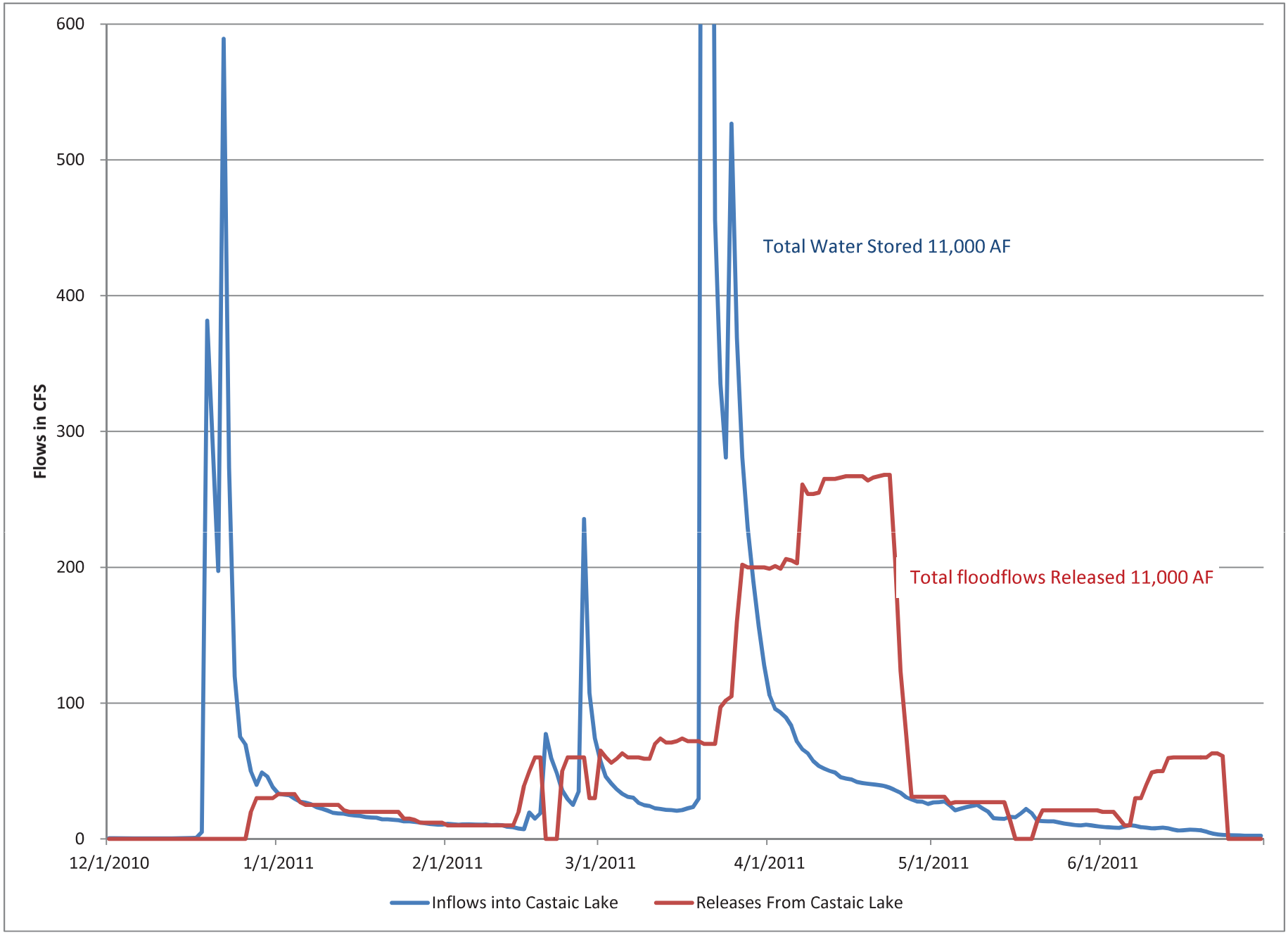


Figure 2.2-6. Conservation release from Castaic Lake for downstream water users

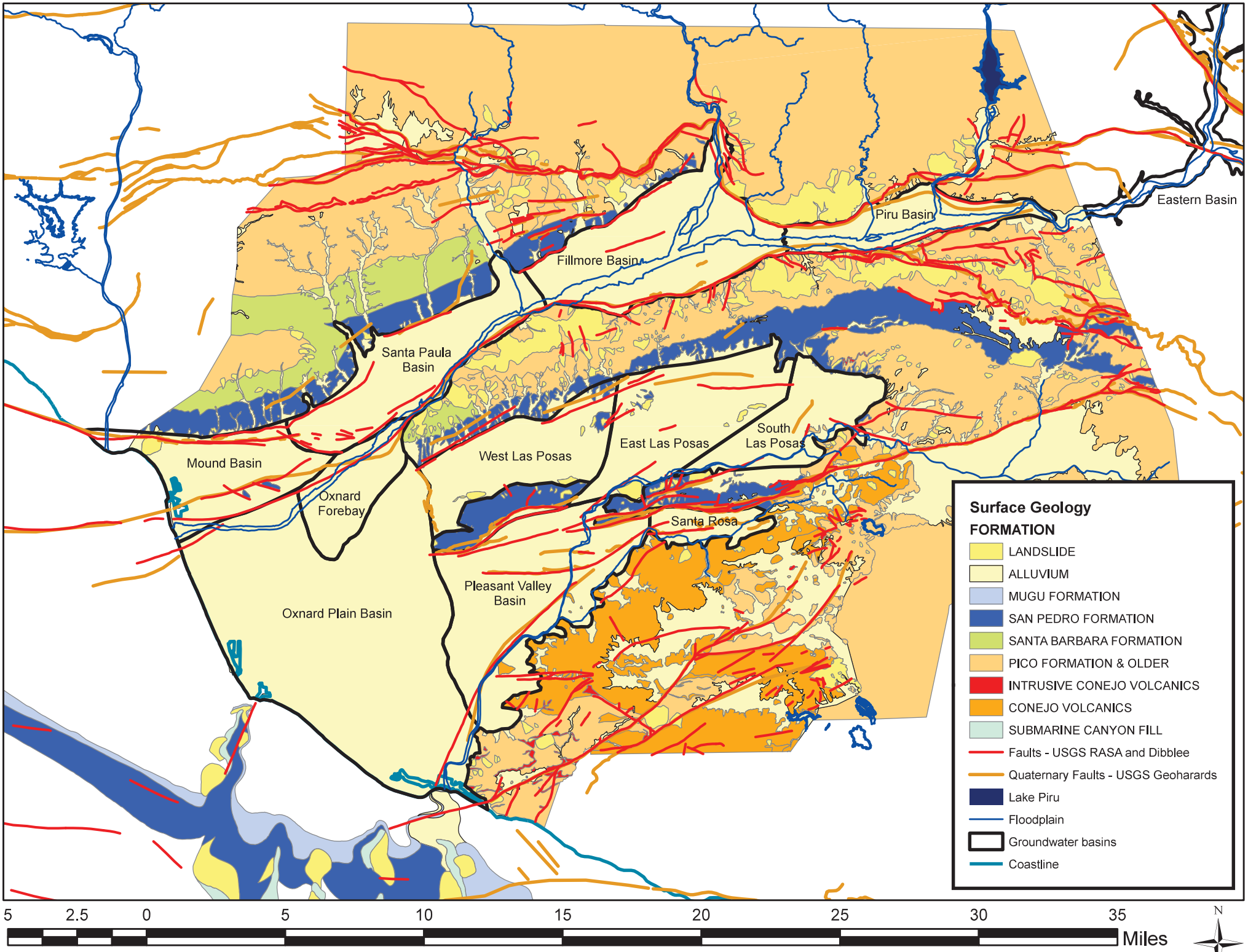


Figure 3.1-1. Surface geology and faults

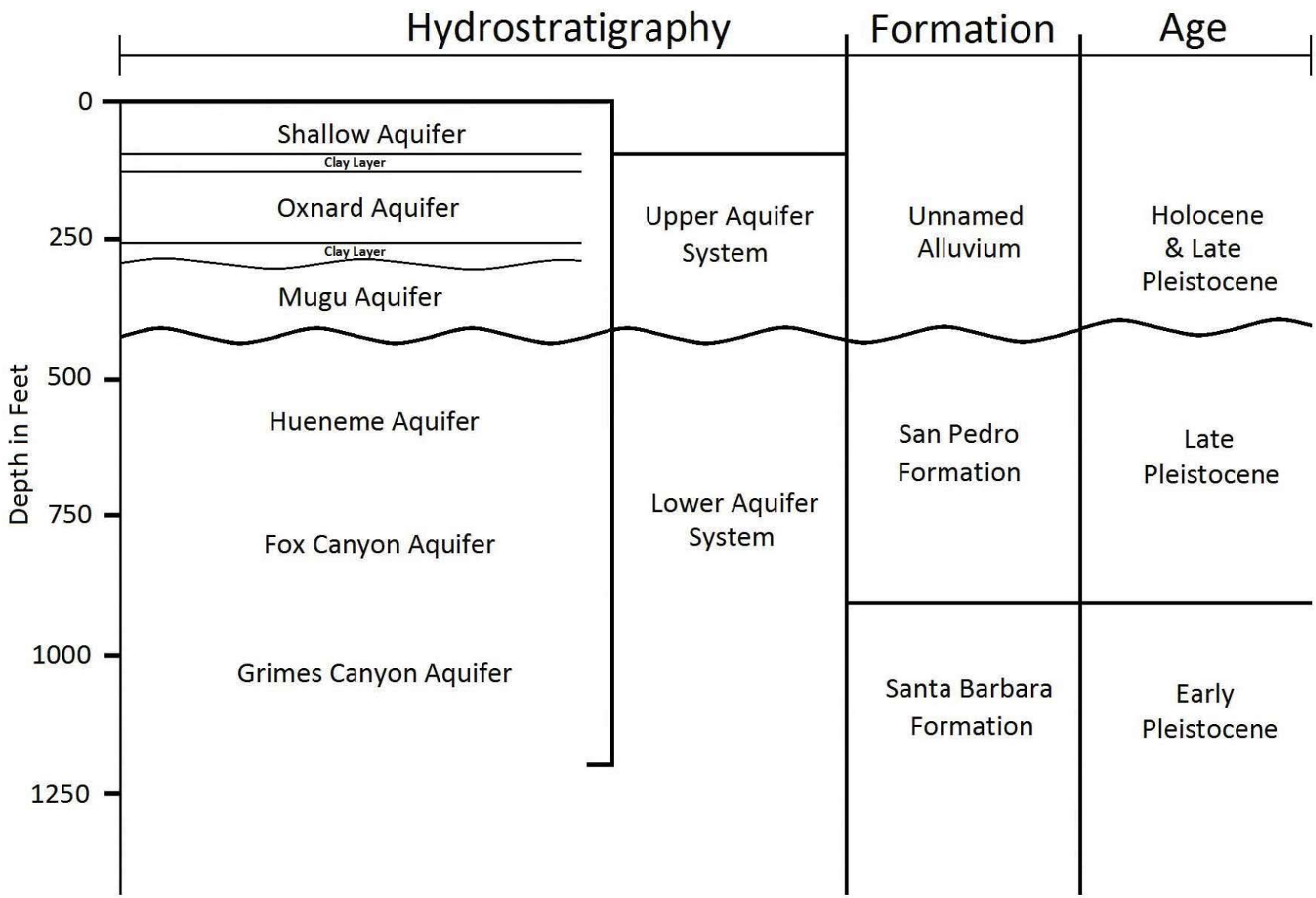


Figure 3.2-1. Schematic of UAS and LAS aquifer systems

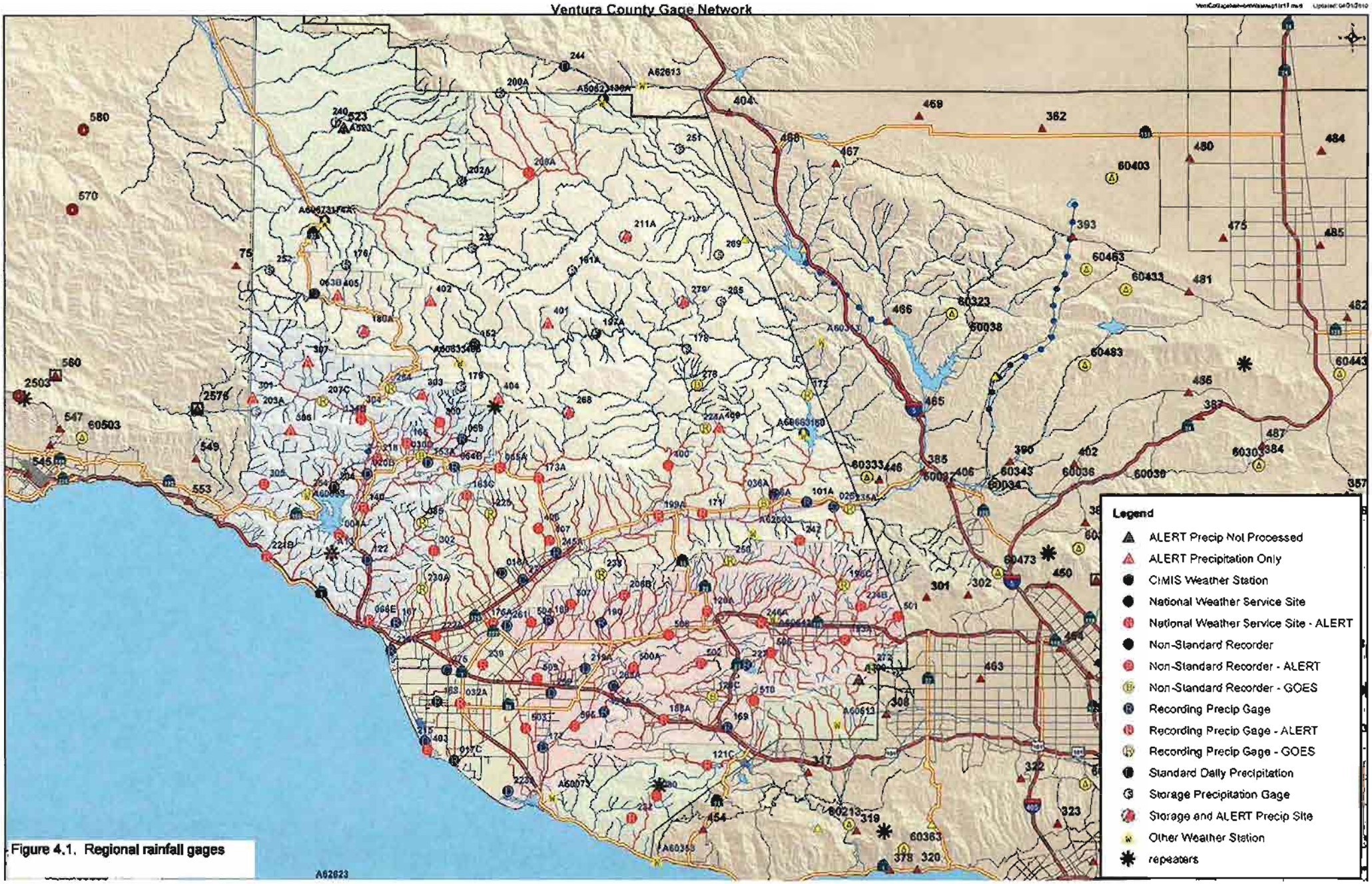


Figure 4.1. Regional rainfall gages

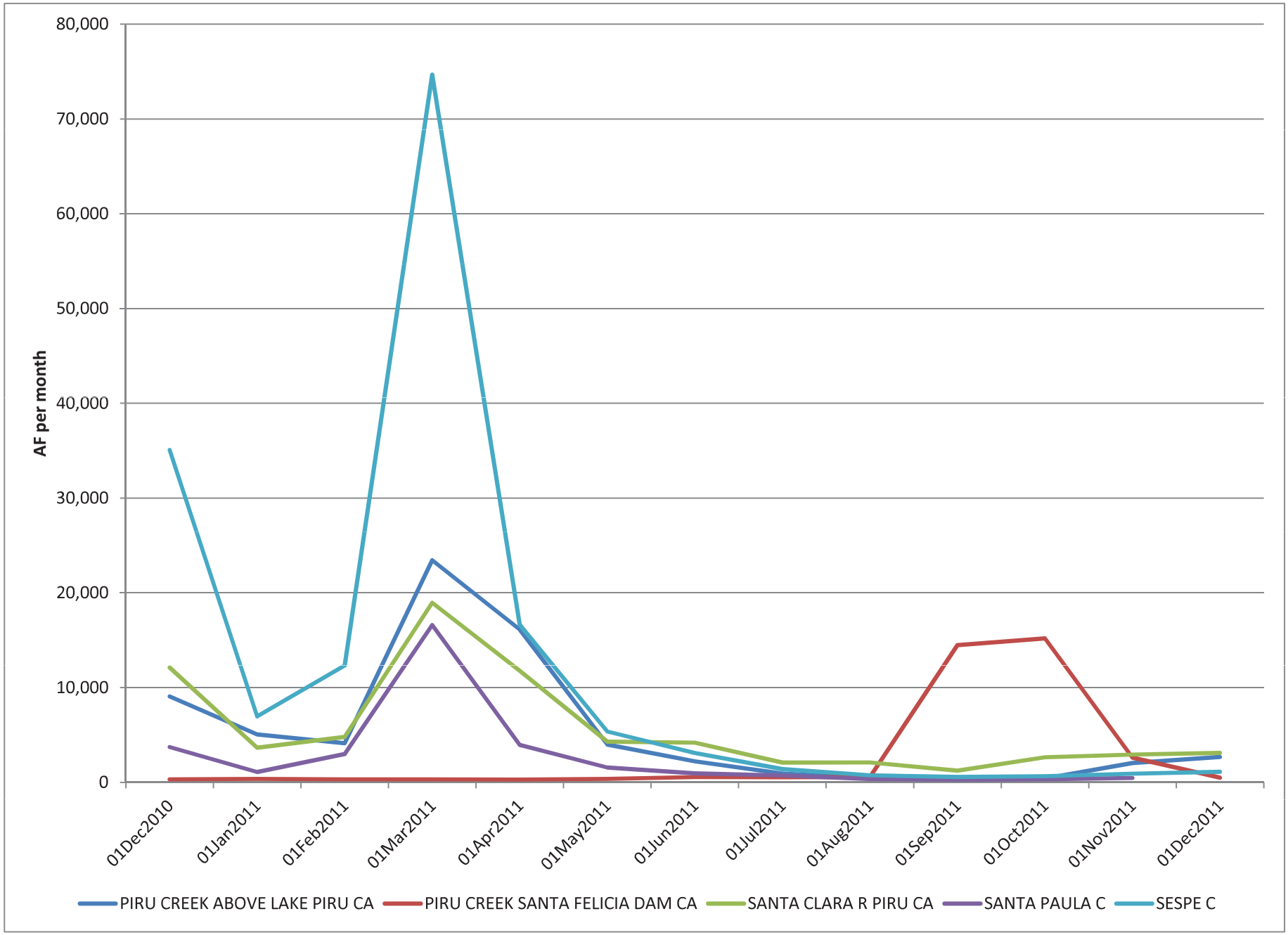


Figure 4.2-1. Monthly flows of the major tributaries in the Santa Clara River Watershed

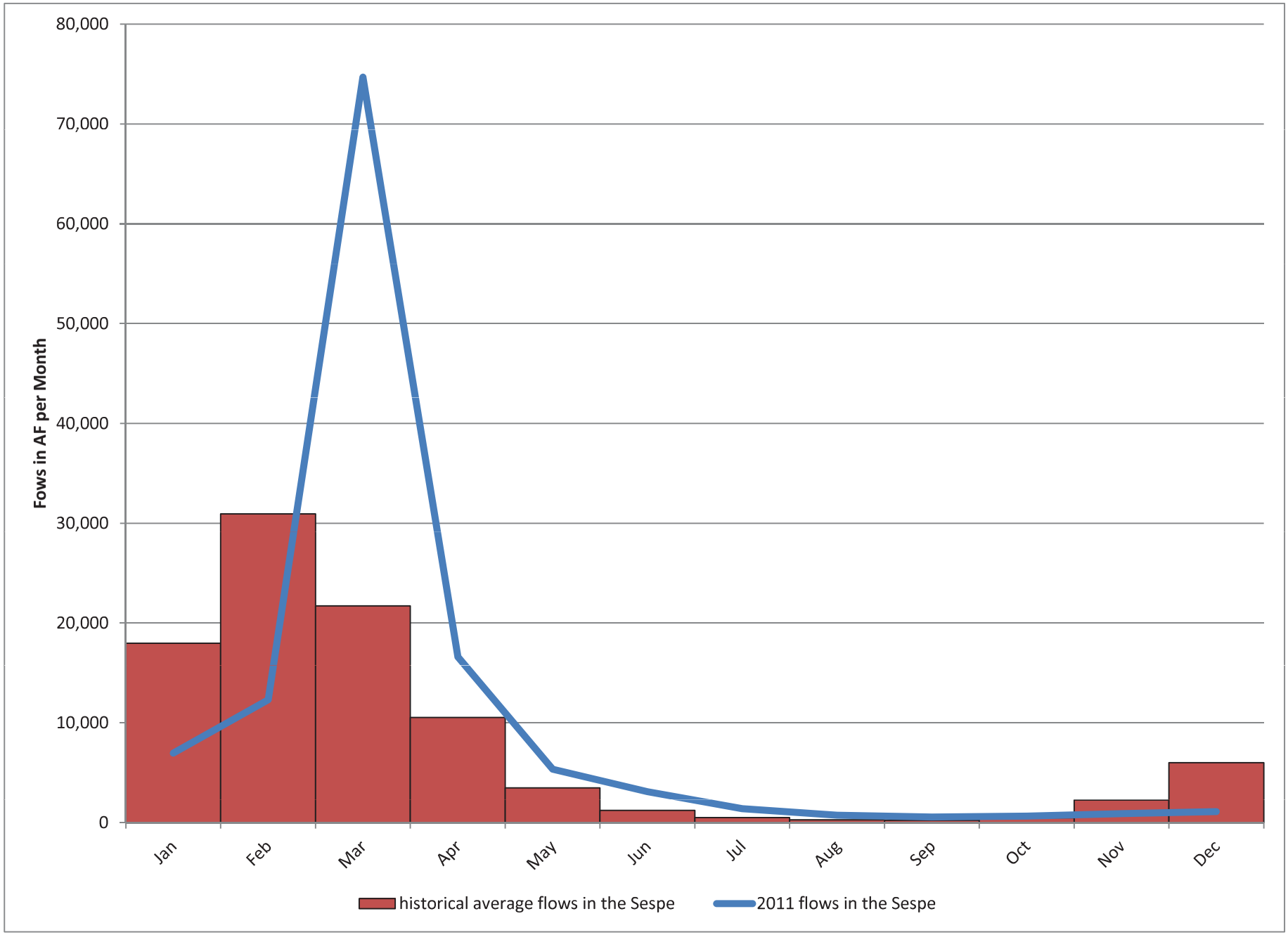


Figure 4.2-2. 2011 Flows in the Sespe Creek compared to average flows (1972-2010)

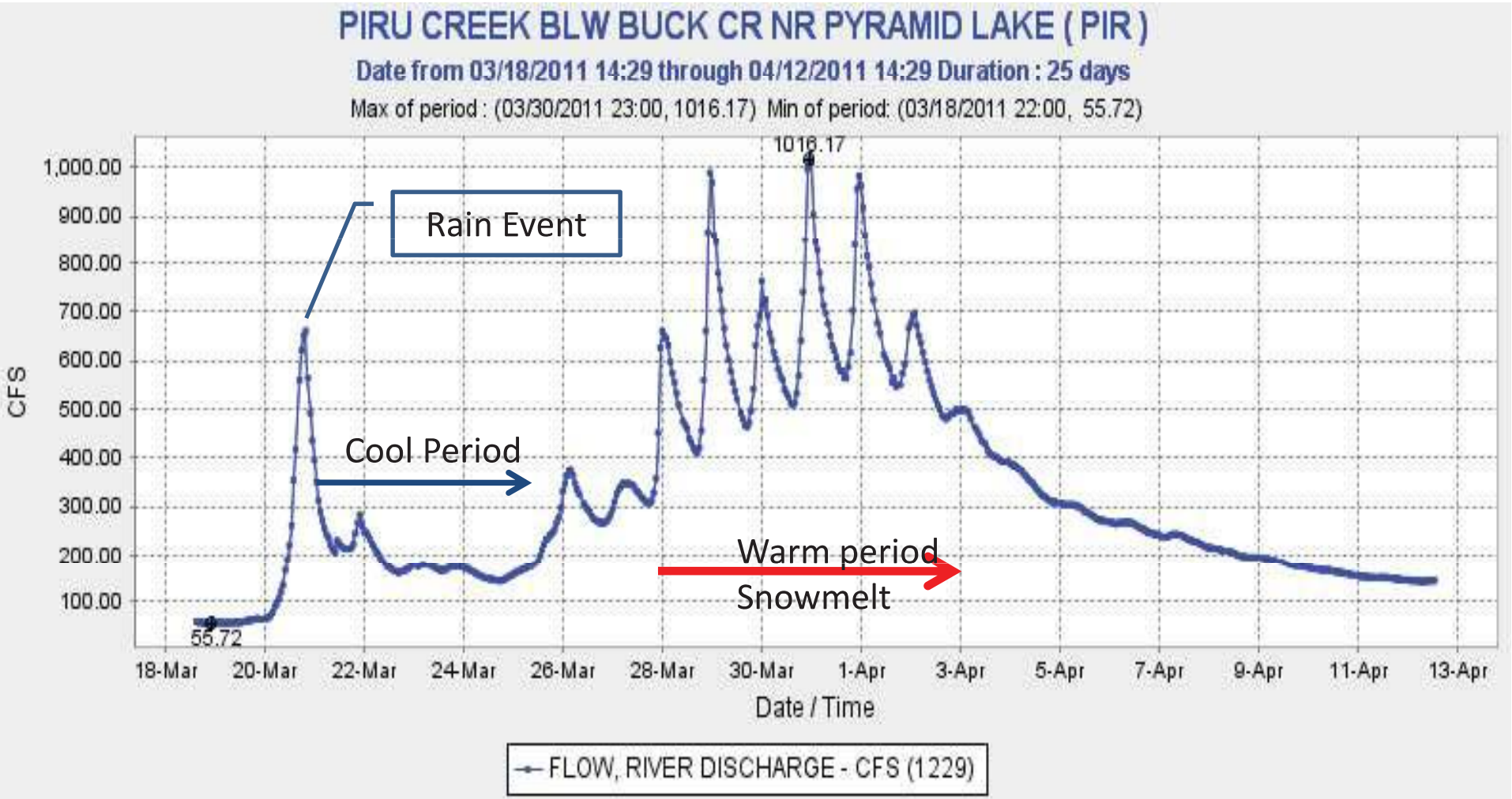


Figure 4.2-3. Spring 2011 snowmelt event in the Piru Watershed

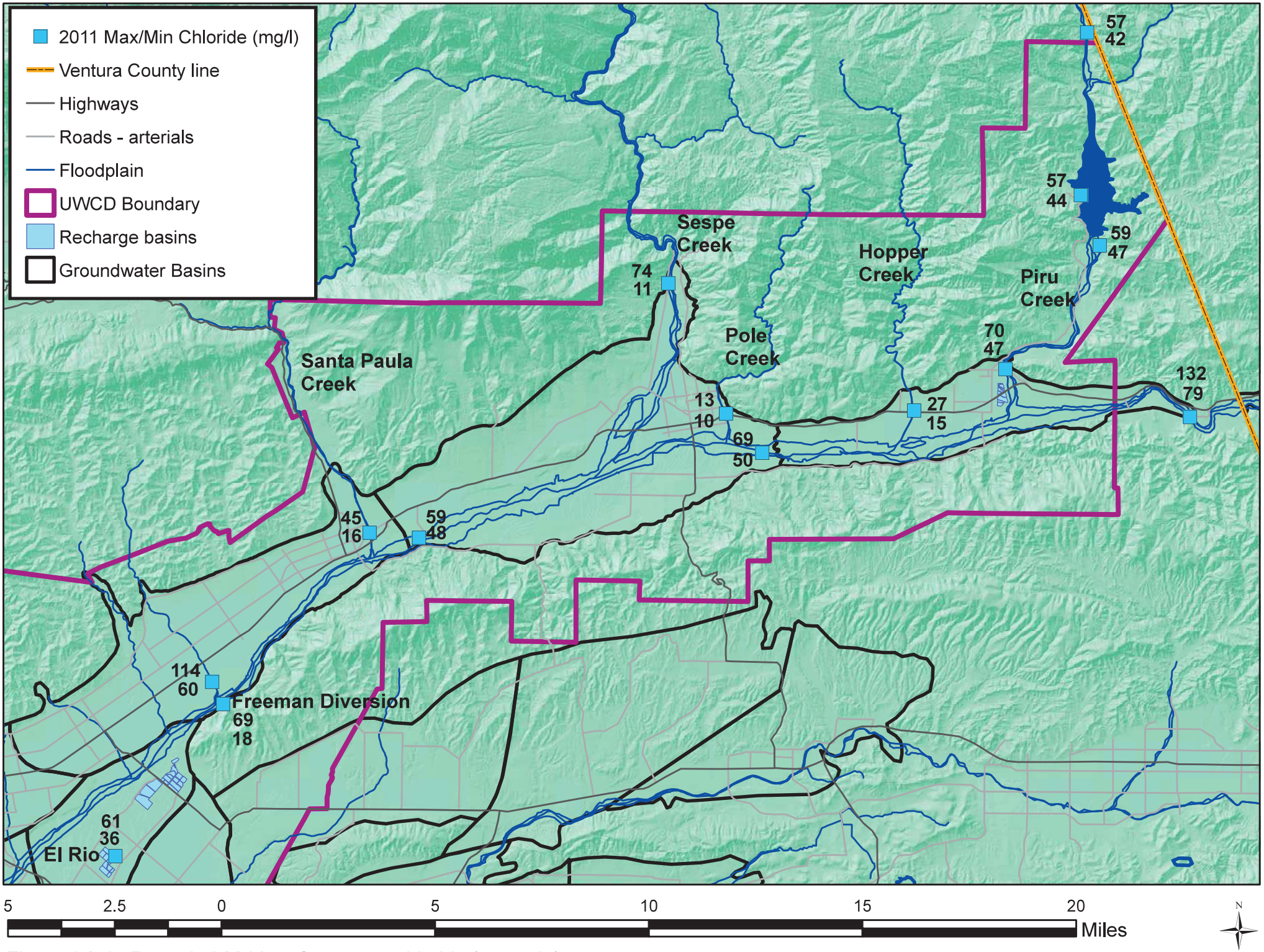


Figure 4.2-4. Recorded 2011 surface water chloride (max-min)

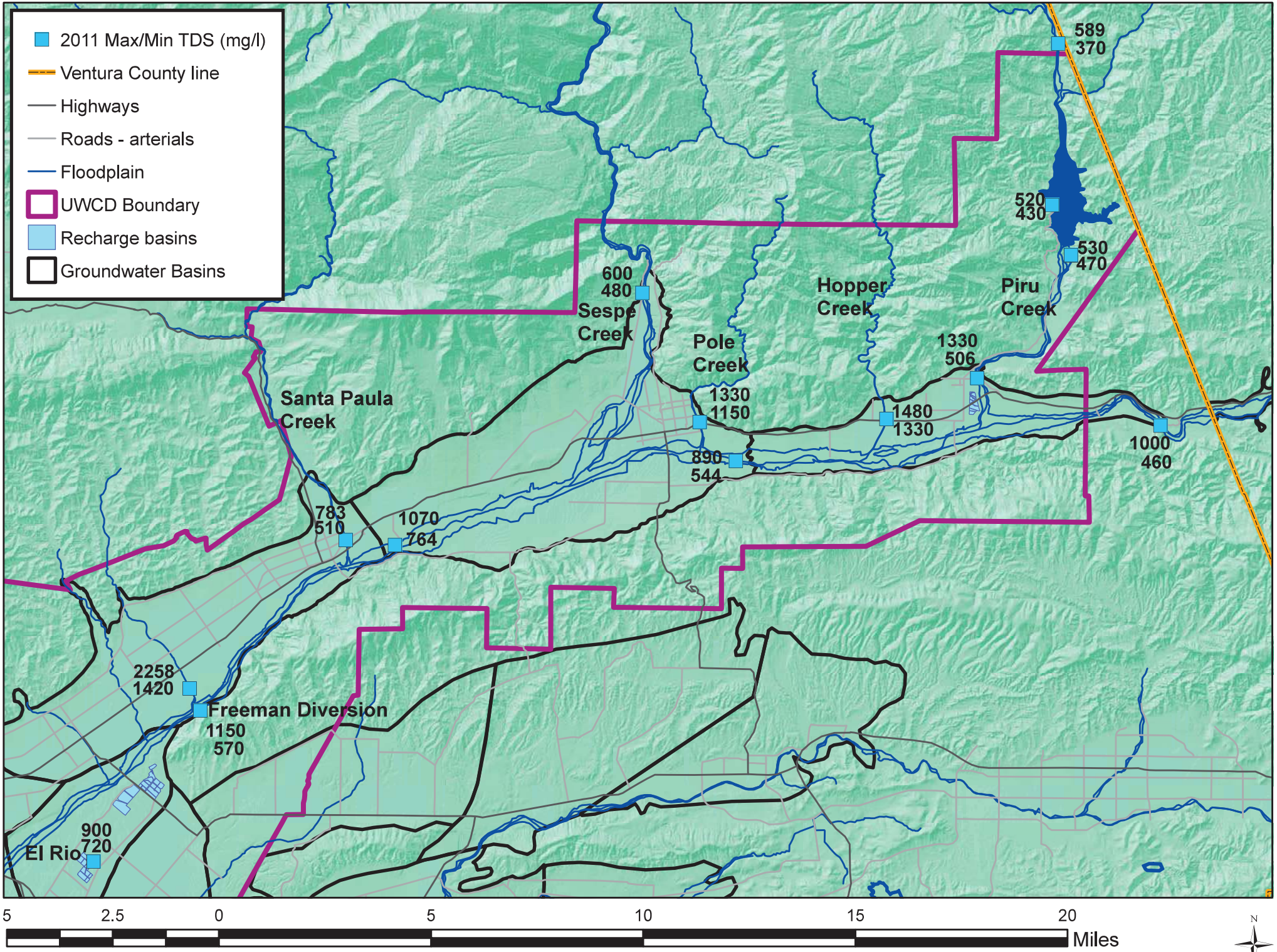


Figure 4.2-5. Recorded 2011 surface water TDS (max-min)

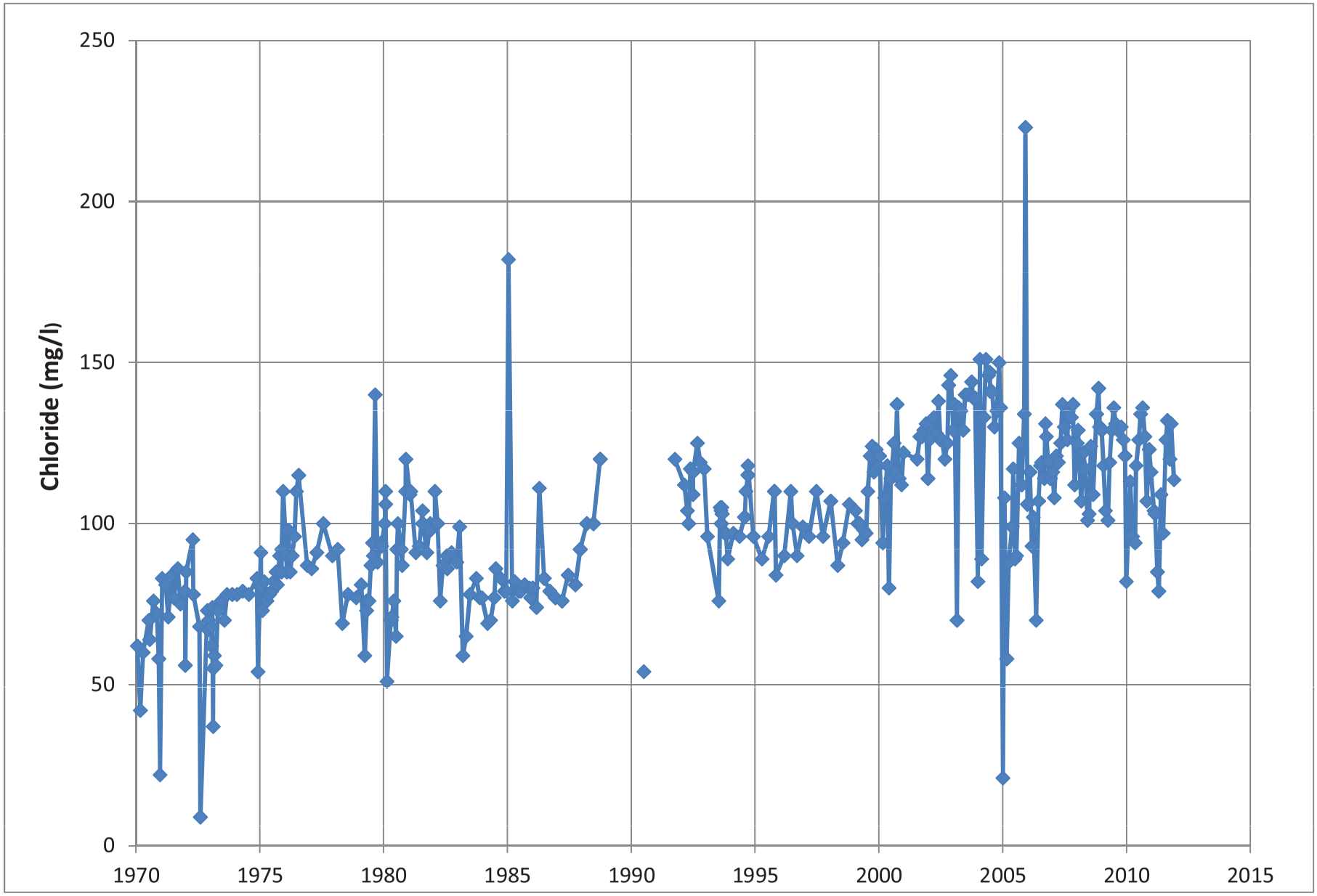


Figure 4.2-6. Historical chloride concentrations in the Santa Clara River near the Ventura-Los Angeles County line

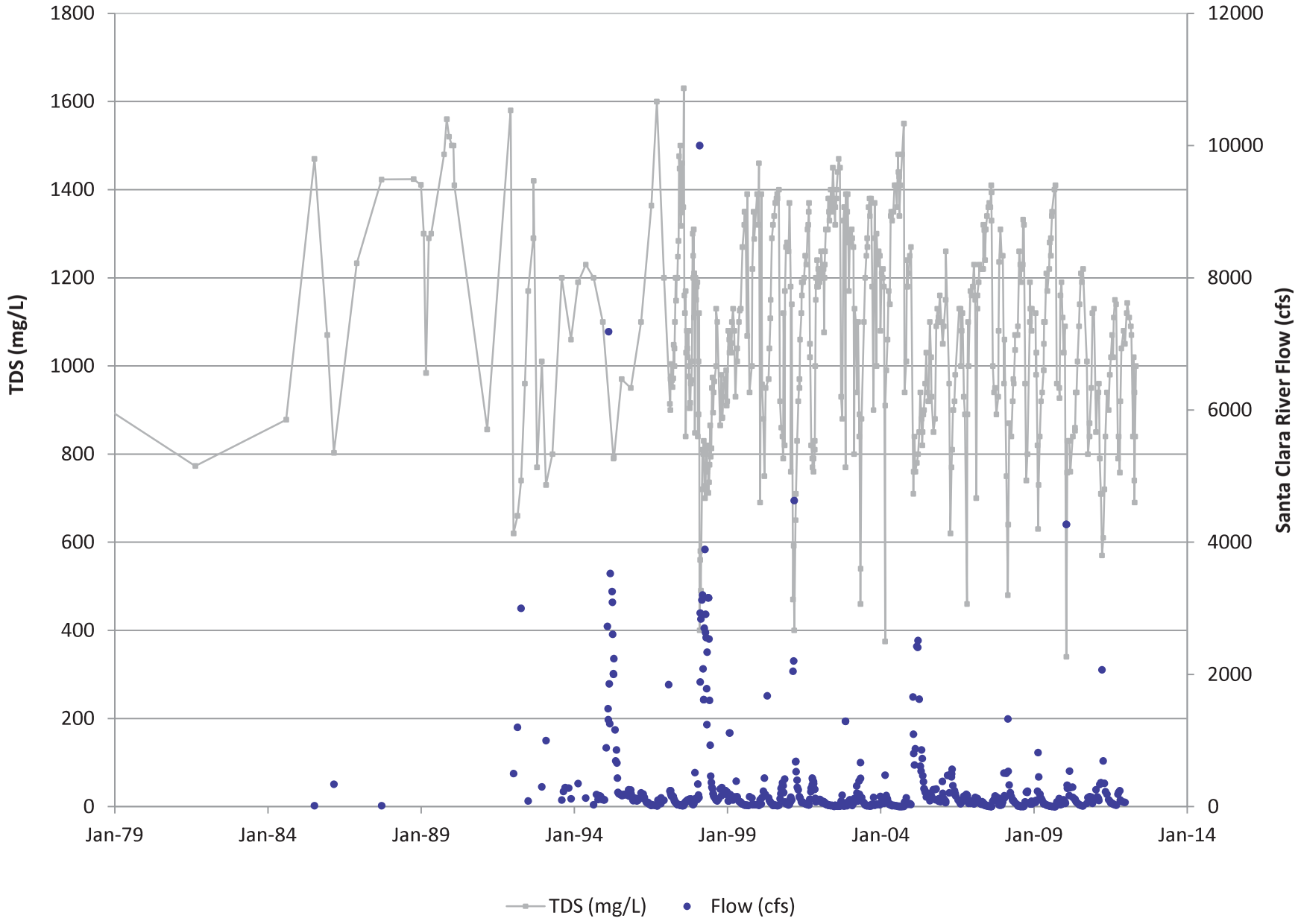


Figure 4.2-7. Historical TDS concentrations in the Santa Clara River at the Freeman Diversion

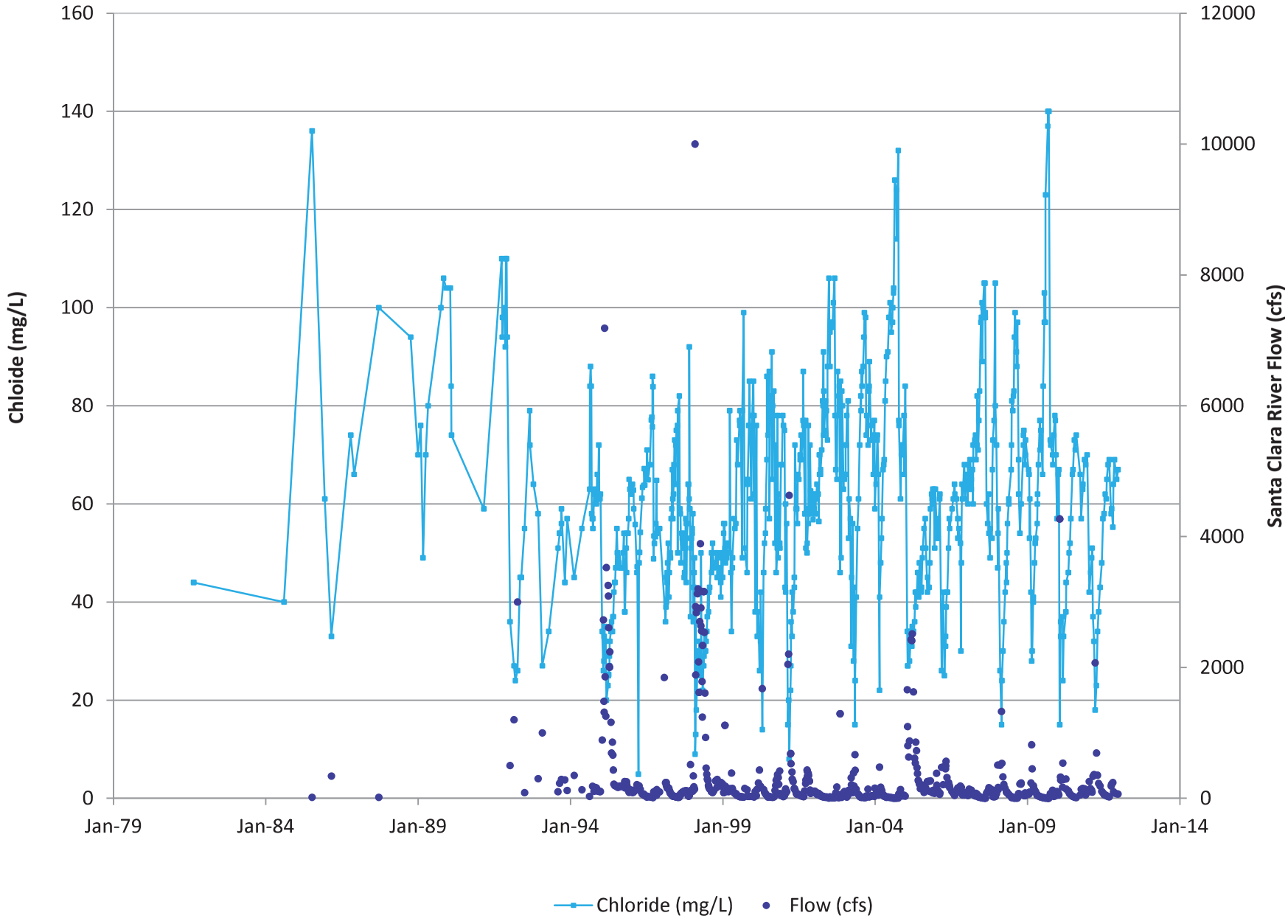


Figure 4.2-8. Historical chloride concentrations in the Santa Clara River at the Freeman Diversion

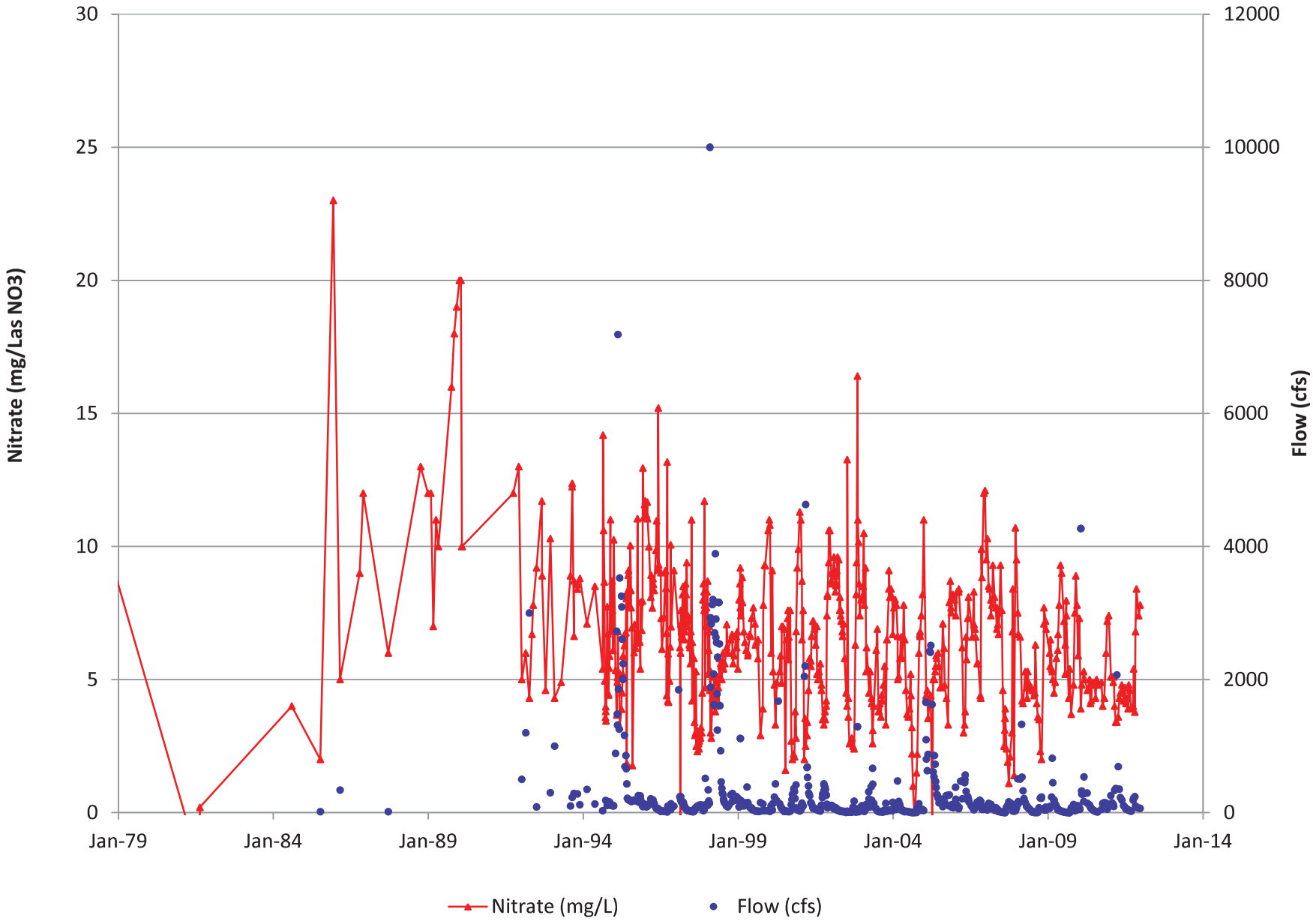


Figure 4.2-9. Historical nitrate (NO3) concentrations in the Santa Clara River at the Freeman Diversion

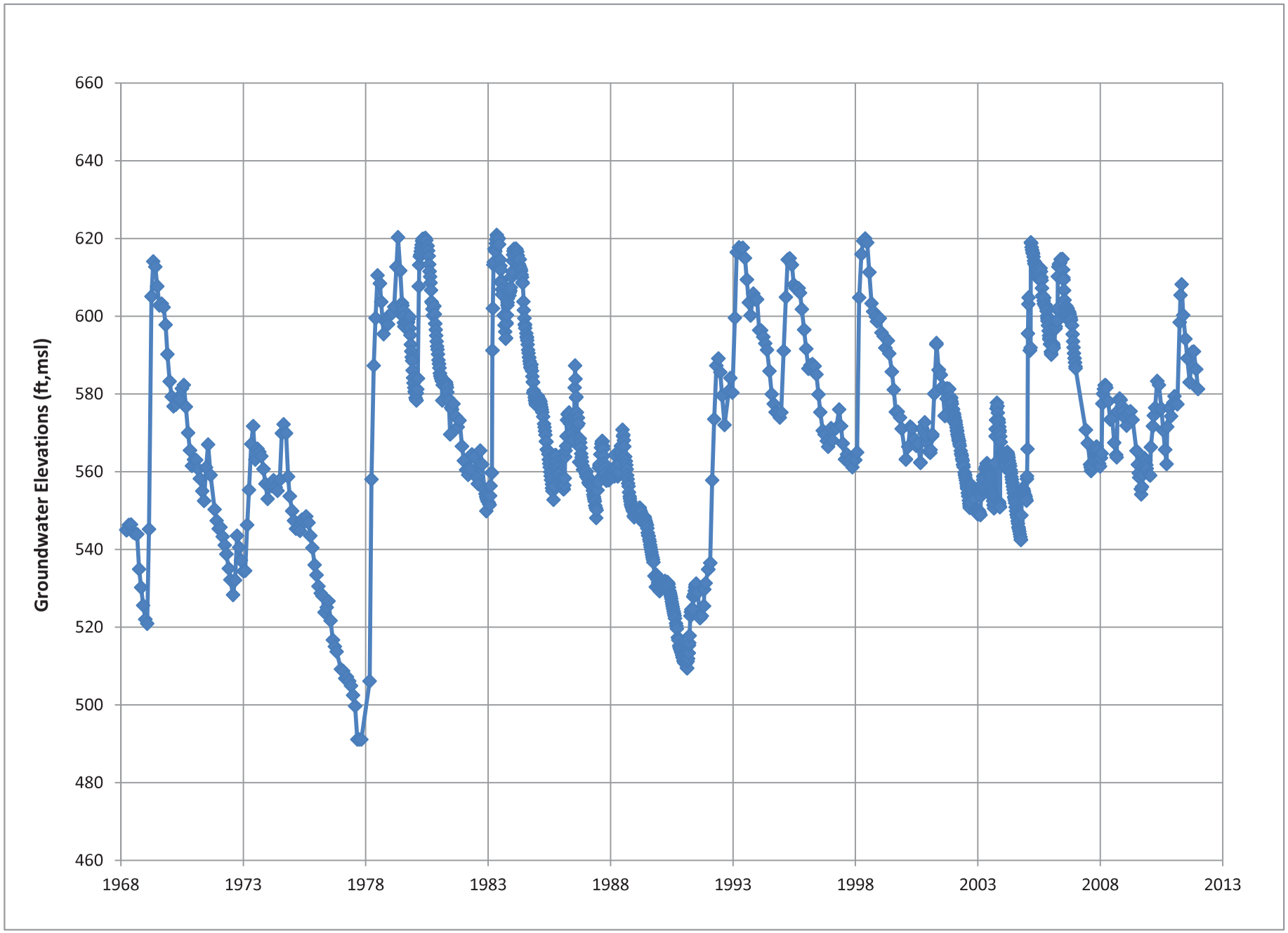


Figure 4.3-1. Historical groundwater elevations in Piru Basin key well

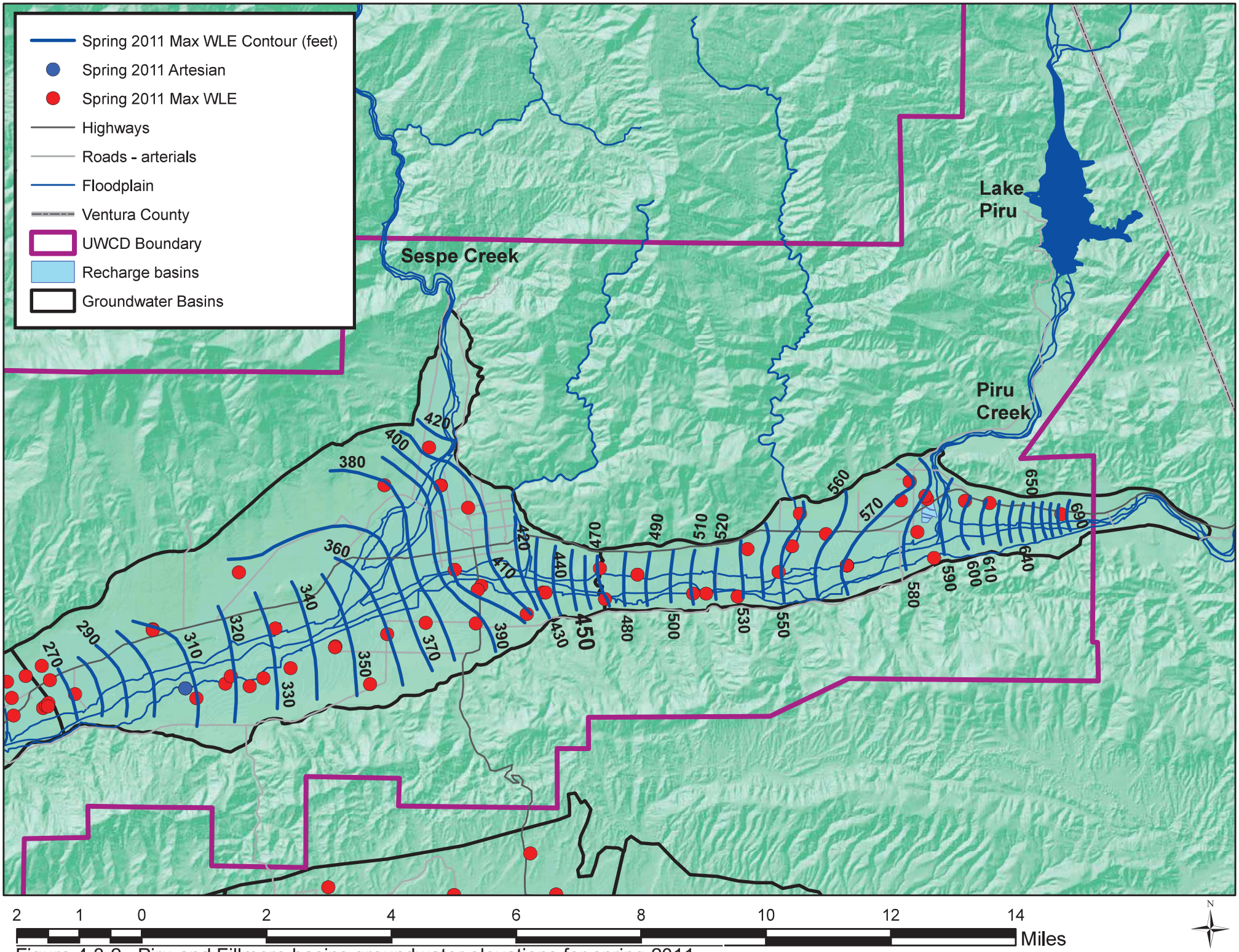


Figure 4.3-2. Piru and Fillmore basins groundwater elevations for spring 2011

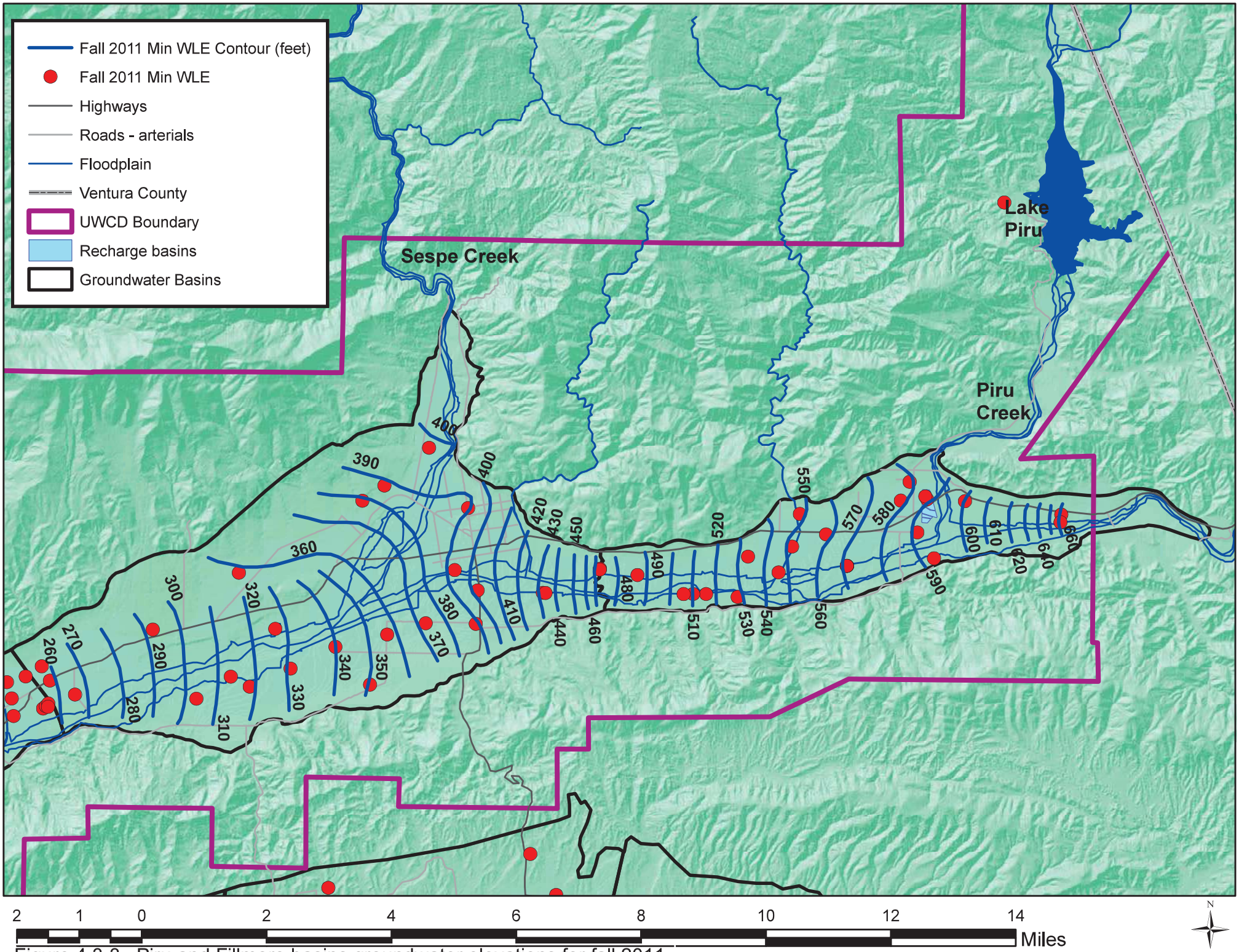


Figure 4.3-3. Piru and Fillmore basins groundwater elevations for fall 2011

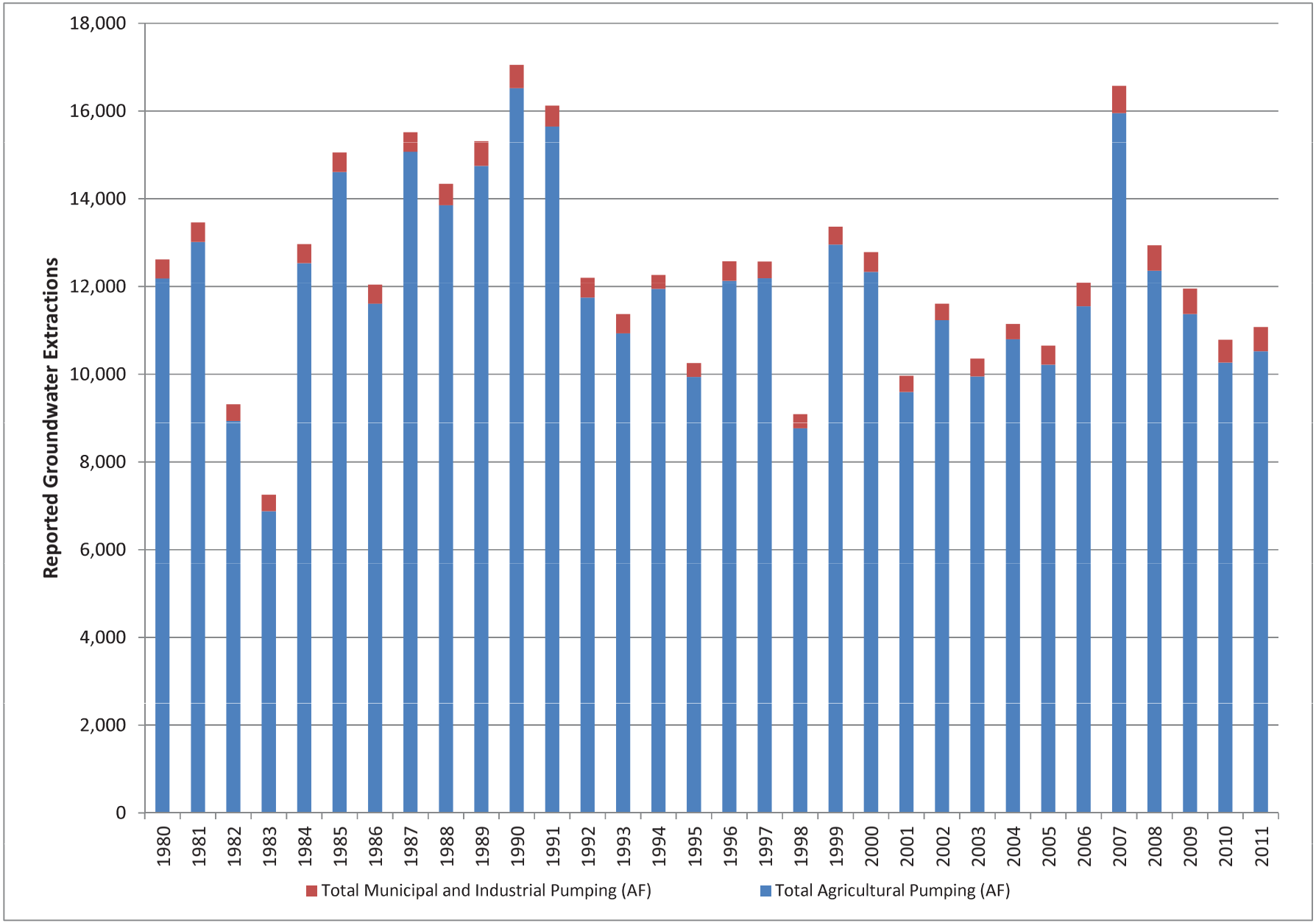


Figure 4.3-4. Historical reported groundwater extractions for the Piru Basin

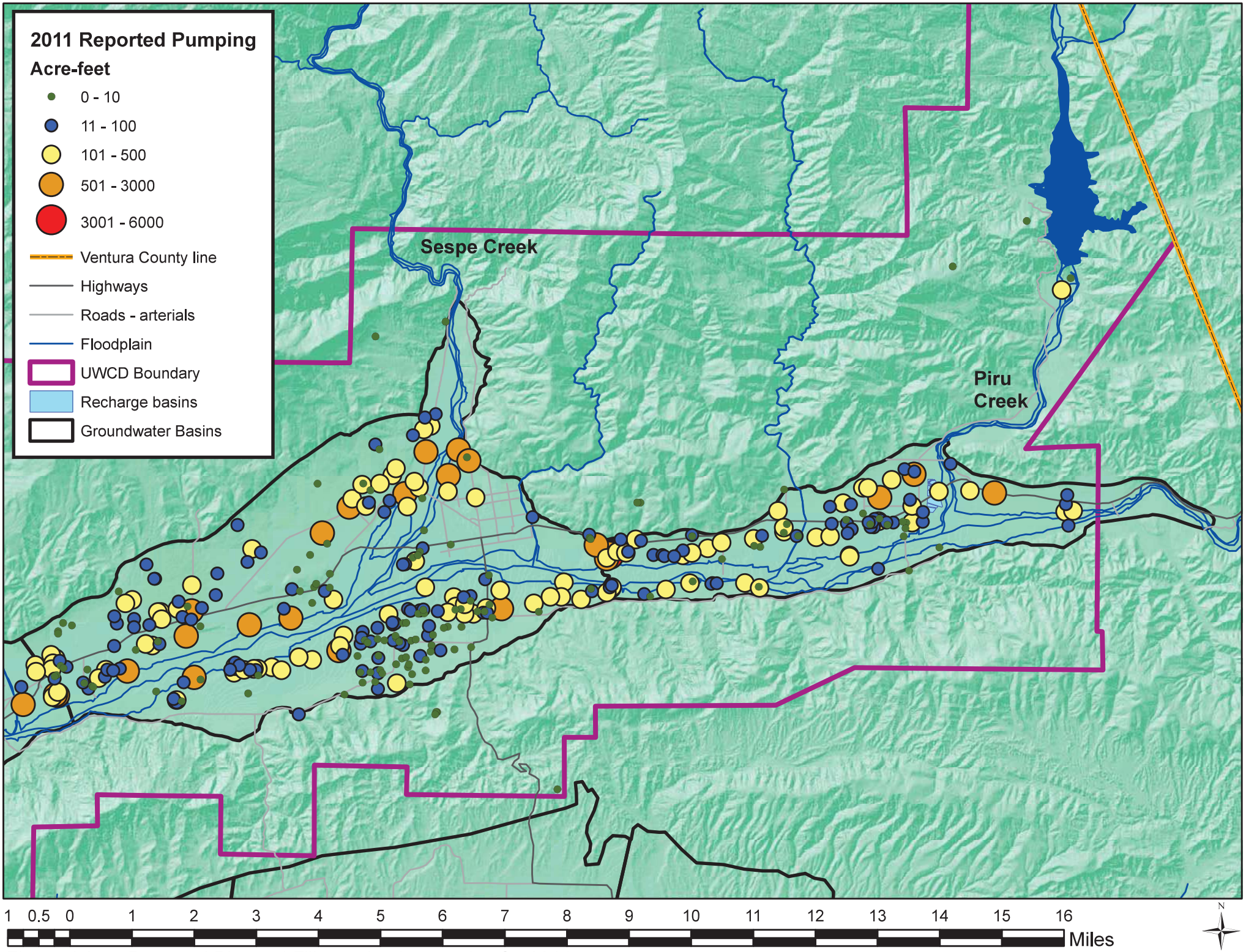


Figure 4.3-5. Reported Piru and Fillmore basin pumping for 2011

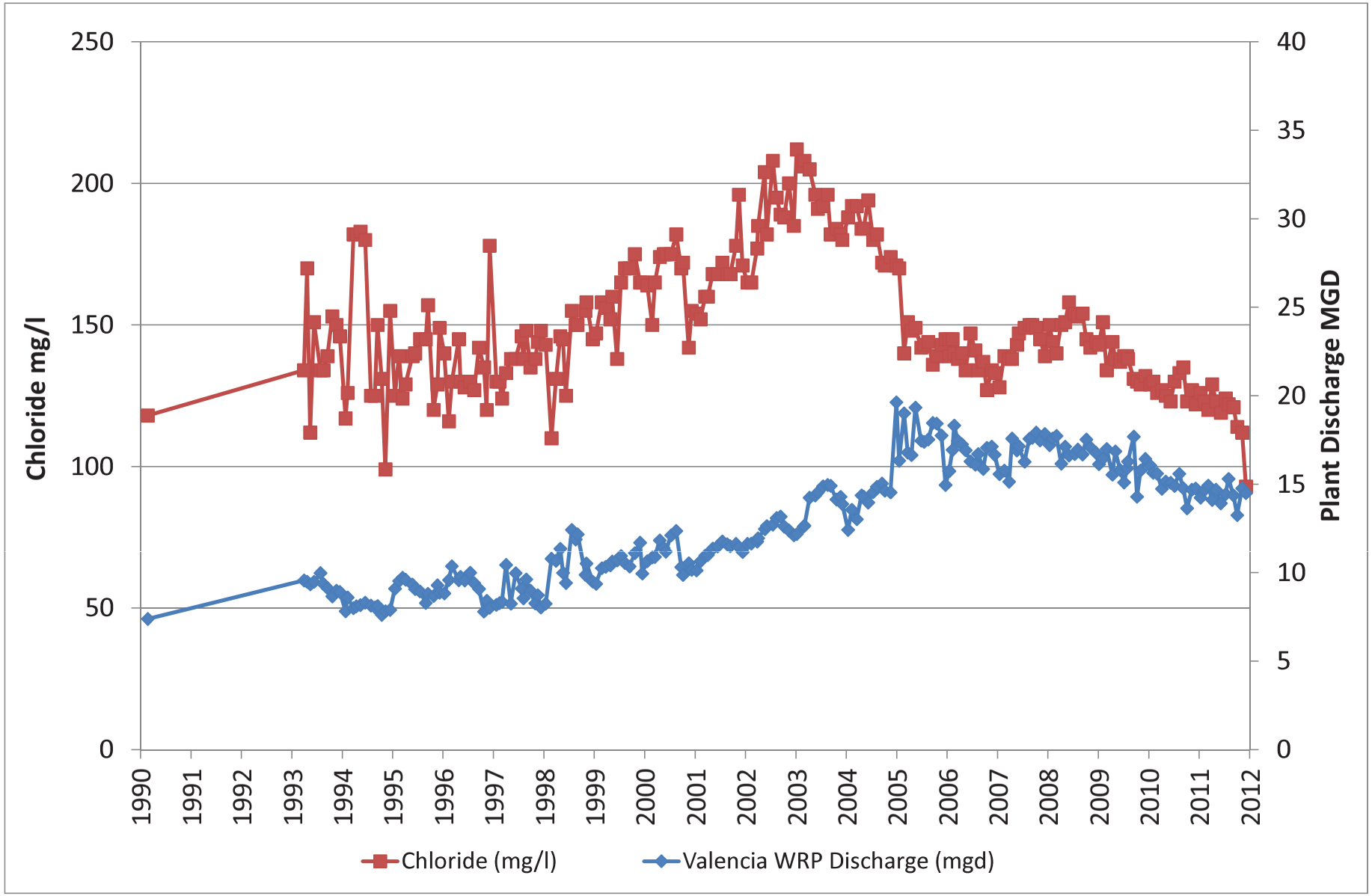


Figure 4.3-6. Historical chloride and discharge volumes at Valencia WRP

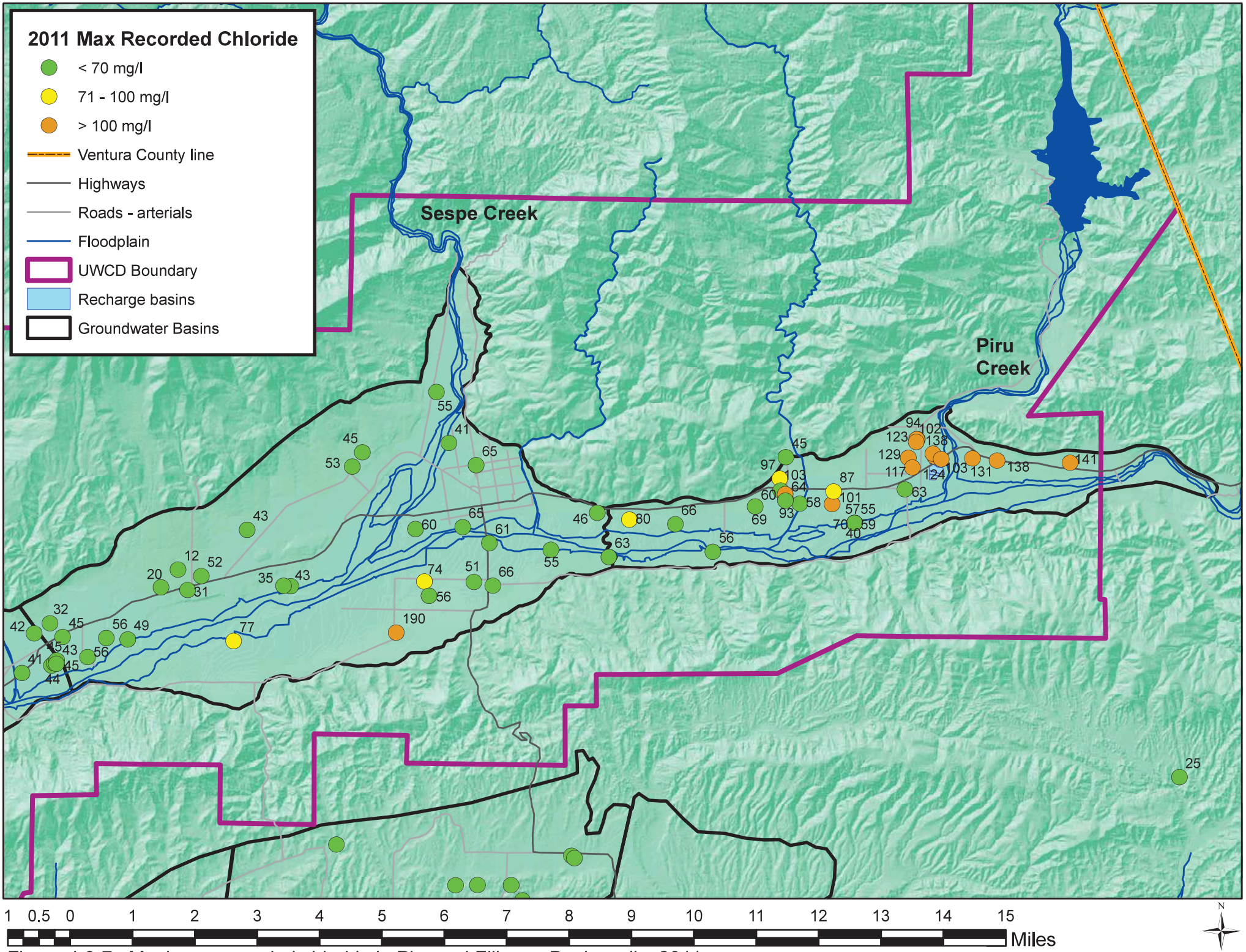


Figure 4.3-7. Maximum recorded chloride in Piru and Fillmore Basin wells, 2011

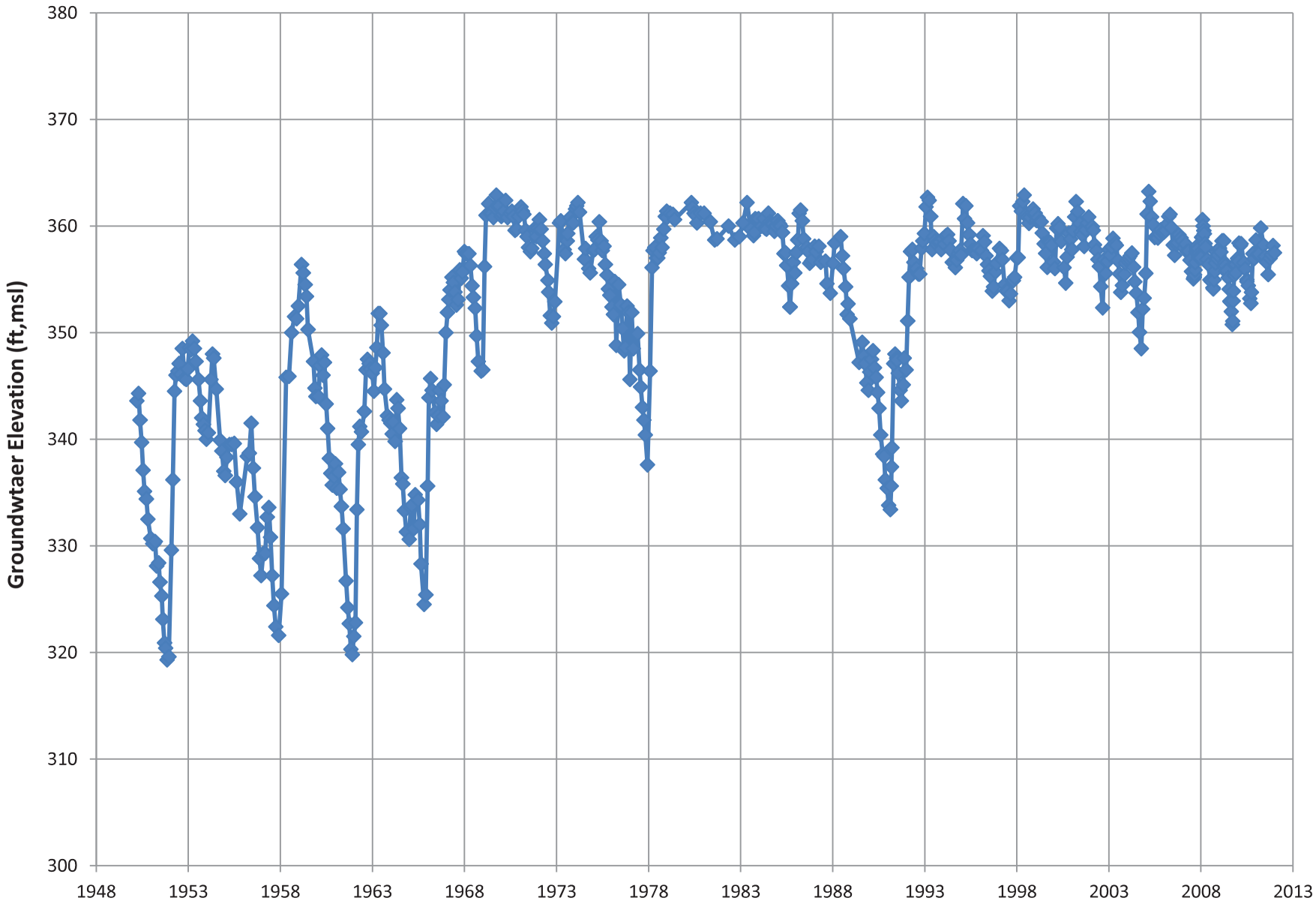


Figure 4.3-8. Historical groundwater elevations in Fillmore Basin key well

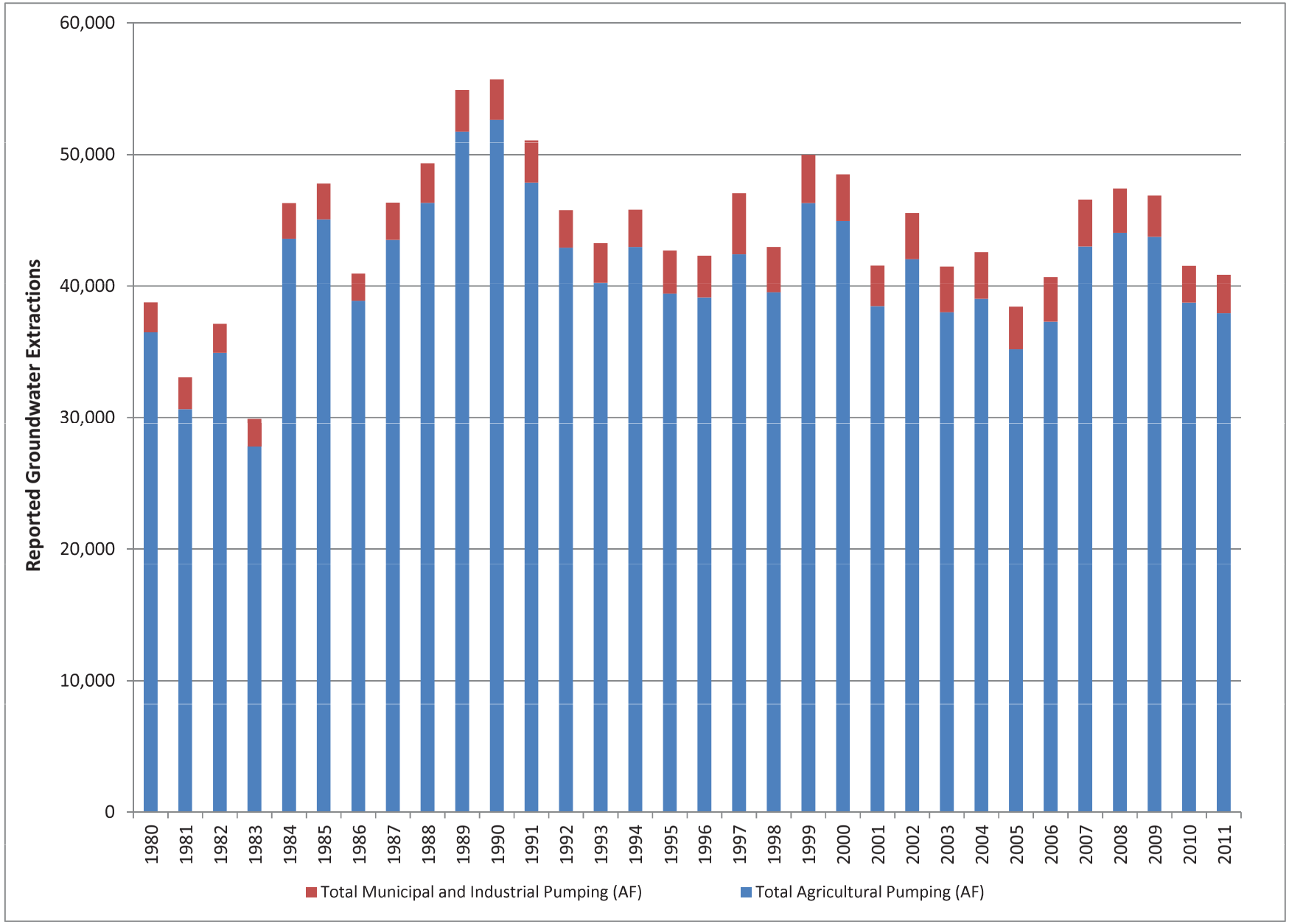


Figure 4.3-9. Historical reported groundwater extractions for the Fillmore Basin

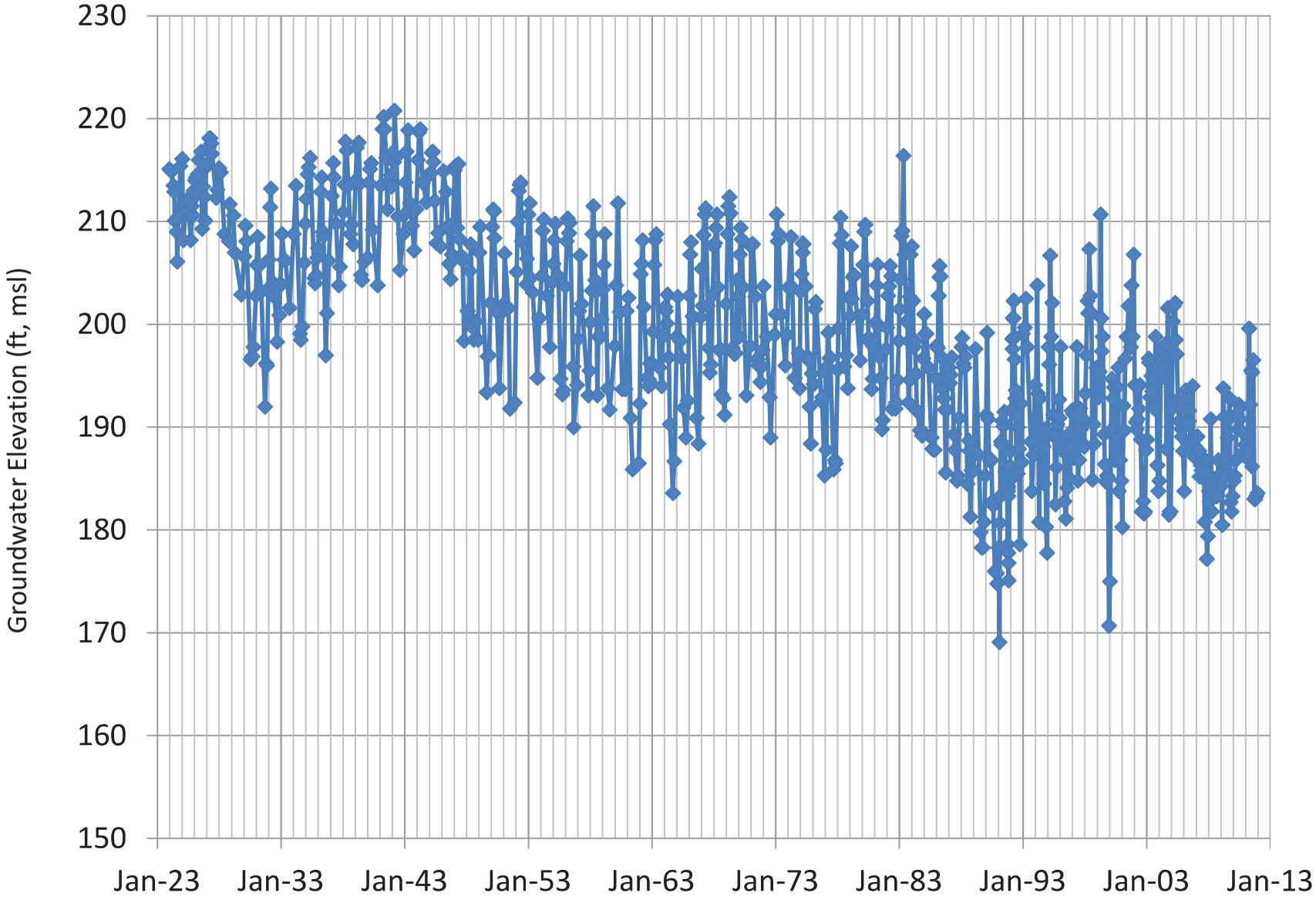


Figure 4.3-10. Historical groundwater elevations in Santa Paula Basin key well

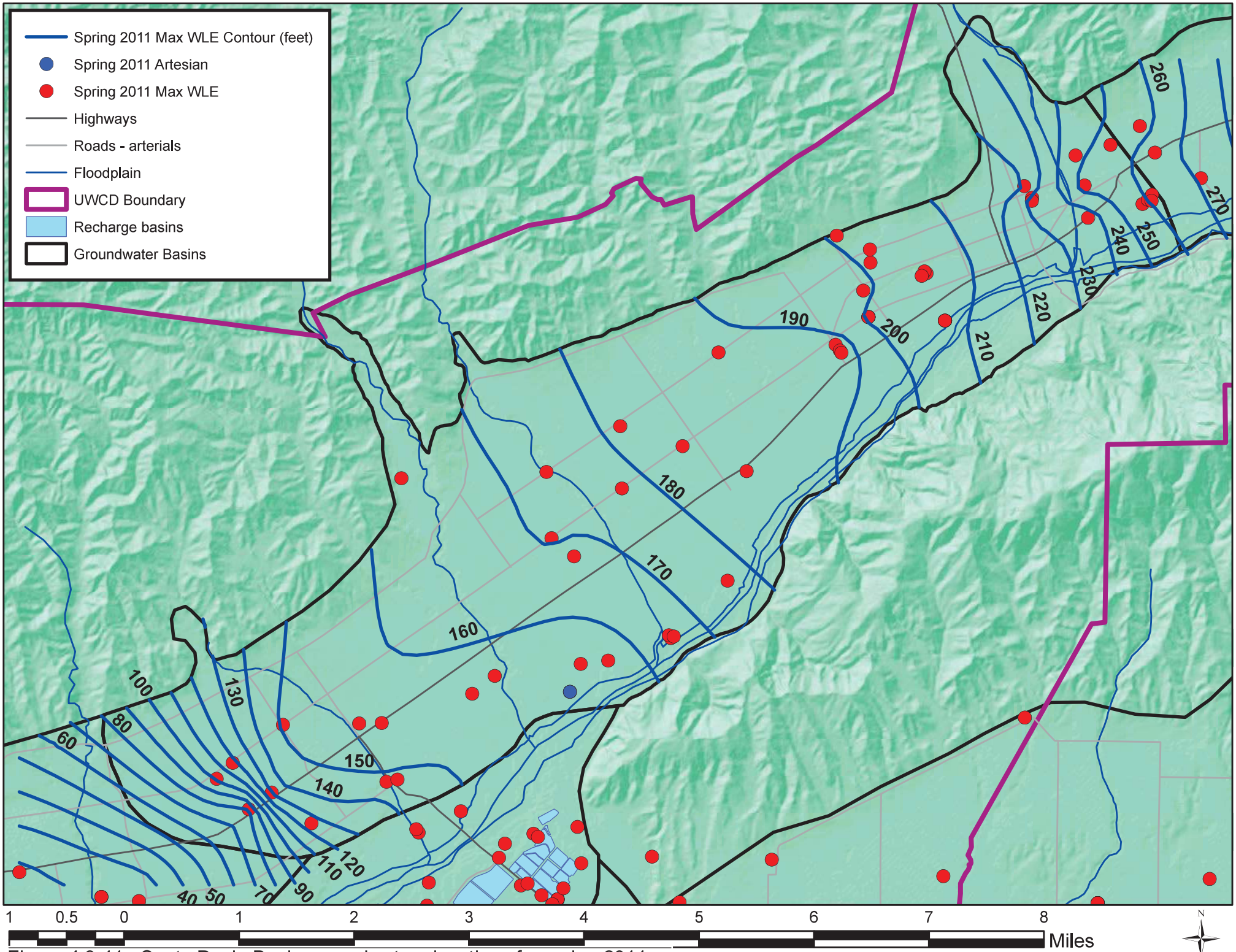


Figure 4.3-11. Santa Paula Basin groundwater elevations for spring 2011

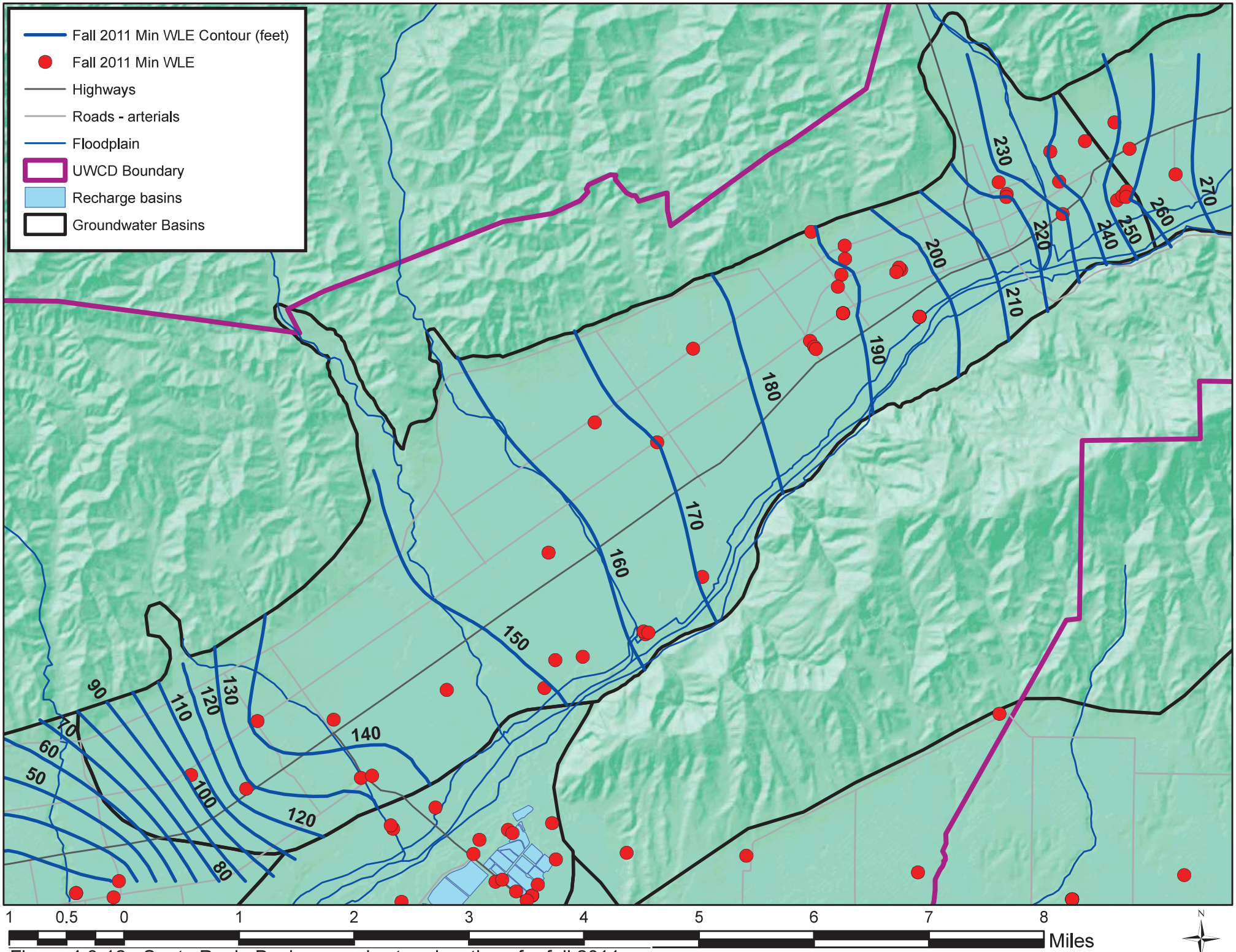


Figure 4.3-12. Santa Paula Basin groundwater elevations for fall 2011

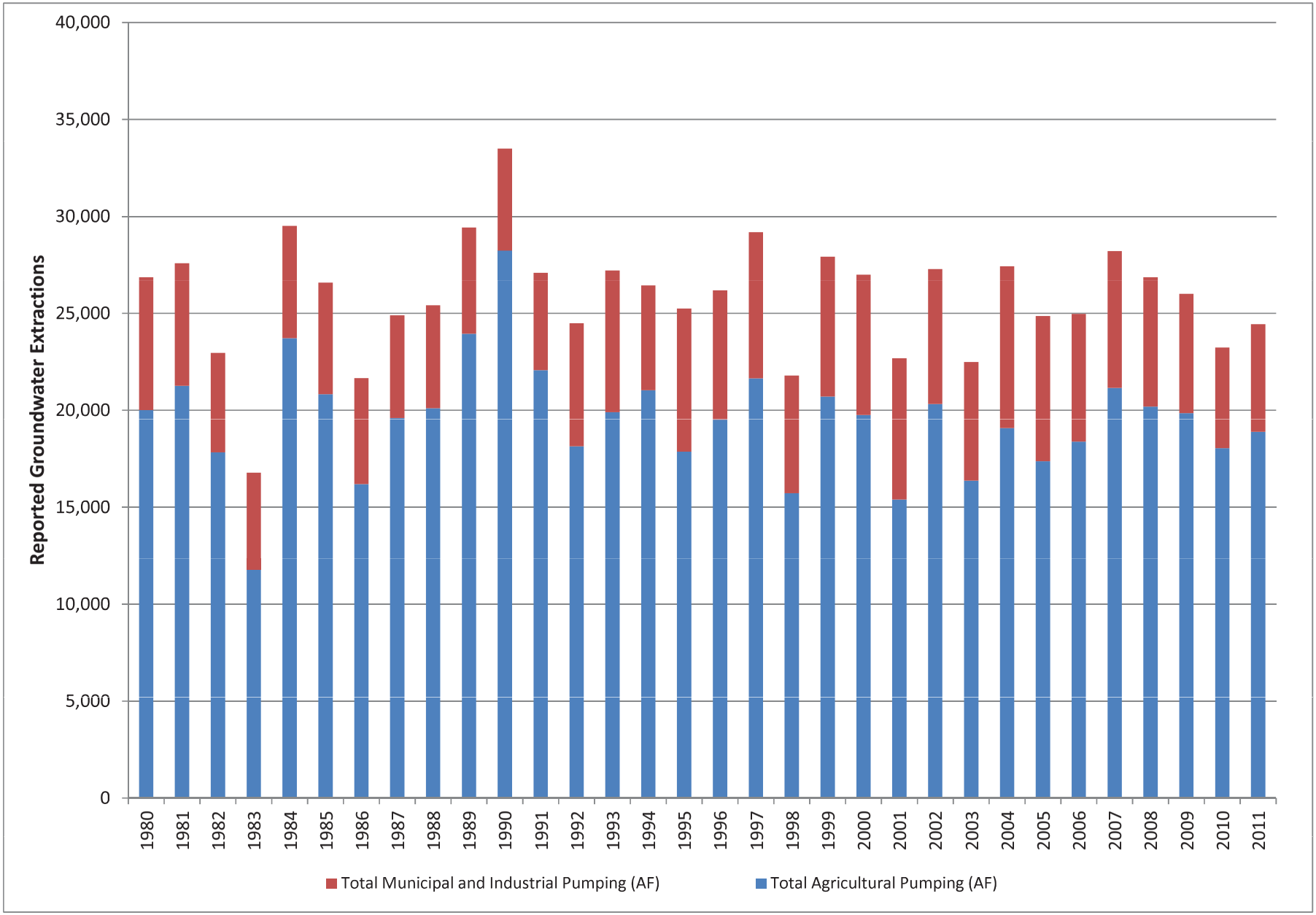


Figure 4.3-13. Historical reported groundwater extractions for the Santa Paula Basin

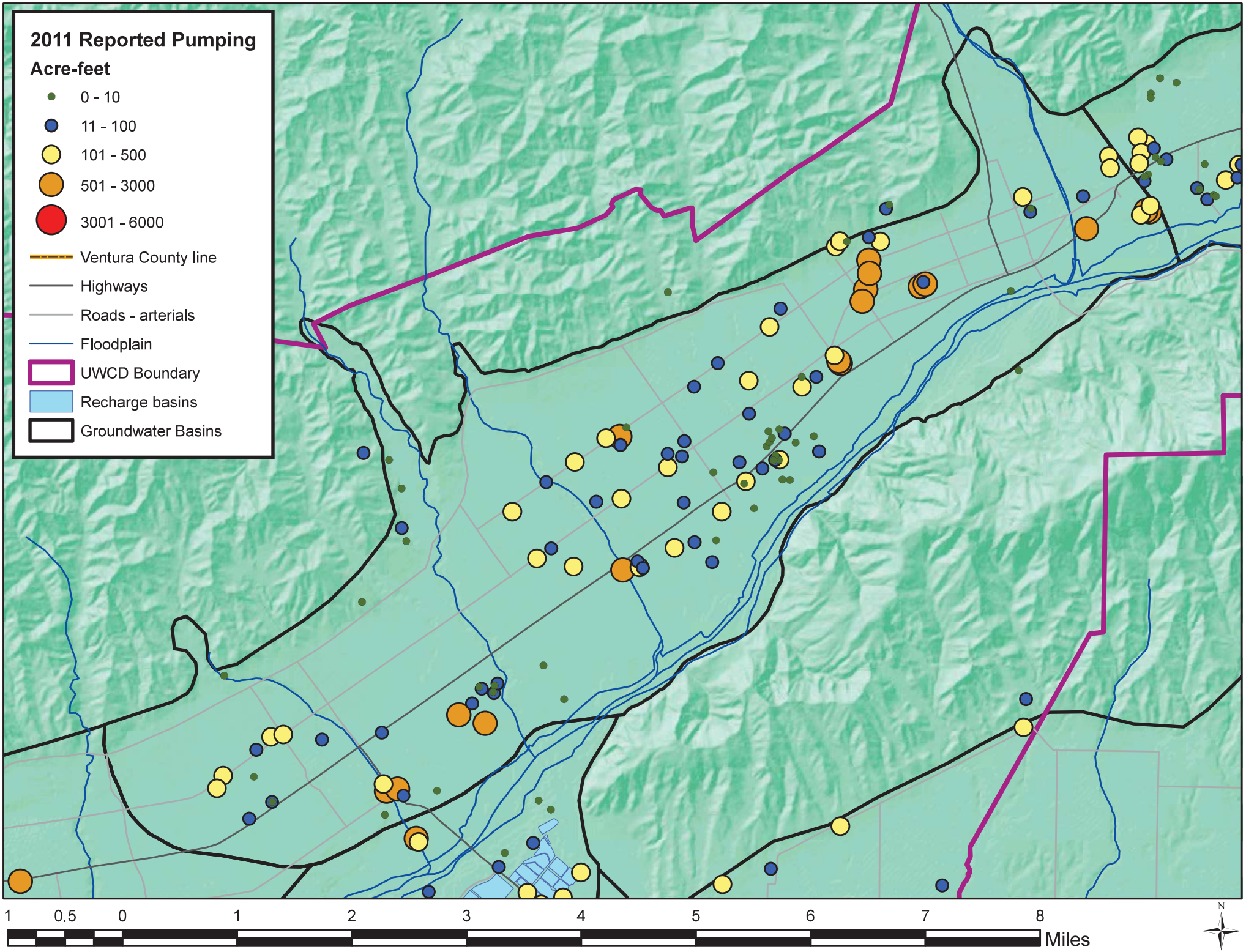


Figure 4.3-14. Reported Santa Paula Basin pumping for 2011

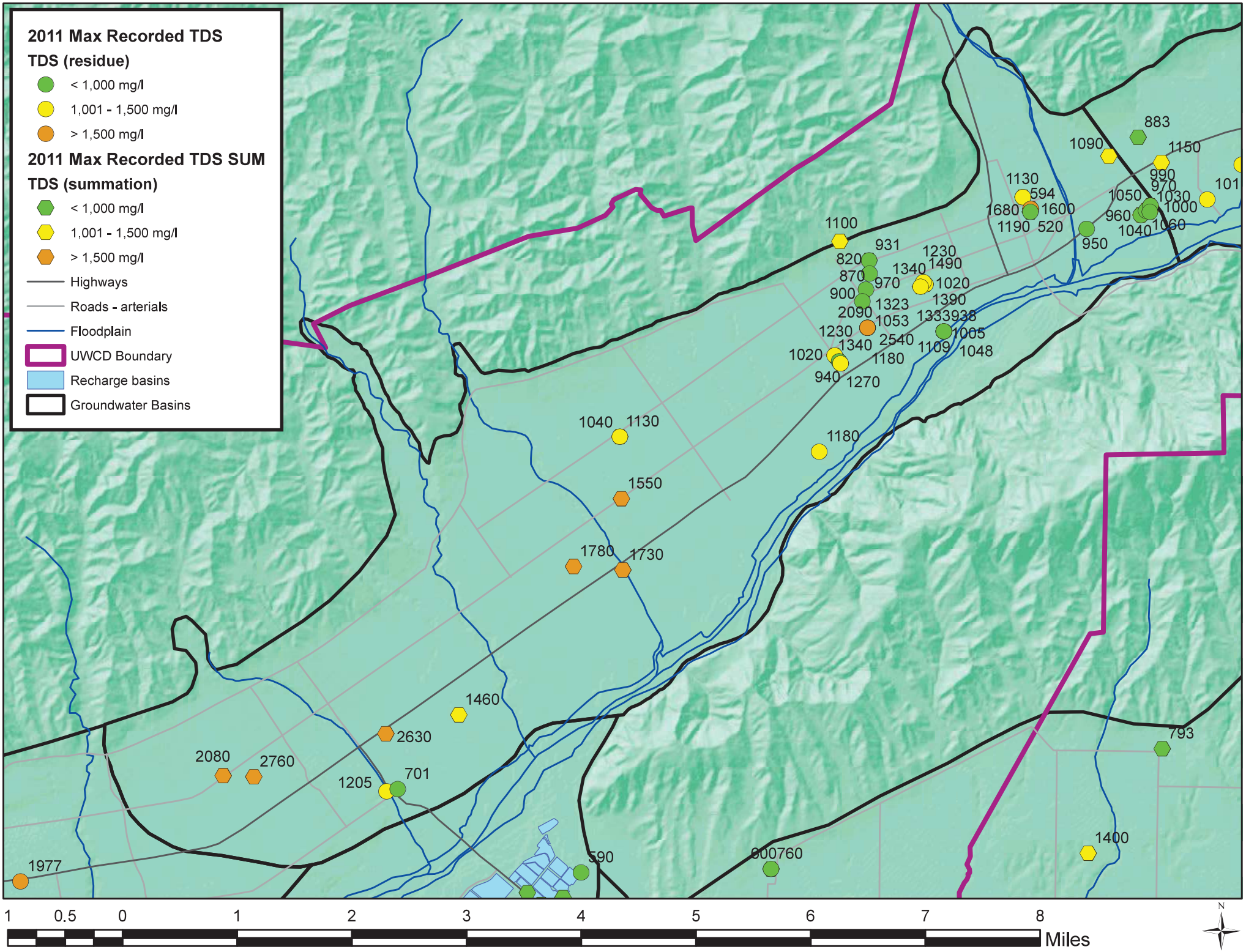


Figure 4.3-15. Maximum recorded TDS in Santa Paula Basin wells, 2011

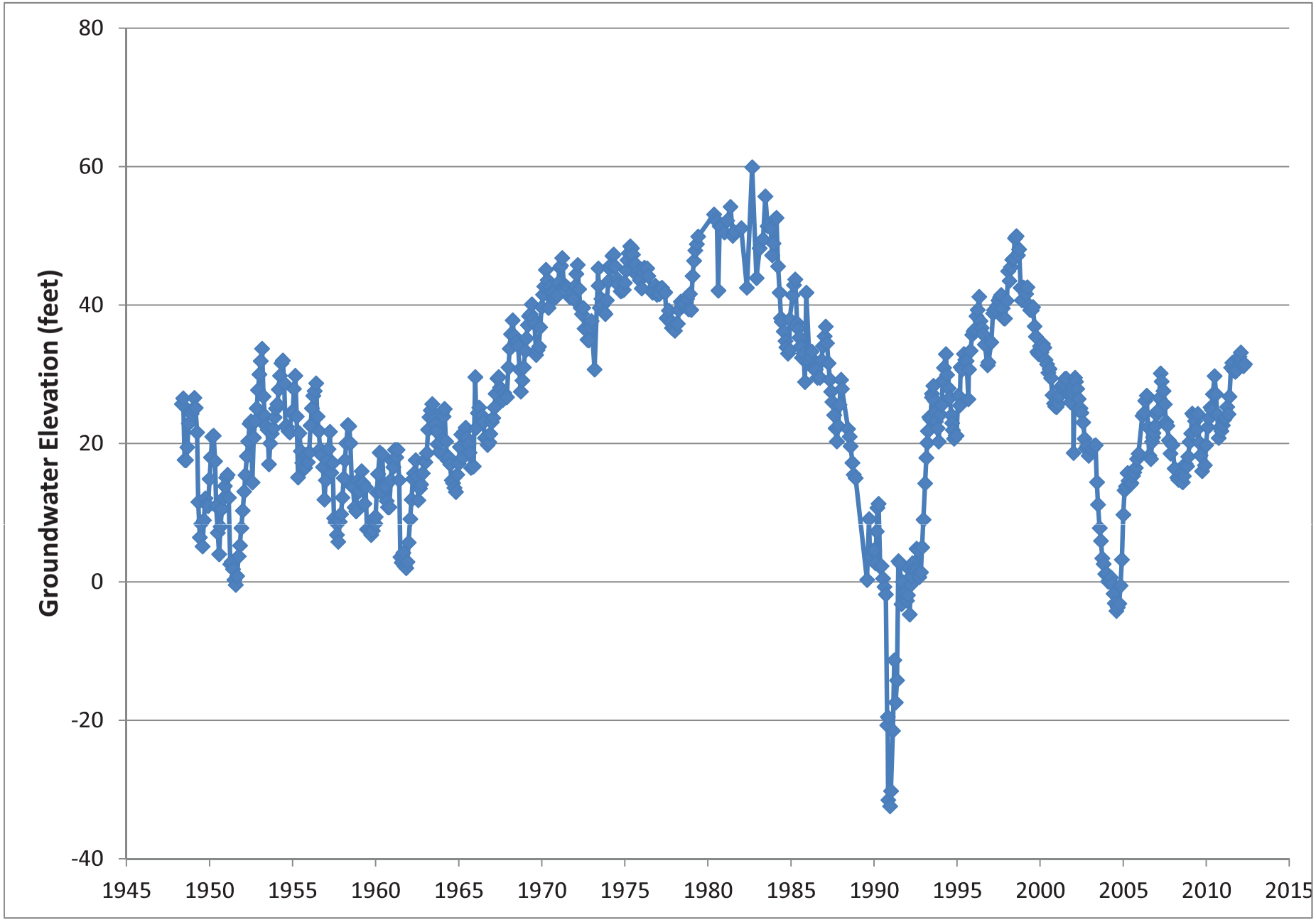


Figure 4.3-16. Historical groundwater elevations in Mound Basin key well

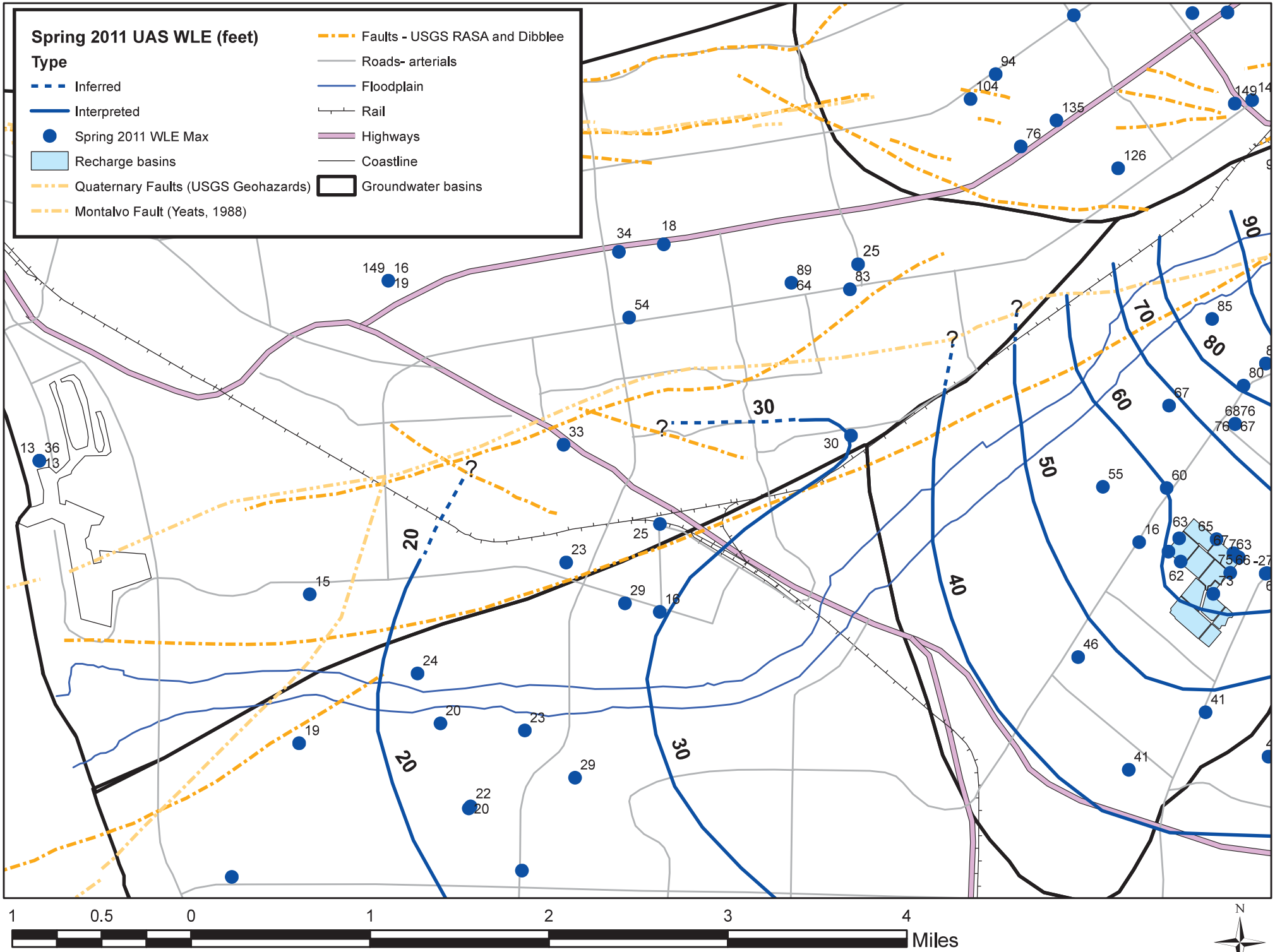


Figure 4.3-17. Mound Basin groundwater elevations for spring 2011

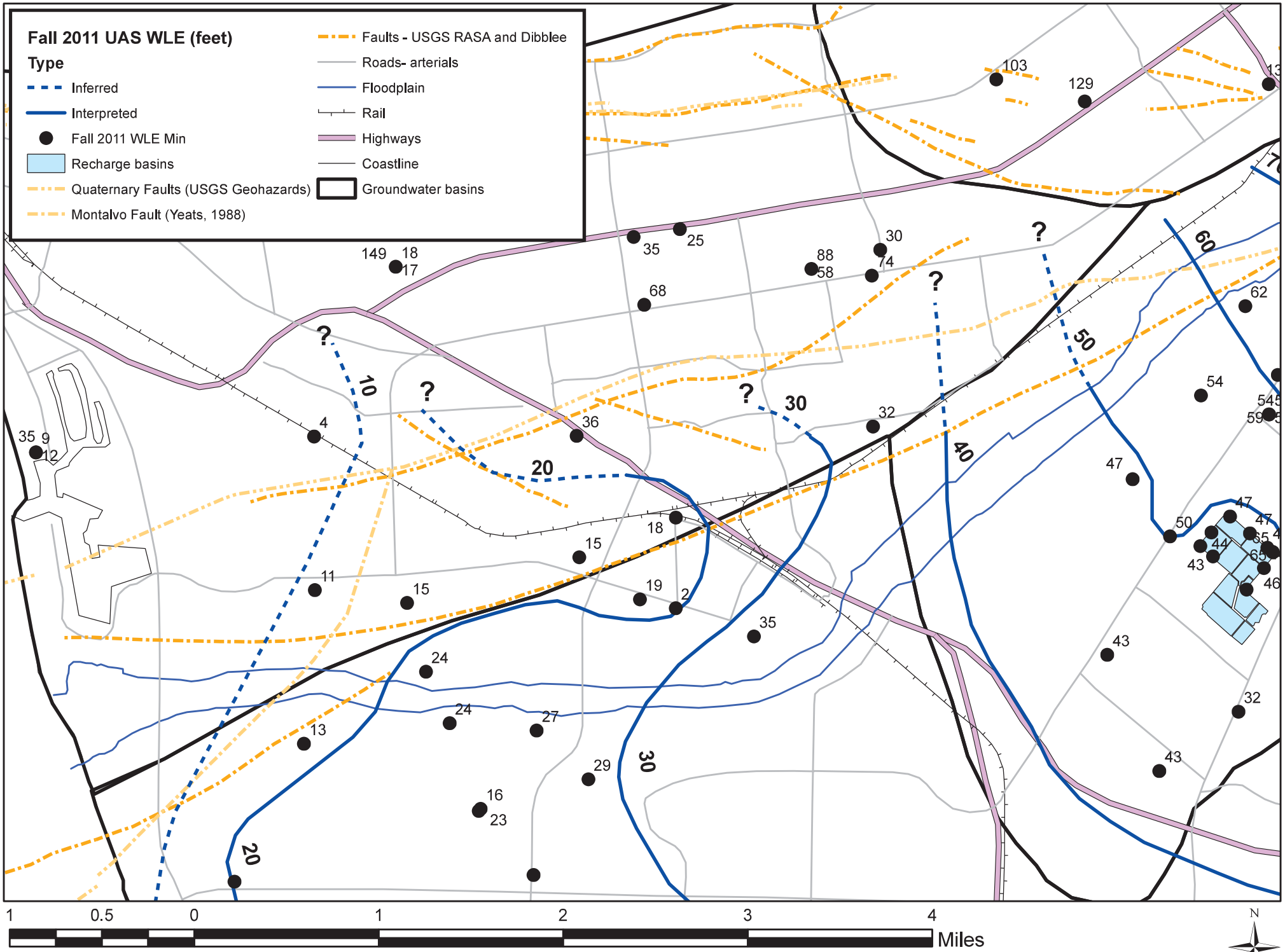


Figure 4.3-18. Mound Basin groundwater elevations for fall 2011

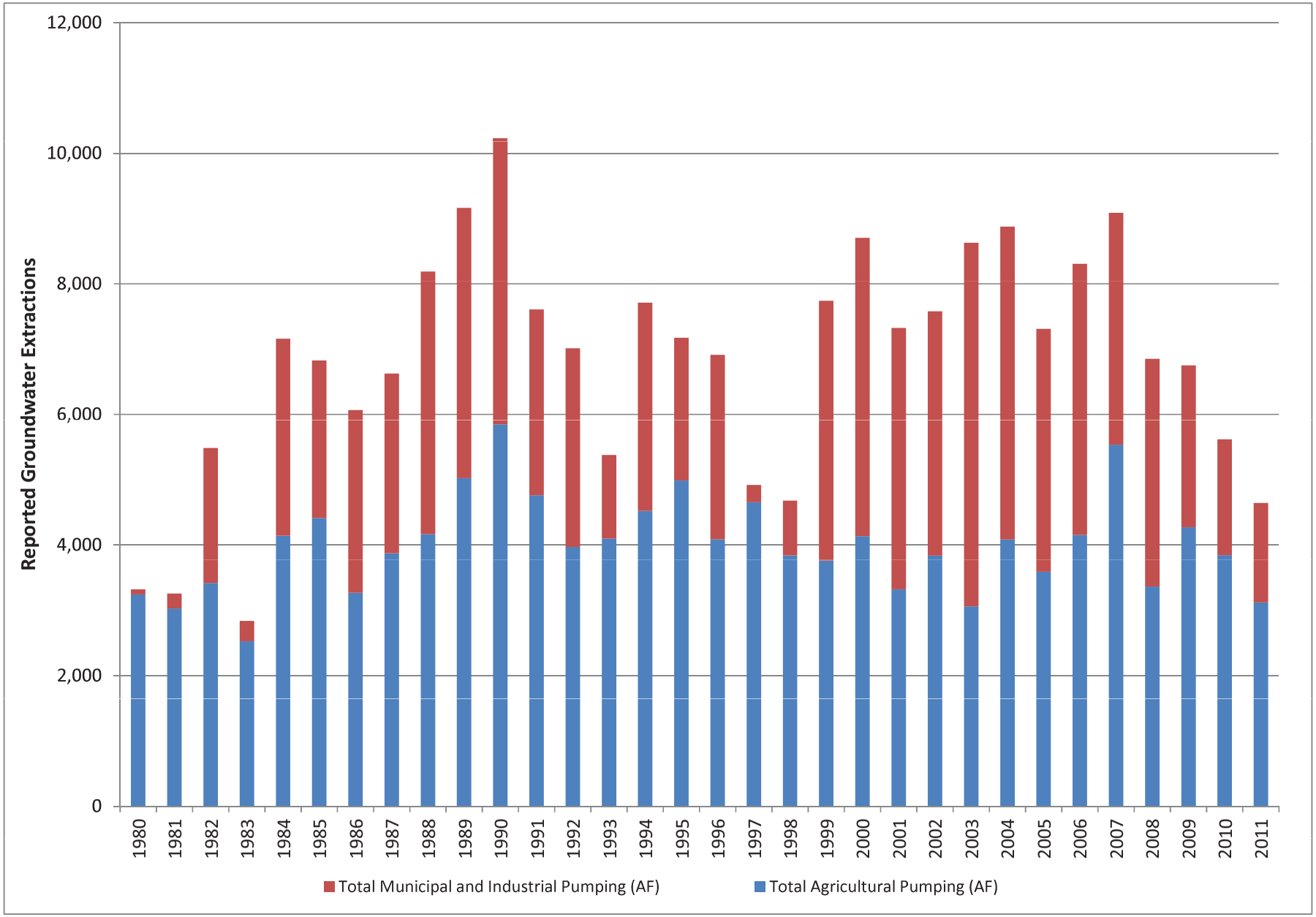


Figure 4.3-19. Historical reported groundwater extractions for the Mound Basin

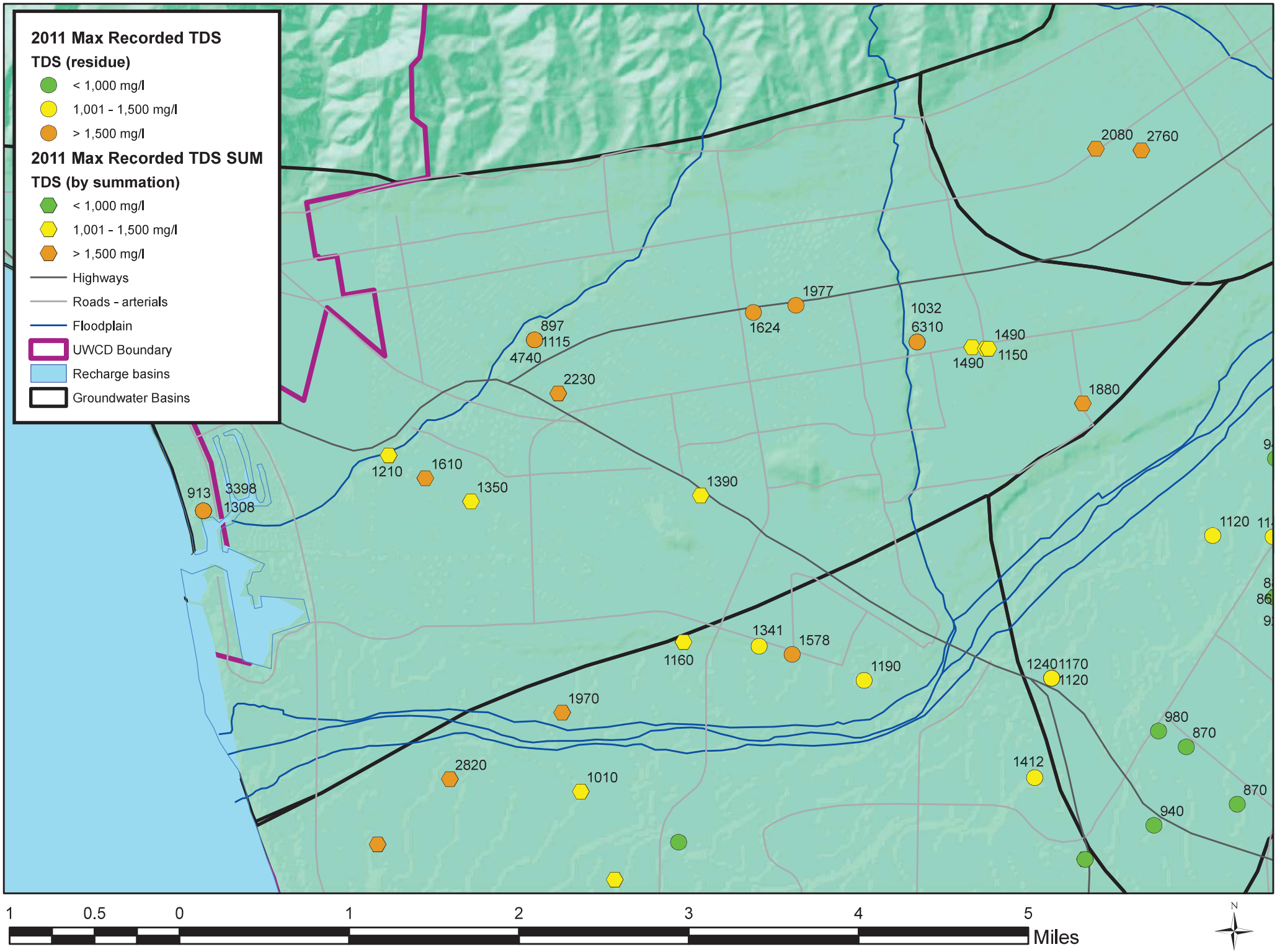


Figure 4.3-20. Maximum recorded TDS in Mound Basin wells, 2011

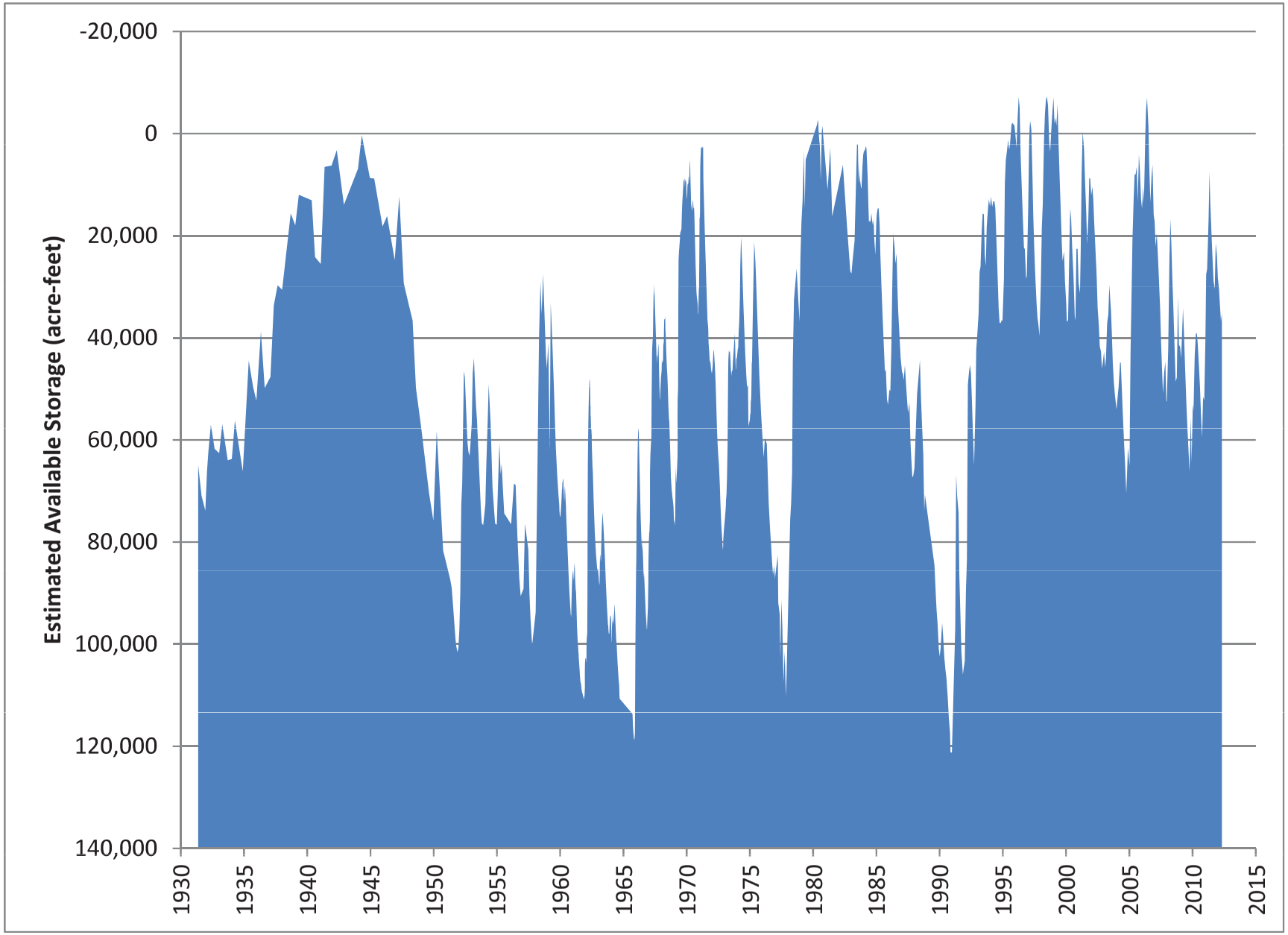


Figure 4.3-21. Historical estimates of available groundwater storage, Oxnard Forebay Basin

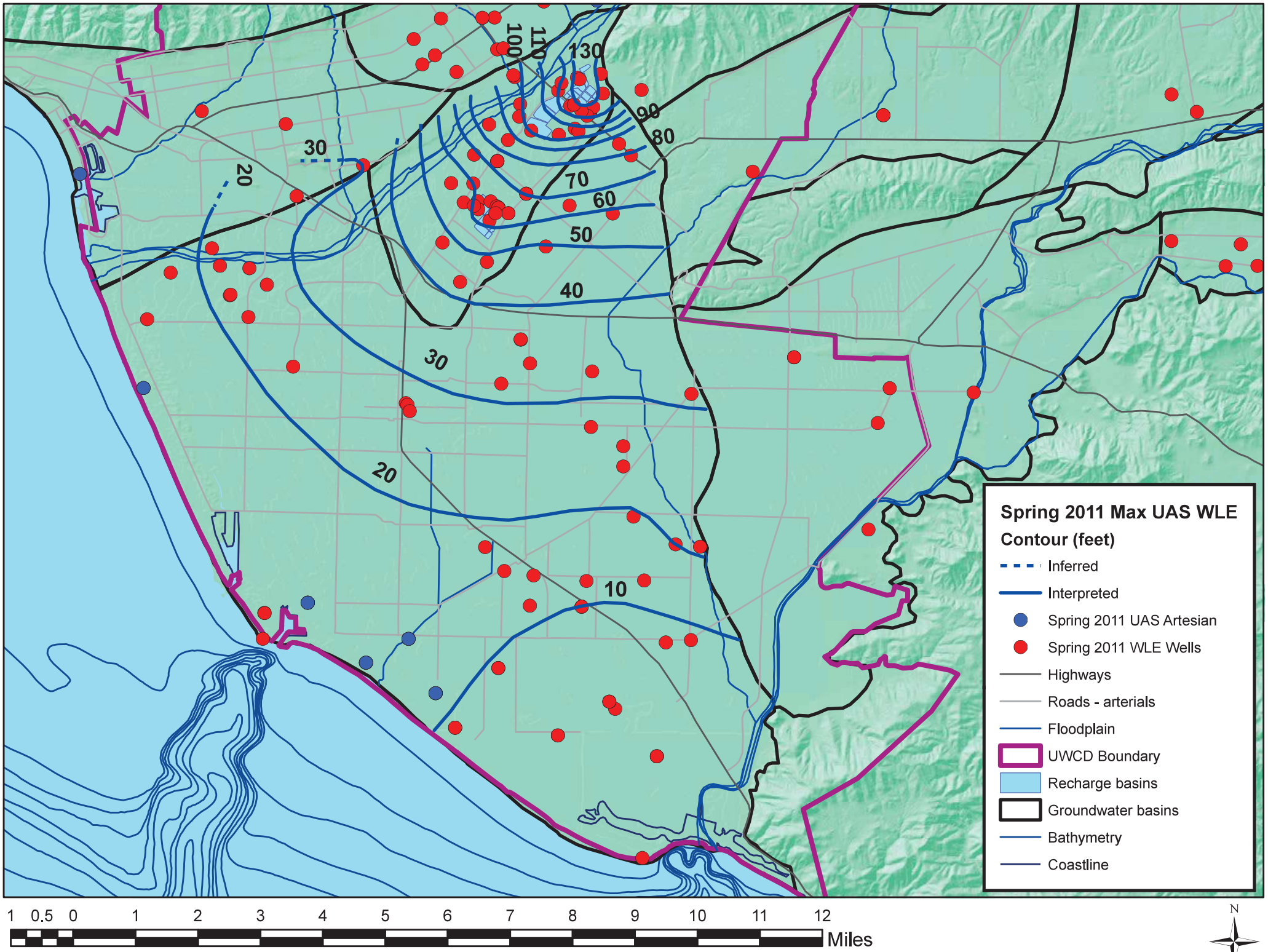


Figure 4.3-22. Oxnard Forebay-Oxnard Plain Upper Aquifer System (UAS) groundwater elevations for spring 2011

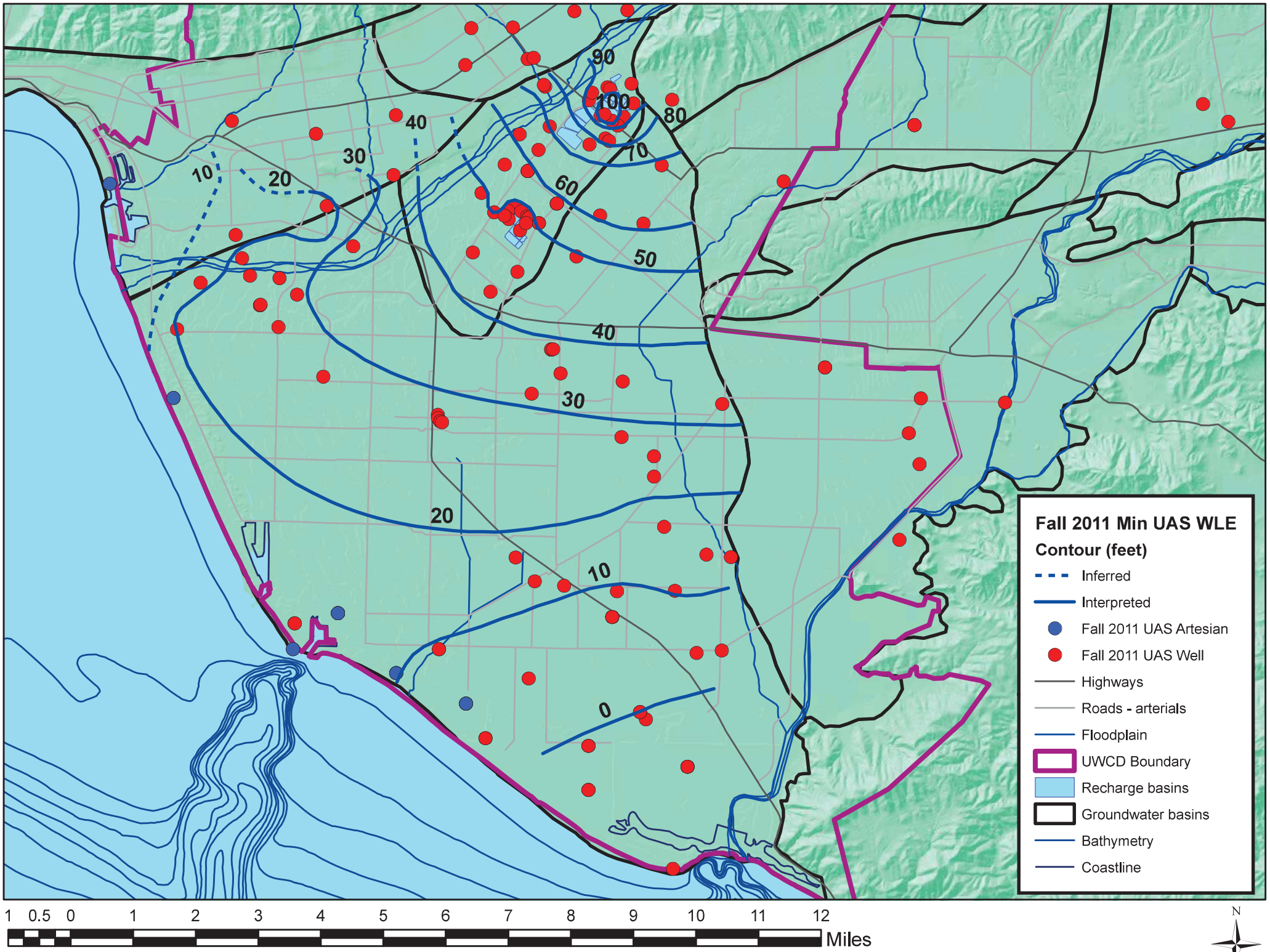
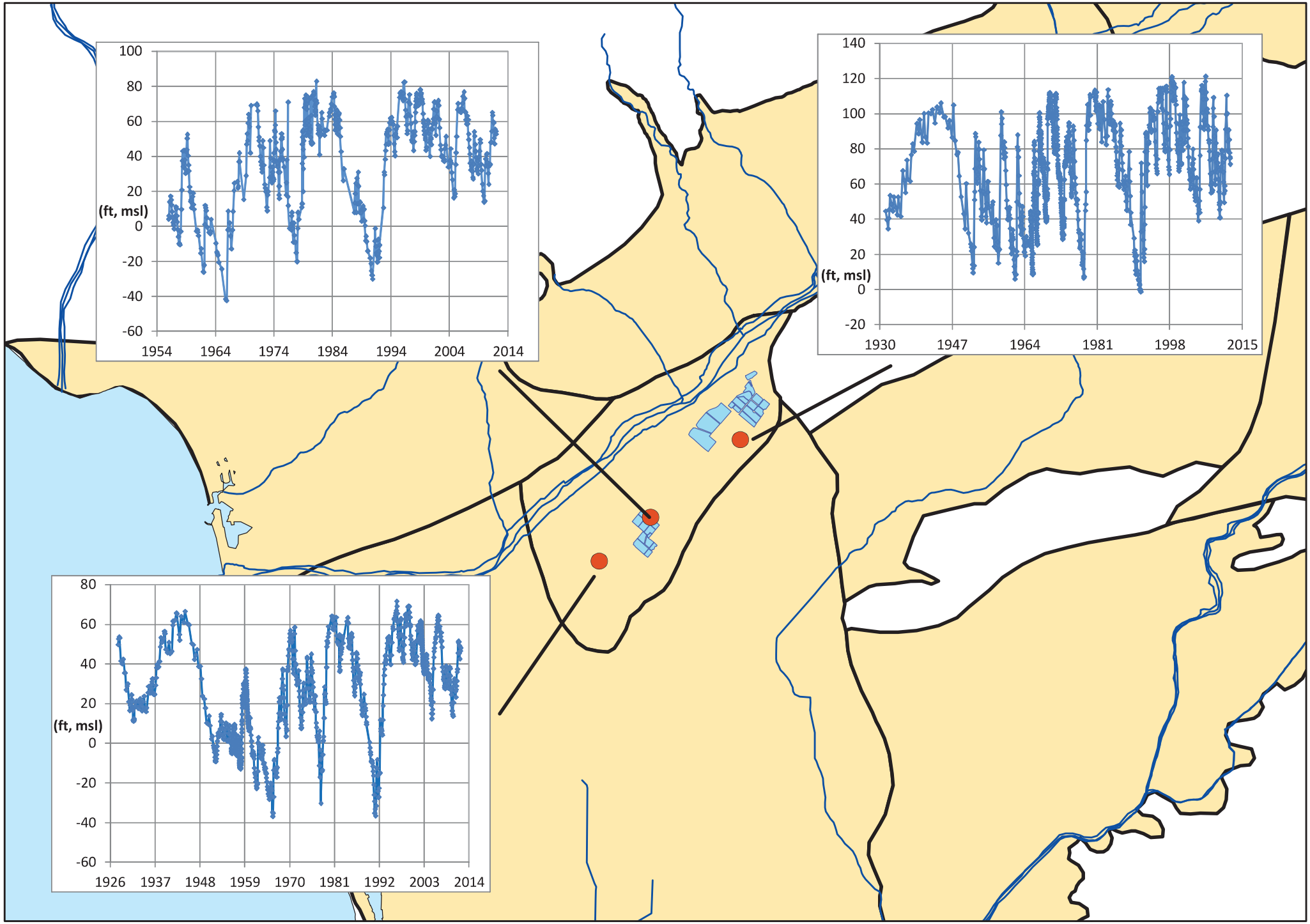


Figure 4.3-23. Oxnard Forebay-Oxnard Plain Upper Aquifer System (UAS) groundwater elevations for fall 2011



1 0.5 0 1 2 3 4 5 6 7 8 9 10 Miles

N W E S

Figure 4.3-24. Oxnard Forebay Upper Aquifer System (UAS) groundwater elevation hydrographs, selected wells

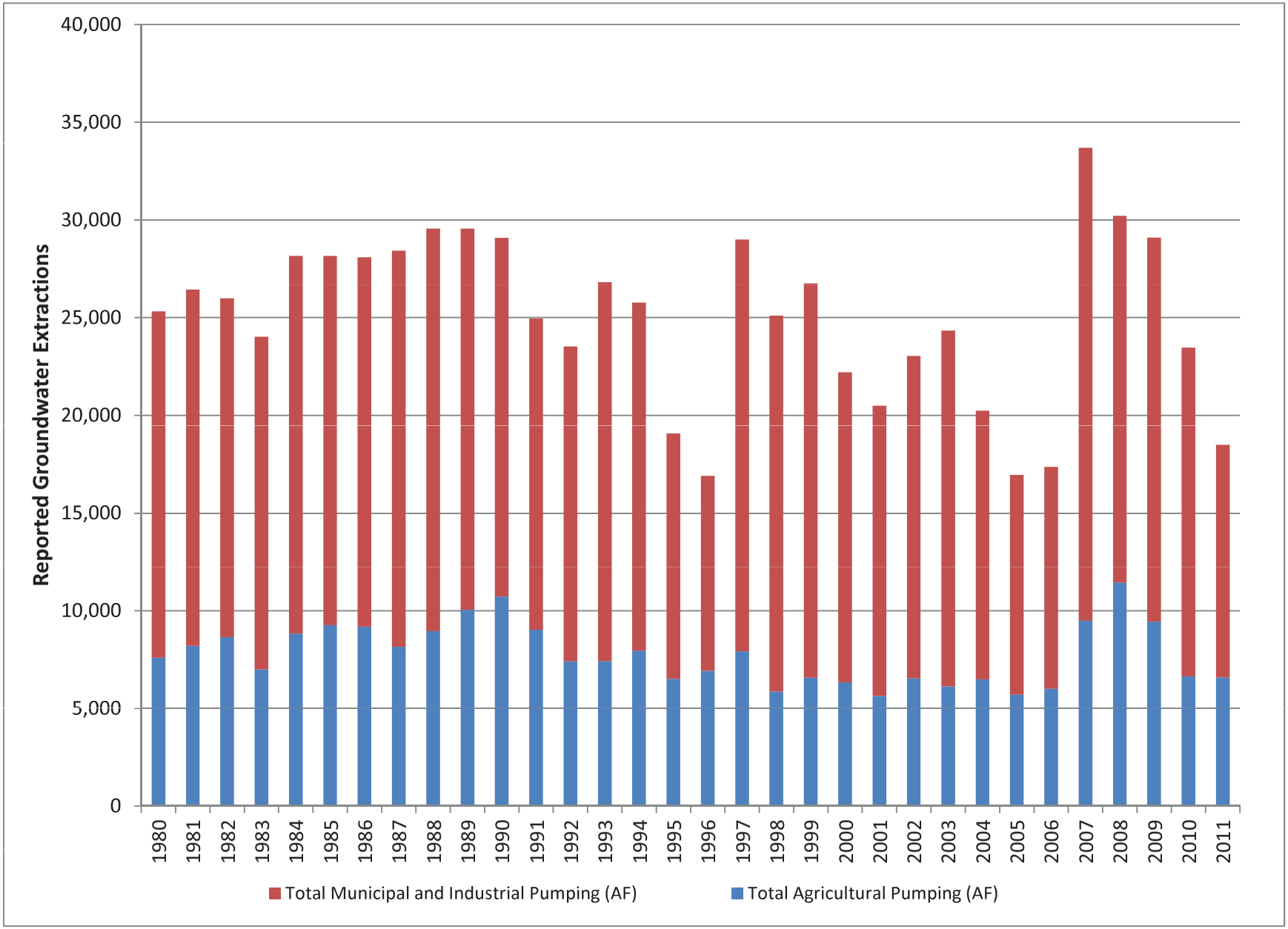


Figure 4.3-25. Historical reported groundwater extractions for the Oxnard Forebay

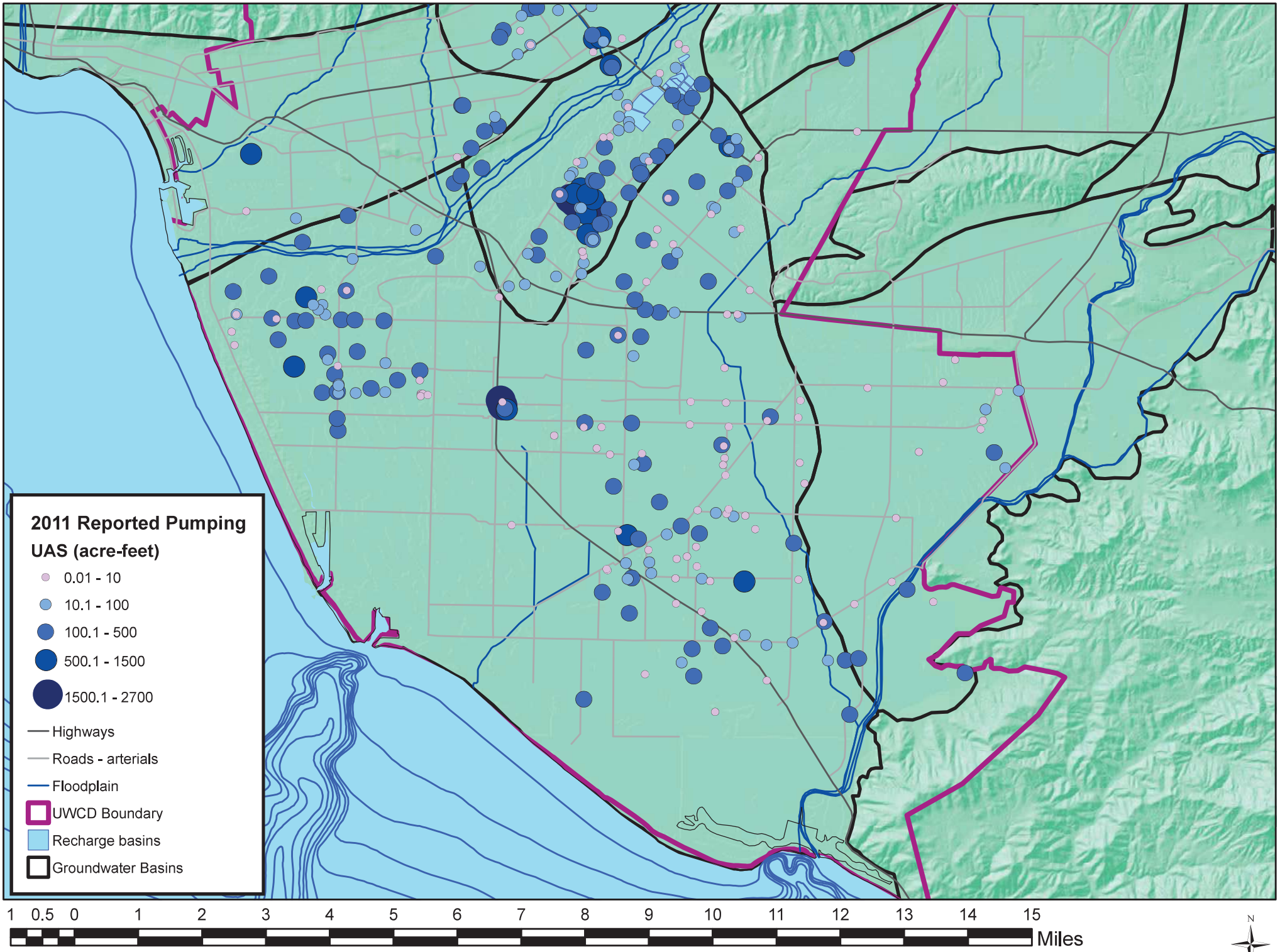


Figure 4.3-26. Reported Oxnard Forebay- Oxnard Plain Reported Upper Aquifer System (UAS) Pumping for 2011

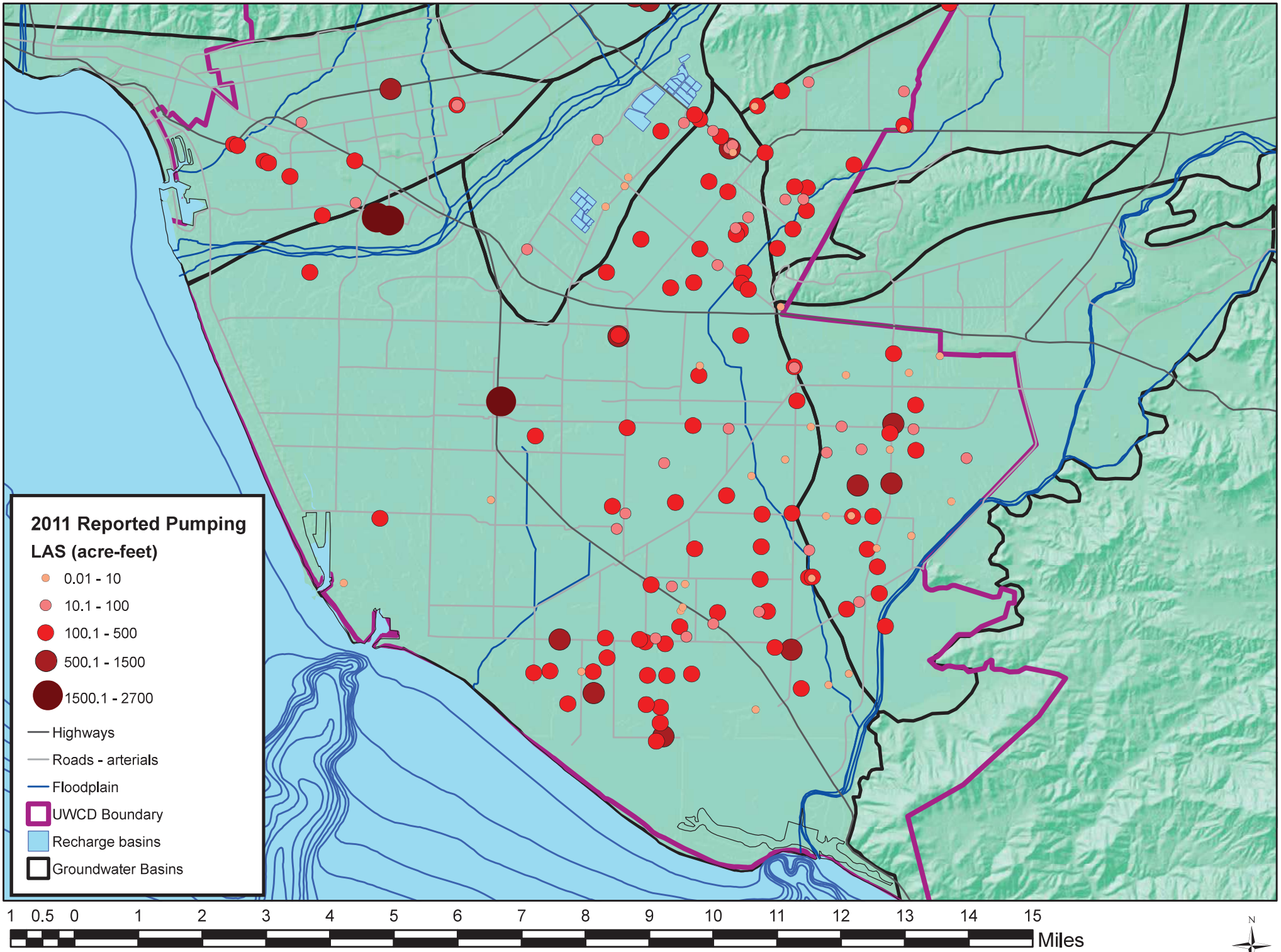


Figure 4.3-27. Reported Oxnard Forebay-Oxnard Plain Lower Aquifer System (LAS) Pumping for 2011

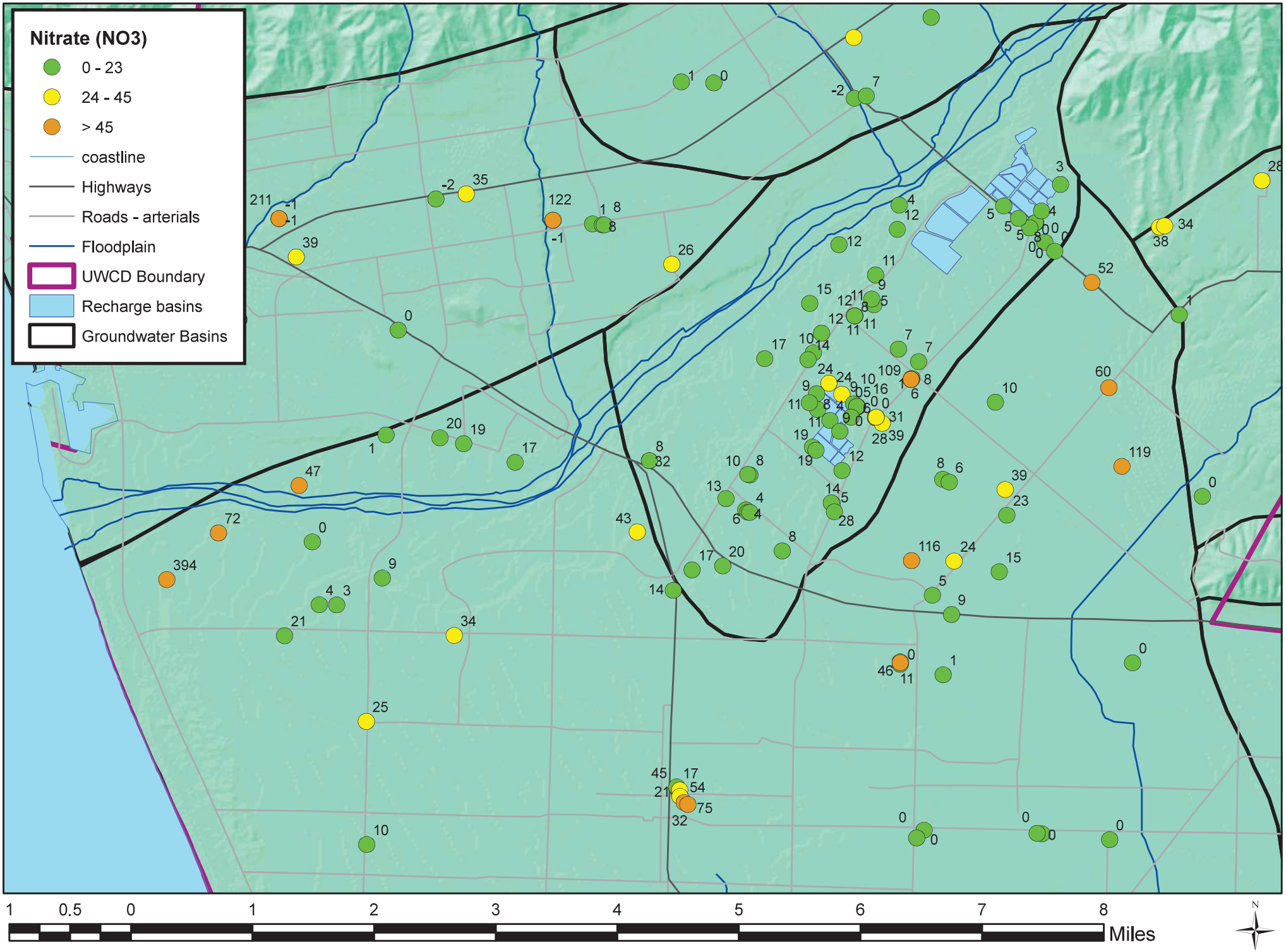


Figure 4.3-28. Maximum recorded nitrate (NO3) in Oxnard Forebay-Oxnard Plain wells, 2011

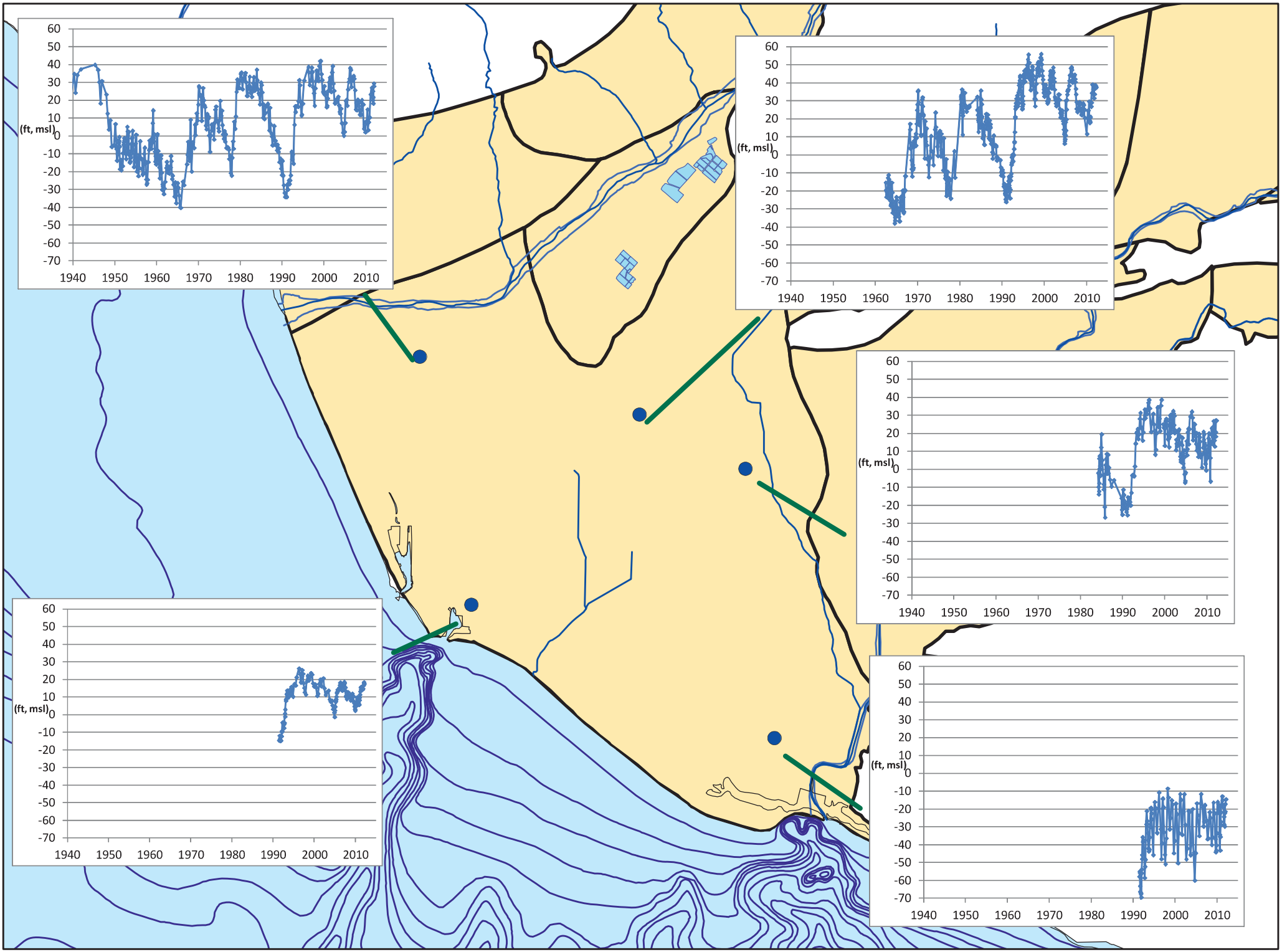


Figure 4.3-29. Oxnard Plain Upper Aquifer System (UAS) groundwater elevation hydrographs, selected wells

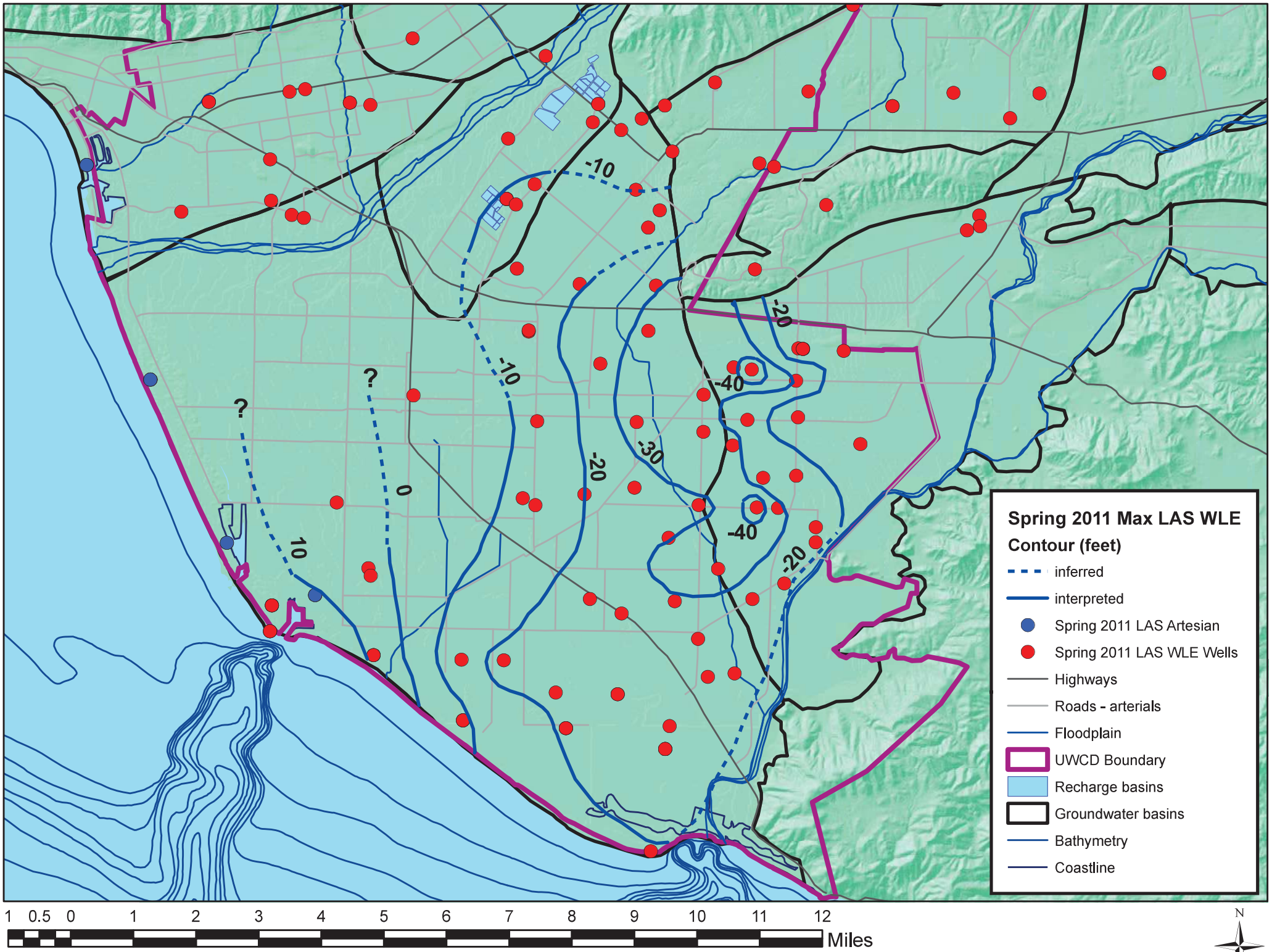


Figure 4.3-30. Oxnard Forebay-Oxnard Plain Lower Aquifer System (LAS) groundwater elevations for spring 2011

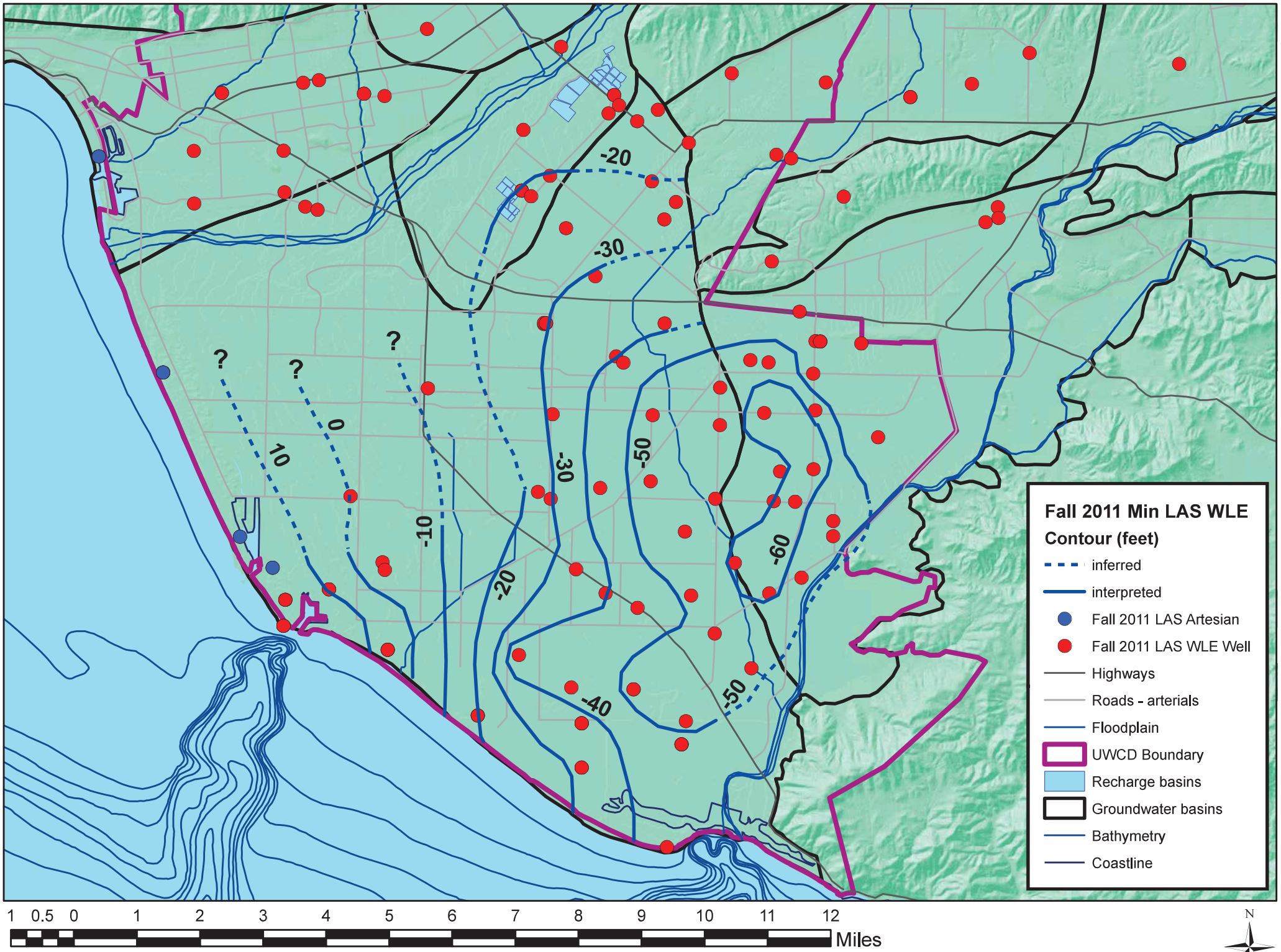


Figure 4.3-31. Oxnard Forebay-Oxnard Plain Lower Aquifer System (LAS) groundwater elevations for fall 2011

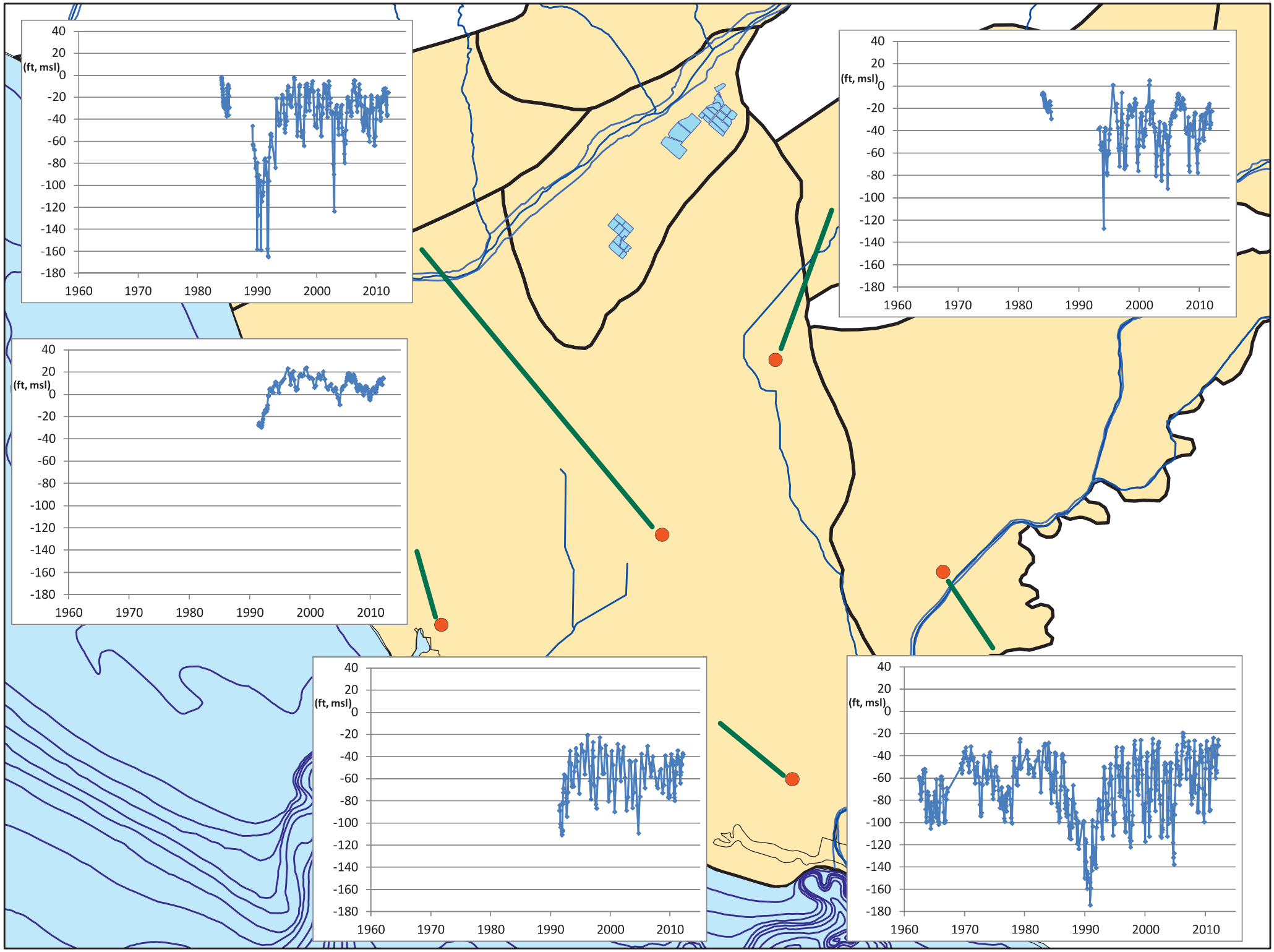


Figure 4.3-32. Oxnard Plain Lower Aquifer System (LAS) groundwater elevation hydrographs, selected wells

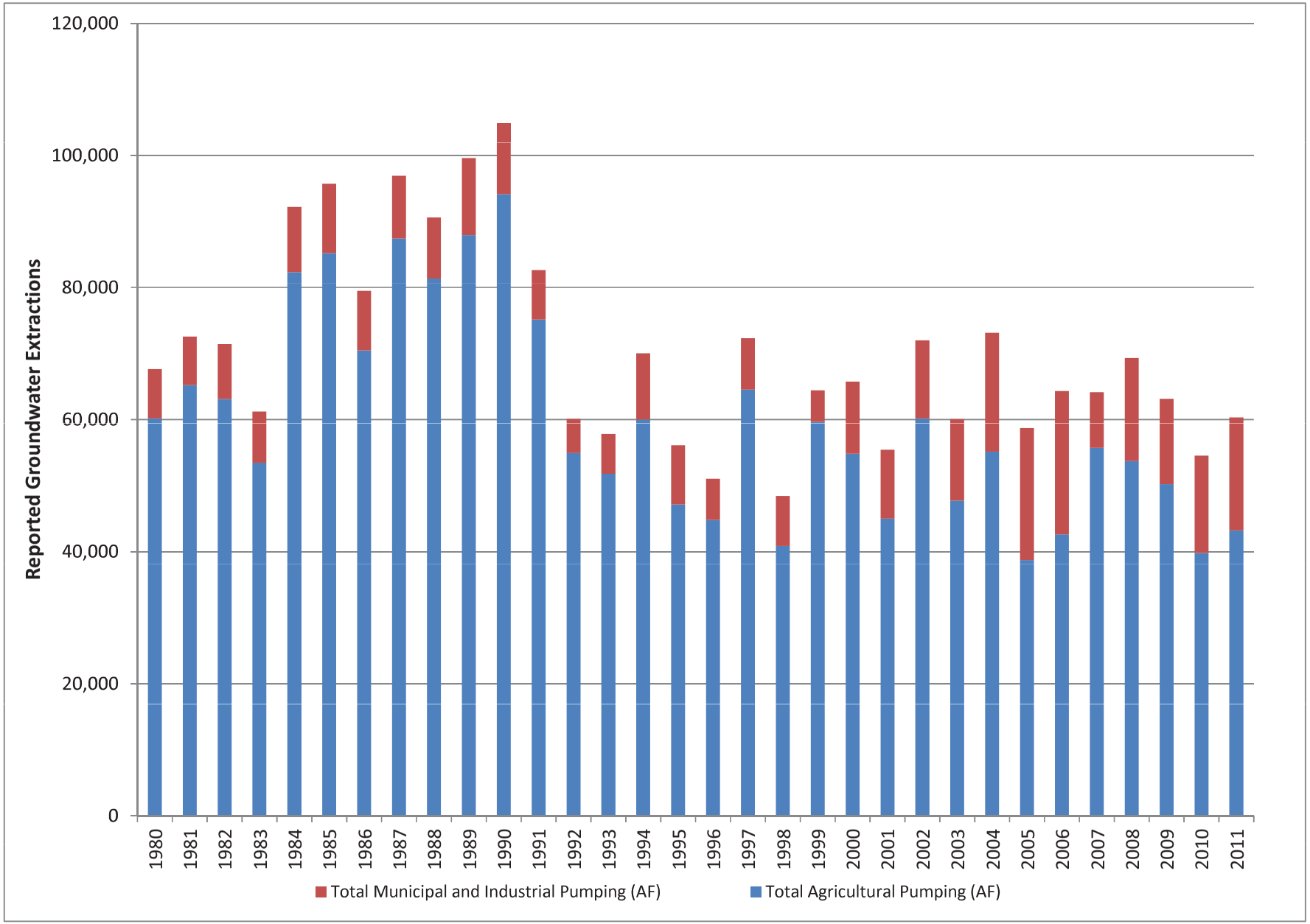


Figure 4.3-33. Historical reported groundwater extractions for the Oxnard Plain and portions of Pleasant Valley and the West Las Posas Basin

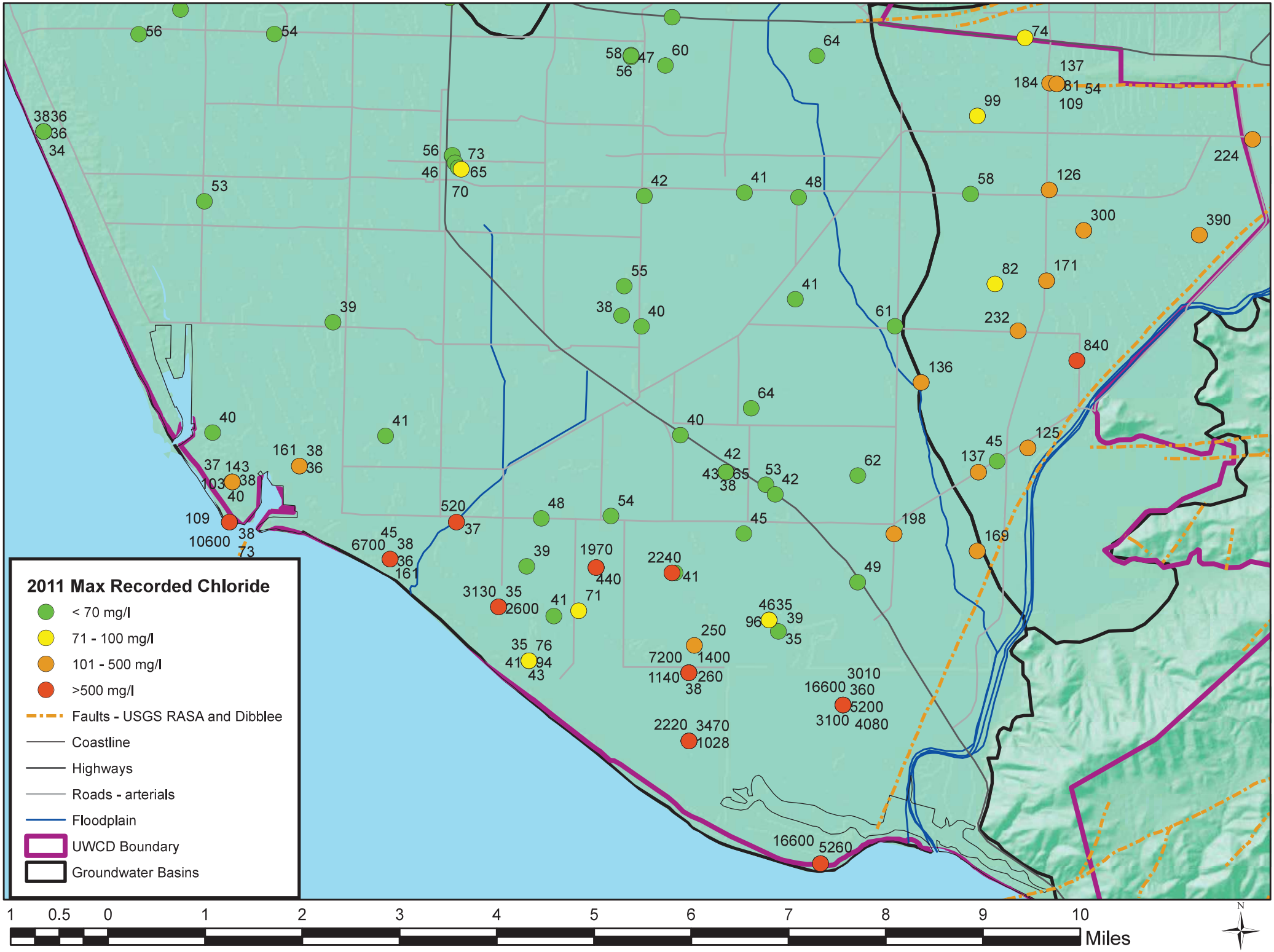


Figure 4.3-34. Maximum recorded chloride for Oxnard Plain and Pleasant Valley Basin wells, 2011

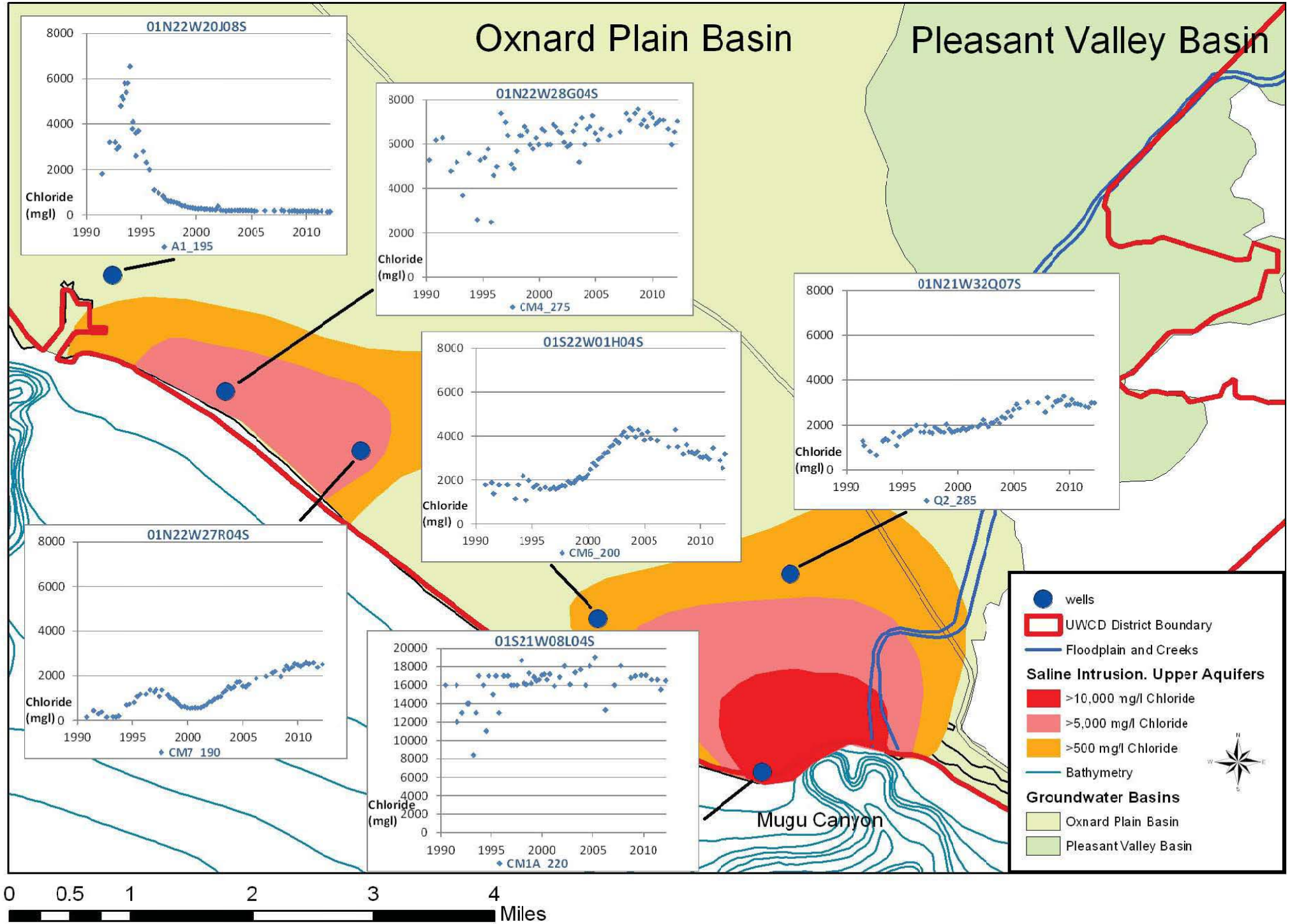


Figure 4.3-35. Chloride time series for selected Upper Aquifer System (UAS) wells, southern Oxnard Plain

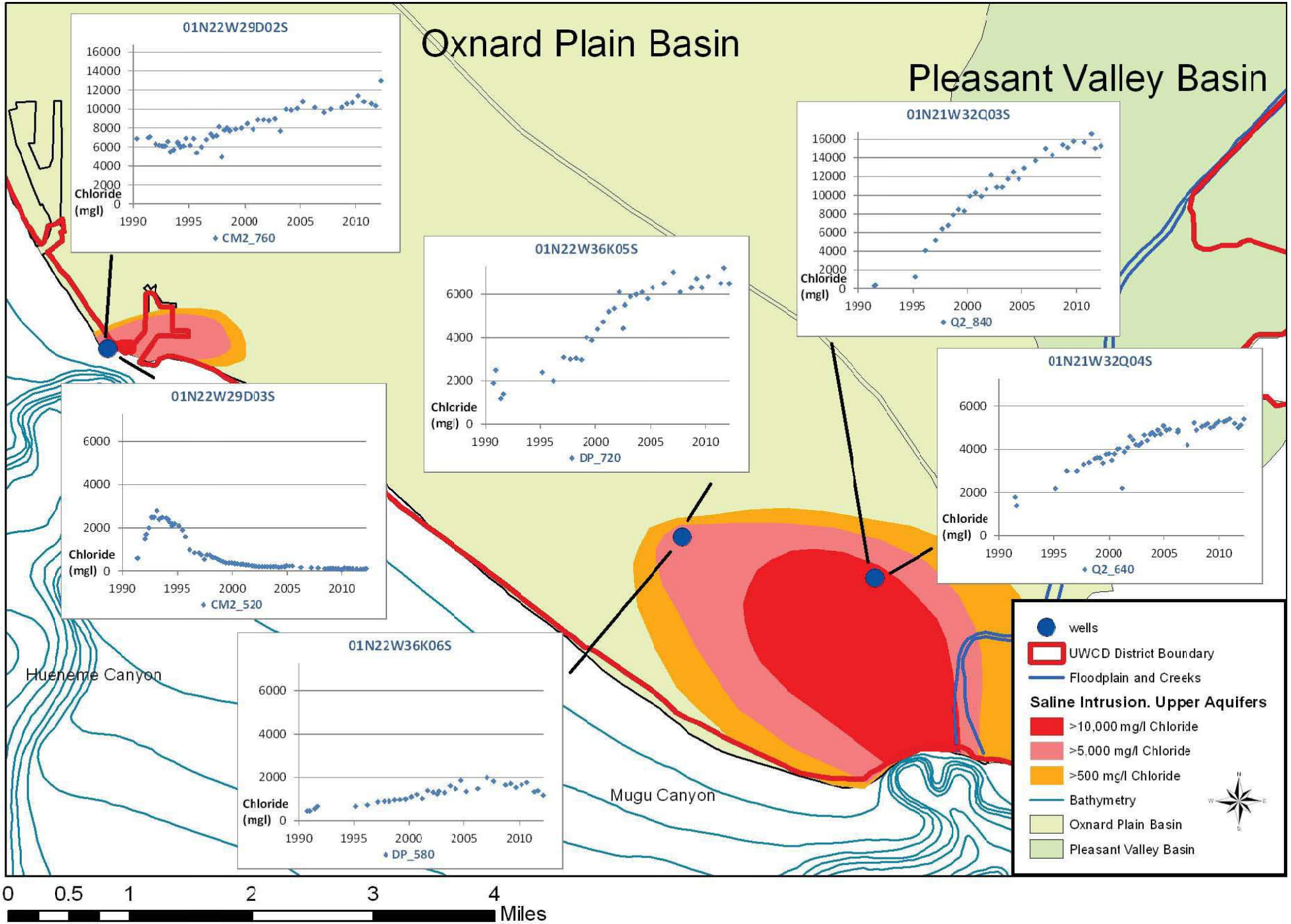


Figure 4.3-36. Chloride time series for selected Lower Aquifer System (LAS) wells, southern Oxnard Plain

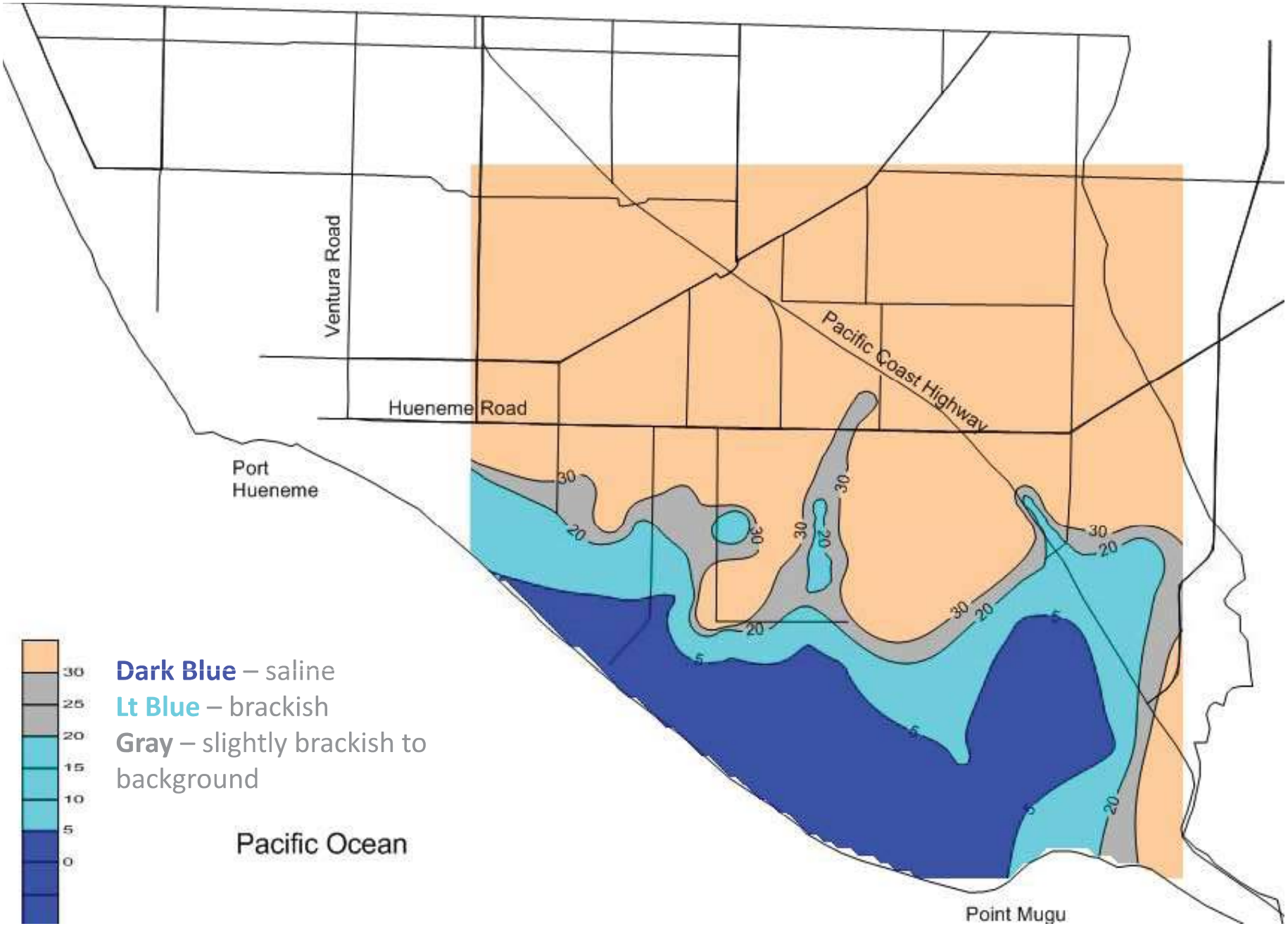


Figure 4.3-37. Geophysical survey (TDEM) of deep Upper Aquifer System (UAS) salinity, southern Oxnard Plain

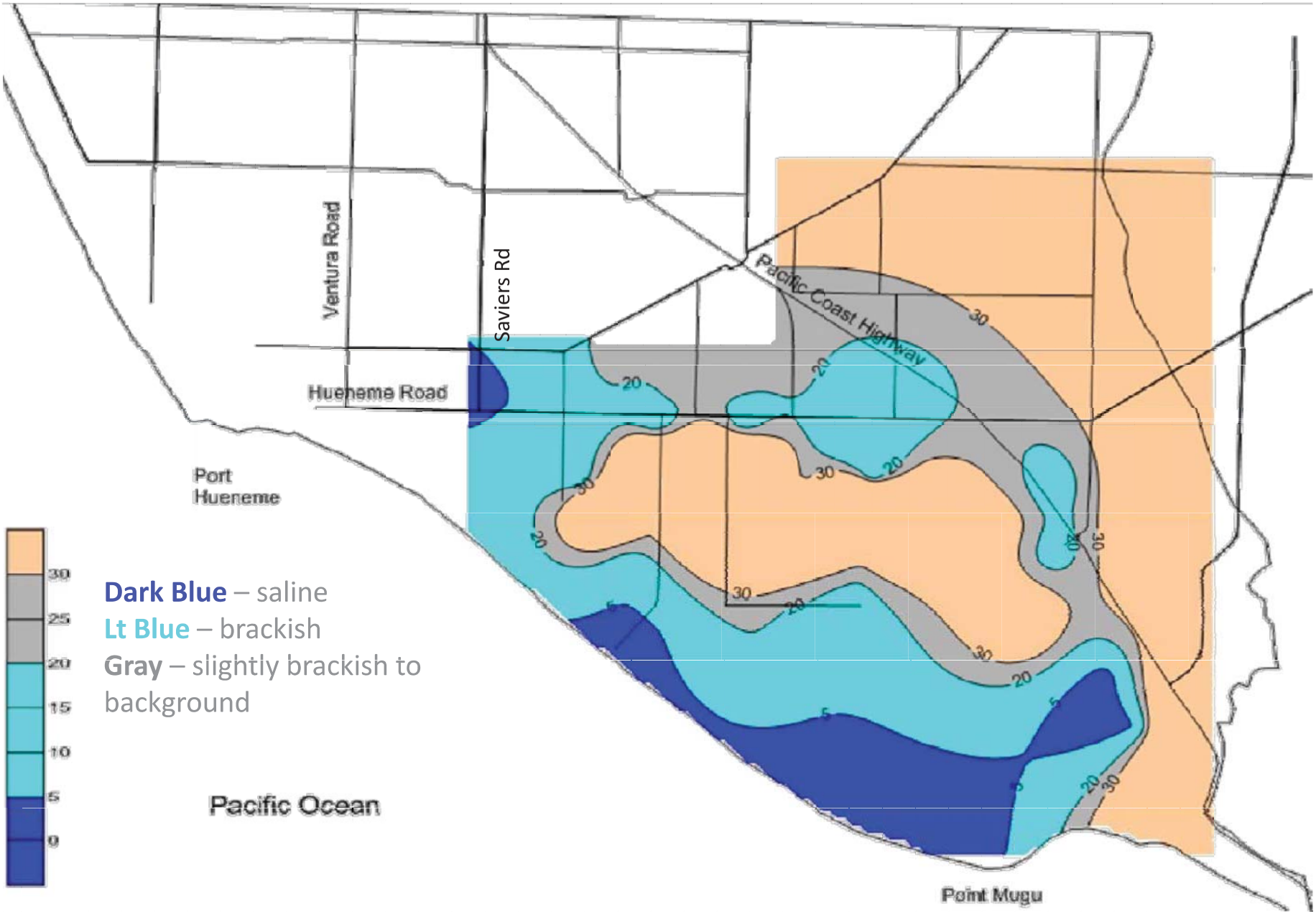


Figure 4.3-38. Geophysical survey (TDEM) of shallow Lower Aquifer System (LAS) salinity, southern Oxnard Plain

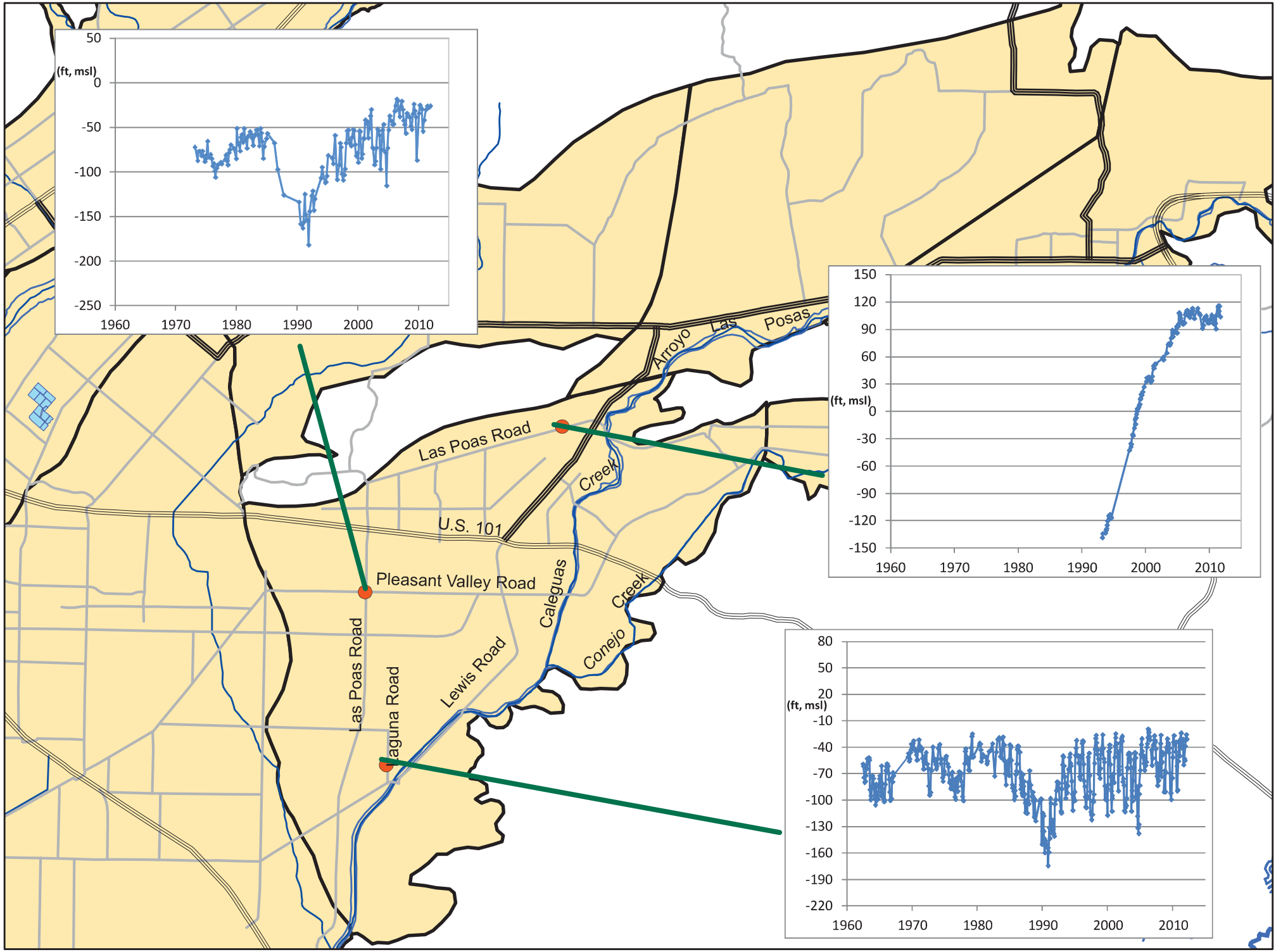


Figure 4.3-39. Pleasant Valley Basin Lower Aquifer System (LAS) groundwater elevation hydrographs, selected wells

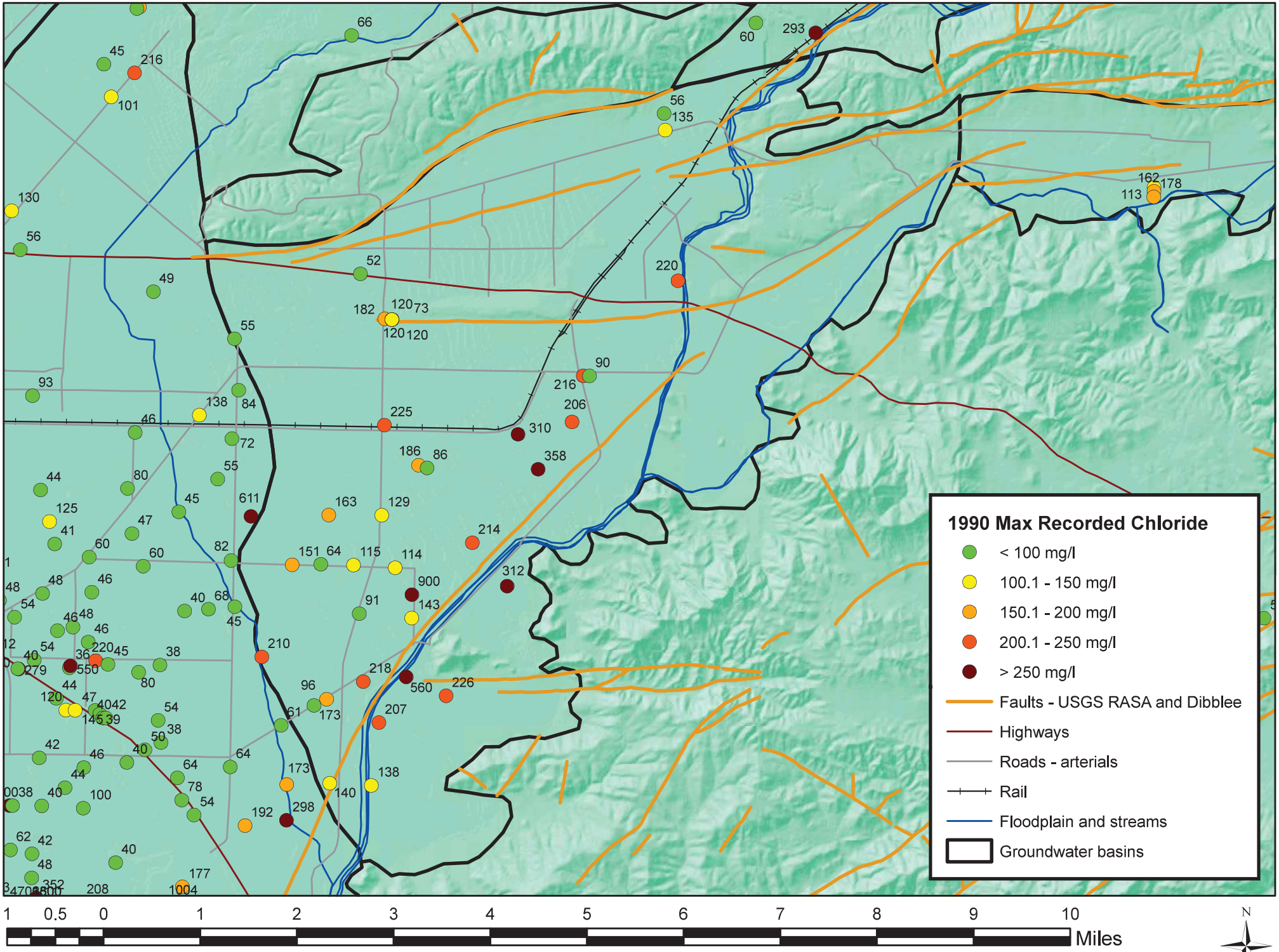


Figure 4.3-40. Maximum recorded chloride in Pleasant Valley Basin wells, 1990

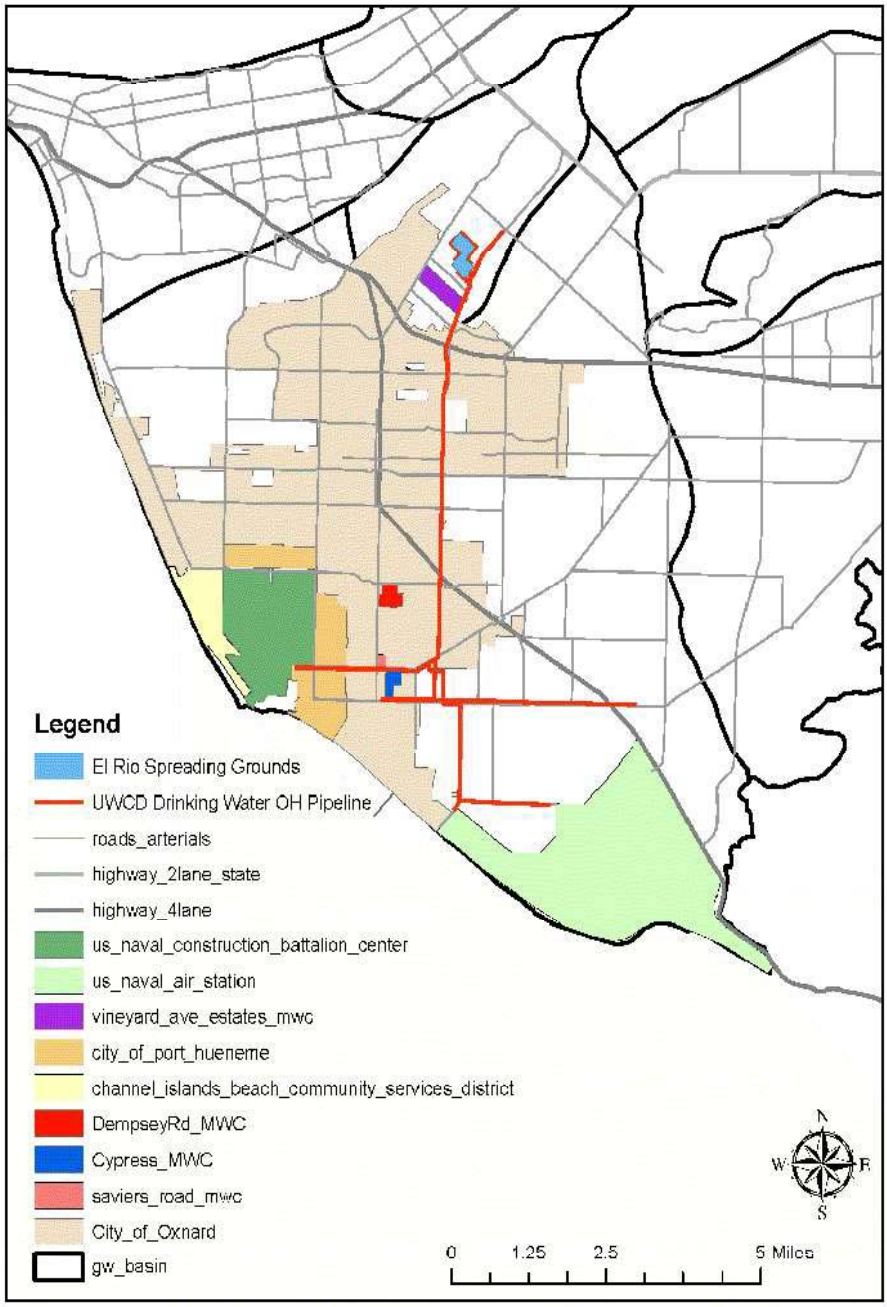
8 APPENDIX A. 2011 CONSUMER CONFIDENCE REPORT, O-H SYSTEM

United Water Conservation District

Oxnard-Hueneme Water Delivery System

2011 Consumer Confidence Report

UWCD Drinking Water Customer Service Area



Testing and Results

Last year we conducted thousands of tests for over 180 chemicals and contaminants that could be found in your drinking water. We did not detect any contaminants that would make the water unsafe to drink. This report highlights the quality of water we delivered to our customers last year. Included are details about where your water comes from, what it contains, and how it compares to State standards. For more information about your water, please call our Operations & Maintenance Manager, Mike Ellis at (805) 485-5114.

Public Meetings

Our monthly Board meetings are usually held on the second Wednesday of every month at 1:00 PM in our board room at 106 North 8th Street in Santa Paula. Our meetings are open to the public and we would welcome your questions and comments.

About Your Water Supply

United Water's Oxnard-Hueneme Delivery System supplies about 15,000 acre-feet of water per year to several agencies in the Oxnard Plain, including the cities of Oxnard and Port Hueneme, two Naval bases, and several smaller water companies. Those agencies supply our water to over 222,000 people, most of it treated or blended with other supplies. Our water source is 100% local groundwater, pumped from wells near El Rio, north of Oxnard. Water from those wells has its origin in the mountains and valleys of the 1,600 square mile Santa Clara River watershed. The wells are in an aquifer called the Oxnard Forebay. Our water is naturally high in minerals that affect its taste, but is safe to drink. Our groundwater is considered to be "under the influence of surface water," which means we do extensive monitoring of turbidity and other parameters to meet health regulations.

United Water Conservation District
106 North 8th Street
Santa Paula, CA 93060
805/525-4431 Fax 805/525-2661
www.unitedwater.org

Water produced by our wells is naturally filtered through the ground. We use chlorine as a disinfectant to kill bacteria, parasites, and viruses. Then we add chloramines to provide a long-lasting disinfection residual to keep the water safe until it reaches our customers. Due to the longer-lasting residual of chloramines, owners of pet fish must treat their tap water before putting it into aquariums or ponds.

Types of Potential Contamination

In general, sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves, naturally-occurring minerals and, in some cases, radioactive material can pick up substances resulting from the presence of animals or from human activity. Contaminants that may be present in source water include:

Microbial contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, and wildlife.

Inorganic contaminants, such as salts and metals, which can be naturally-occurring or result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming

Organic chemical contamination, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production, and can also come from gas stations, urban stormwater runoff, agricultural application, and septic systems.

Pesticides and herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses.

Radioactive contaminants, which can be naturally-occurring or be the result of oil and gas production and mining activities.

In order to ensure that tap is safe to drink USEPA and the California Department of Public Health prescribes regulations that limit the amount of certain contaminants in public drinking water. We treat our water to meet these health regulations. The Department's regulations also establish limits for contaminants in bottled water, which must provide the same protection for public health. Scientists and health experts are continually studying the effects of various chemicals in drinking water to make sure the public water supply is safe.

Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of contaminants does not necessarily indicate that water poses a health risk. More information about contaminants and potential health effects can be obtained by calling the USEPA's Safe Drinking Water Hotline (1-800-426-4791).

Definitions

Public Health Goal (PHG): The level of a contaminant in drinking water below which there is no known or expected risk to health. PHGs are set by the California Environmental Protection Agency.

Maximum Contaminant Level Goal (MCLG): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs are set by the U.S. Environmental Protection Agency.

Maximum Contaminant Level (MCL): The highest level of a contaminant that is allowed in drinking water. Primary MCLs are set as close to the PHGs (or MCLGs) as is economically and technologically feasible. Secondary MCLs are set to protect to odor, taste and appearance of drinking water.

Primary Drinking Water Standard (PDWS): MCLs for contaminants that affect health along with their monitoring and reporting requirements, and water treatment requirements.

Maximum Residual Disinfectant Level (MRDL): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

Maximum Residual Disinfectant Level Goal (MRDLG): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLG's do not reflect the benefits of the use of disinfectants to control microbial contaminants.

Treatment Technique (TT): A required process intended to reduce the level of a contaminant in drinking water.

Detection Limit for Reporting (DLR): The level above which a chemical is to be reported.

NA: Not applicable

ppm: parts per million, or milligrams per litre

ppb: parts per billion, or micrograms per litre

ND: none detected

pCi/L: picocuries per litre (a measure of radioactivity)

Turbidity

Turbidity is a measure of the cloudiness of the water. We monitor it because it is a good indicator of the effectiveness of our water treatment. Turbidity is measured in units called NTUs. We achieved 100% compliance with turbidity standards in 2011.

Contaminants Detected in 2011

Chemical	State MCL MRDL	State DLR	PHG MCLG MRDLG	Units	Range	Avg	Date	Major Sources in Drinking Water
Primary Standards - Clarity								
Delivered water turbidity	TT	N/A	N/A	NTU	0.14 - 0.04	0.07	2011	Well corrosion byproducts. Microscopic soil particles.
Primary Standards - Radioactivity Contaminants								
Gross Alpha	15	3	NA	pCi/L	6.68 - 4.30	5.29	2011	Decay of natural and man-made deposits.
Uranium	20	1	0.43	pCi/L	8.41 - 4.63	6.64	2011	Erosion of natural deposits.
Radon	N/A	100	NA	pCi/L	364 - 129	273.25	2011	Decay of natural deposits.
Primary Standards - Inorganic Contaminants								
Arsenic	10	2	0.04	ppb	3 - ND	1.5	2011	Erosion of natural deposits.
Fluoride	2	0.1	1	ppm	0.8 - 0.7	0.75	2011	Erosion of natural deposits.
Nitrate (as NO_3)	45	2	45	ppm	9.5 - 4.7	6.72	2011	Leaching from fertilizers and septic systems.
Selenium	50	5	30	ppb	9 - 5	7	2011	Erosion of natural deposits. Discharge from mines, runoff from livestock lots.
Primary Standards - Disinfection								
Chloramine Residual (as Cl_2)	4	4	4	ppm	2.4 - 1.3	1.91	2011	Drinking water disinfectant added for treatment.
Total Haloacetic Acids	60	NA	NA	ppb	6 - 1	4.06	2011	By-product of drinking water disinfection.
Dibromoacetic Acid	N/A	2	NA	ppb	6 - 4	5.45	2011	By-product of drinking water disinfection.
Monobromoacetic Acid	none	1		ppb	1 - 1	1	2011	By-product of drinking water disinfection.
Trichloeoacetictic Acid	none	1		ppb	1 - 1	1	2011	By-product of drinking water disinfection.
Primary Standards - Disinfection By-Products								
Total Trihalomethanes	80	N/A	1.8	ppb	49.8 - 19.8	30.3	2011	By-product of drinking water disinfection.
Bromodichloromethane	N/A	1	NA	ppb	6.2 - 3.3	4.5	2011	By-product of drinking water disinfection.
Bromoform	N/A	1	NA	ppb	23.7 - 7.8	12.5	2011	By-product of drinking water disinfection.
Chloroform	N/A	1	NA	ppb	1.3 - 0.6	1	2011	By-product of drinking water disinfection.
Dibromochloromethane	N/A	1	NA	ppb	19.1 - 8.0	12.4	2011	By-product of drinking water disinfection.
Microbiological Contaminants								
Total Coliform bacteria	Systems that collect <40 samples/month: no more than 1 positive		0	Absense/ Presence/ 100ml	Absent	Absent	2011	Naturally present in the environment.
Fecal Coliform bacteria and E.*coli*	A routine and repeat sample are total coli-form positive, and one of these is fecal or E.coli positive		0	Absense/ Presence/ 100ml	Absent	Absent	2011	Human and animal fecal waste.
Secondary Standards								
Sodium	N/A	N/A	N/A	ppm	79 - 71	75	2011	Leaching from natural mineral deposits.
Sulfate	500	0.5	N/A	ppm	420 - 308	374.31	2011	Runoff/leaching from natural deposits.
Total Dissolved Solids, TDS	1,000	NA	N/A	ppm	900 - 670	803.85	2011	Leaching from natural mineral deposits.
Total Hardness	N/A	N/A	N/A	ppm	467 - 400	433.5	2011	Leaching from natural mineral deposits.
Total Organic Carbon (TOC)	N/A	0.3	N/A	ppb	1.3 - 0.8	1.03	2011	Naturally present in the environment.
Unregulated Chemicals								
Boron	N/A	100	N/A	ppb	600 - 500	550	2011	Erosion of natural deposits.

Water Quality Data

The table on page 3 lists all of the drinking water contaminants that we detected during the 2011 calendar year. The presence of these contaminants in the water does not indicate that the water poses a health risk. In addition to the contaminants on the table, we tested for many other chemicals which were not detected at significant levels. Please call us if you would like a copy of the complete list of chemicals we tested for and the test results.

Total Dissolved Solids and Sulfate

Total Dissolved Solids, or TDS, is a measure of the total mineral content of the water. TDS and sulfate are secondary standards related to the taste of the water, and water exceeding the MCL is generally safe for human consumption. Our water exceeds the secondary standards for TDS and sulfate because of naturally occurring minerals in the water.

Source Water Assessment

United Water completed a Source Water Assessment for its drinking water wells in October 2001. The current report is available for public review at our office in Santa Paula. The assessment provides a survey of potential sources of contamination of the groundwater that supplies our wells. Activities that constitute the highest risk to our water are the following: petroleum storage tanks and fueling operations, septic systems, and animal feed lots that are no longer in use. The most recent update for the Surface Water Sanitary Survey was completed in January of 2011 and was submitted to the Department of Health Services.

Cryptosporidium

Cryptosporidium is a microbial pathogen found in surface water throughout the U.S. Although filtration removes Cryptosporidium, the most commonly-used filtration methods cannot guarantee 100 percent removal. Our monitoring indicates the presence of these organisms in our source water and/or finished water. Current test methods do not allow us to determine if the organisms are dead or if they are capable of causing disease. Ingestion of Cryptosporidium may cause cryptosporidiosis, an abdominal infection. Symptoms of infection include nausea, diarrhea, and abdominal cramps. Most healthy individuals can overcome the disease within a few weeks. However, immuno-compromised people are at greater risk of developing life-threatening illness. We encourage immuno-compromised individuals to consult with their doctor regarding appropriate precautions to take to avoid infection. Cryptosporidium must be digested to cause disease, and it may be spread through means other than drinking water.

Radon

Radon is a radioactive gas that you cannot see, taste or smell. It is found throughout the U.S. Radon can move up through the ground and into a home through cracks and holes in the foundation. Radon can build up to high levels in all types of homes. Radon can also get into indoor air when released from tap water from showering, washing dishes and other household activities. Compared to radon entering the home through soil, radon entering the home through tap water will be a small source of radon in indoor air. Radon is a known human carcinogen. Breathing air containing radon can lead to lung cancer. Drinking water containing radon may also cause increased risk of stomach cancer. If you are concerned about radon in your home, you may test the air in your home. There are simple ways to fix a radon problem that are not too costly. For additional information, call the National Safety Council's Radon Hotline (800-SOS-RADON).

About Nitrate

Nitrate in drinking water at levels above 45 ppm is a health risk for infants of less than six months of age. High nitrate levels in drinking water can interfere with the capacity of the infant's blood to carry oxygen, resulting in a serious illness. Symptoms include shortness of breath and blueness of the skin. High nitrate levels may also affect the ability of the blood to carry oxygen in some individuals, such as pregnant women and those with certain specific enzyme deficiencies. Nitrate levels may rise quickly because of rainfall or agricultural activity and groundwater movement. If you are caring for an infant, or are pregnant, you should ask advice from your doctor, or choose to use bottled water for drinking and for mixing formula and juice for your baby.

Immuno-compromised Persons

Some people may be more vulnerable to contaminants in drinking water than the general population. Immune-compromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly and infants, can be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. USEPA/Centers for Disease Control (CDC) guidelines on appropriate means to lessen the risk of infection by *Cryptosporidium* and other microbial contaminants are available from the Safe Drinking Water Hotline (1-800-426-4791).

Security of your Water

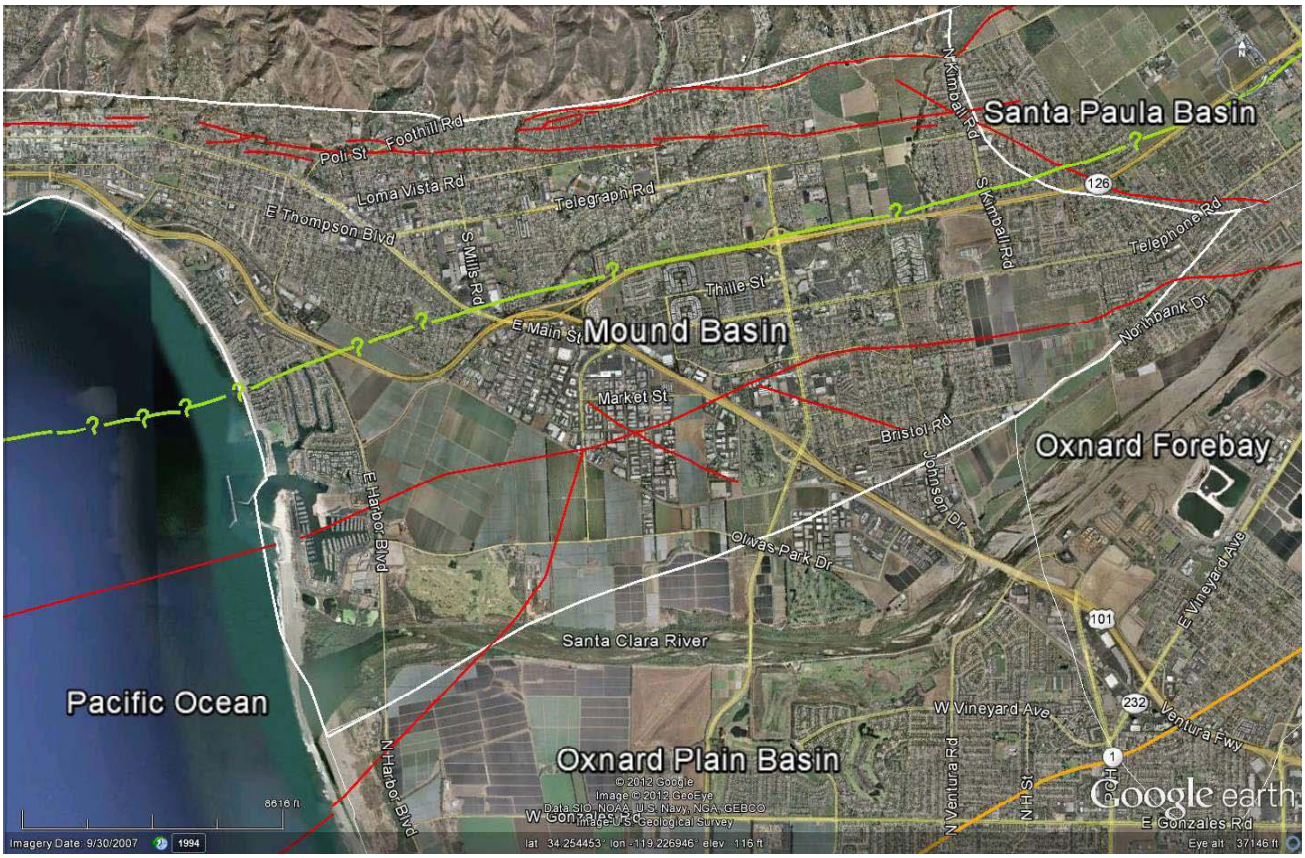
We have completed a Vulnerability Assessment of our OH water facilities. This work, funded by an EPA grant, has improved the security and safety of our water supply.

Hablamos Español

Para información en español llámenos al (805) 525-4431.

HYDROGEOLOGIC ASSESSMENT OF THE MOUND BASIN

United Water Conservation District
Open-File Report 2012-01
May 2012



THIS REPORT IS PRELIMINARY AND IS SUBJECT TO MODIFICATION BASED UPON FUTURE ANALYSIS AND EVALUATION

PREPARED BY:

GROUNDWATER DEPARTMENT

UNITED WATER CONSERVATION DISTRICT

HYDROGEOLOGIC ASSESSMENT OF THE MOUND BASIN

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Citation: United Water Conservation District, 2012, Hydrogeologic Assessment of the Mound Basin, United Water Conservation District Open-File Report 2012-001, June 11, 2012 update.

HYDROGEOLOGIC ASSESSMENT OF THE MOUND BASIN

UWCD OPEN-FILE REPORT 2012-001

EXECUTIVE SUMMARY / ABSTRACT

This open file report addresses the hydrogeologic and geologic conditions of the Mound Basin in Ventura County, California. The United Water Conservation District (United Water) manages the surface water and groundwater resources for either all or part of eight groundwater basins. United Water manages the most significant portion of the Mound Basin. Much of the Mound Basin lies within the boundaries of the City of Ventura. The downtown, midtown, and west side areas of the city fall within the boundaries of the Casitas Municipal Water District. Areas south and east of midtown Ventura fall within the United Water Conservation District.

The Mound Basin has a limited amount of data for characterization of the conditions within the basin. However, the purpose of this report is to assess and outline the hydrogeologic conditions of the Mound Basin with the data that are available. This includes the geology, hydrogeology and groundwater dynamics within the basin as they relate to water supply issues. This was completed by compiling United Water's direct technical data and information from previous works related to the Mound Basin. This information can potentially be used for establishing a basis for further development and management of the groundwater resources of the basin. The scope of work included:

- Assessing the geology and hydrogeology which characterizes the Mound Basin;
- Assessing recharge characteristics and mechanisms for the basin;
- Assessing water level hydrograph records for key wells;
- Assessing water quality data for the basin;
- Assessing changes in well status throughout the basin; and
- Assessing groundwater extractions from the basin for recent years.

The Mound Basin is essentially characterized by a low lying alluvial plain mainly occupied by the City of San Buenaventura. Much of the remainder of the basin is occupied by agricultural lands. The present day boundaries of the basin include: the Ventura fault and foothills to the north, the Country Club fault to the east, the Montalvo anticline to the south and the Pacific Ocean to the west. The Santa Paula Basin borders the Mound Basin on the east side and the Oxnard Plain Basin and Forebay Basin are adjacent to the Mound Basin on the south side.

The Mound Basin lies within the greater regional Ventura Basin which is part of the Transverse Ranges geologic province. In the Ventura Basin the total stratigraphic thickness of upper Cretaceous, Tertiary, and Quaternary strata exceeds 55,000 feet

The Mound Basin is characterized by a significant east-west trending fold axis (Ventura syncline) and a significant amount of faulting. This study conducted a thorough review of geologic articles and reports, which covered 87 years of information, to generate the Mound Basin conceptual geologic model. The Mound Basin water-bearing sediments are generally Pleistocene (San Pedro formation) and Holocene (alluvium) deposits. These deposits are limited to approximately the upper 3,000 feet. The faulting is primarily reverse faulting, with some strike-slip movement, on the north (Ventura and Foothill faults), south (Oak Ridge, McGrath faults, Mound NW 3, and Mound NW 2 faults), and east (Country Club fault) sides of the basin. The Ventura and Oak Ridge faults contribute to the structural boundaries on the north and south side of the basin. The Montalvo anticline located south of the Oak Ridge fault is the present day southern boundary of the basin. However, some researchers suggest that the Oak Ridge fault may be a more appropriate southern structural boundary of the basin, as it forms the southern structural fault and uplift on the south side of the basin.

Aquifer materials and sediments within the adjacent Oxnard Plain and Forebay Basins extend into the Mound Basin. However, the sediments change in character. Some of the shallow alluvium is dominated by clays in the Mound Basin. In addition, the Fox Canyon aquifer zone becomes much more lenticular in nature on the northern side of the Mound Basin. Water level records suggest groundwater likely flows from the Oxnard Plain Basin, Forebay Basin, and Santa Paula Basin into the Mound Basin. Although there are some appreciable offsets on the faults bounding the Mound Basin, the low-permeability Santa Barbara formation does not extend to sufficiently shallow depths to impede groundwater flow. In most cases, there is a significant thickness of the San Pedro formation (aquifer materials) existing above the faults, or on both sides of the faults. The nature of the faults themselves as an impedance to flow is not known. However, groundwater flow and basin recharge across these zones is most probable.

Water levels vary considerably within the Mound Basin as evidenced in the few wells that are located within the basin. Groundwater flows generally from east to west. Gradients within the basin remain fairly flat most of the time (especially during dry periods) and water levels tend to vary somewhat among nearby wells. Water levels in many wells respond in a similar fashion to wet and dry periods, although deeper wells often have lower groundwater elevations. Groundwater production is concentrated in several areas within and around the basin, creating the potential for pumping interference in some water-level measurements.

Agricultural pumping has been the main water user in the Mound Basin (approximately 70 percent). Since the mid-1980s agricultural pumping has averaged nearly 4,200 acre-feet per year with a peak annual production of 5,850 acre-feet recorded in 1990. The City of Ventura's pumping generally increased through the 1980s, and was variable in the 1990s. Municipal pumping peaked in 2003 and has declined fairly steadily in recent years.

While the quality of the groundwater produced by most wells within the Mound Basin is suitable for municipal and agricultural uses, the basin is not known for the high quality of its groundwater. In addition, the lenticular nature of many San Pedro formation sediments within the basin, and their suggested connate waters that likely remain in this setting, impair water quality in many zones. Although groundwater flow likely occurs through areas where interconnected or continuous aquifer materials exist, the less-continuous nature of some highly permeable deposits within the basin (compared to nearby basins) have likely inhibited the flushing of poor-quality waters from the basin. Water quality is variable between wells, and many records indicate somewhat elevated concentrations of TDS, sulfate, hardness and other analytes. Water quality appears to be relatively stable among many of the Mound Basin wells having long-term water quality records. Available records from wells near the coast do not show evidence of saline intrusion.

1 INTRODUCTION AND BACKGROUND

United Water Conservation District (United Water) is a public agency within Ventura County, California that is charged with conserving the water of the Santa Clara Rivers and tributaries. United Water works to manage the surface water and groundwater resources within all or part of eight groundwater basins. These basins include the Piru, Fillmore, Santa Paula, Oxnard Forebay, Oxnard Plain, Pleasant Valley, and parts of the west Las Posas and Mound basins. Figure 1-1 shows the locations of the basins relative to each other.

United Water stores surface water in a surface reservoir (Lake Piru impounded by Santa Felicia Dam), replenishes the groundwater aquifers along the Santa Clara River, diverts natural and reservoir released water, replenishes groundwater through percolation ponds, and delivers both diverted surface water and pumped water to those areas vulnerable to overdraft and saline water intrusion. Since the 1950s, United Water has been studying means to improve groundwater management throughout the District. Projects for improved conservation of water and groundwater management have been executed since the 1950s and these efforts continue to the present day.

During the 1990s and up to the present represents a period of more detailed studies by United Water to improve the understanding of the hydrogeology, basin yields, additional water quality issues, river dynamics, and impacts of the continued high demand for water resources. These studies progressively became more fine-tuned to address more localized issues. One major issue is to actively assess and outline the hydrogeologic conditions of the Mound Basin. This includes understanding the geology, hydrogeology and groundwater dynamics within the basin. The purpose of this study is to establish a basis for planned development and management of the groundwater resources of the Mound Basin.

1.1 OBJECTIVE AND PURPOSE

The objective of this report is to investigate and compile direct technical data and other information from previous works related to the Mound Basin. This information is required to manage the

groundwater resources of the basin to maximize its long-term supply, protect the groundwater quality of the basin, and balance long-term average annual water replenishment and extractions. The direct technical data are data that United Water has had direct access or has developed from its own efforts. A review of previous work, spanning eighty-seven years of available literature related to the Mound Basin, was also conducted.

The scope of this report includes the following tasks:

- Assess geology and hydrogeology which characterizes the Mound Basin;
- Assess recharge characteristics and mechanisms for the basin;
- Assess water level hydrograph records for key wells;
- Assess water quality data for the basin;
- Assess changes in well status throughout the basin; and
- Assess groundwater extractions from the basin for recent years.

Since this report is intended to be a tool for the management of the groundwater resources of the Mound Basin it relies heavily on basic hydrogeologic and GIS data from United Water, as well as data obtained from the City of San Buenaventura and the County of Ventura.

1.2 PHYSICAL SETTING

The Mound Basin is located in Ventura County, California, and has been an important source of water supply to both agricultural and municipal users since at least the 1920s. The basin is characterized by a low-lying alluvial plain which gently rises in a northerly direction. It is the westernmost basin within the Santa Clara River Valley drainage. The basin is approximately 7 miles long and 4 miles wide and contains approximately 10,000 acres. The majority of the Mound Basin is occupied by the city/suburban environment of San Buenaventura (Ventura), California. The remainder of the basin is occupied by agricultural lands.

The present day mapped boundaries of the Mound Basin are indicated on Figure 1-2. The southern boundary extends from approximately the mouth of the Santa Clara River and trends northeastward toward South Mountain. This boundary approximately coincides with the axis of the subsurface structure consisting of the Montalvo anticline. The northern boundary consists of the Ventura Foothills north of the City of Ventura with the approximate trace of the Country Club fault forming the eastern boundary. The Country Club fault does not have a surface expression and is considered to be a concealed fault. The Pacific Ocean borders the basin to the west. The Oxnard Forebay Basin and Oxnard Plain Basin are directly adjacent to the Mound Basin on the south side and the Santa Paula Basin is directly adjacent on the eastern side.

As evidenced in Figure 1-2, most of the Mound Basin is occupied by the City of San Buenaventura. The city streets and structures occupy approximately 70 percent of the basin. The remainder of the

basin is occupied by agricultural lands. Generally, the main crops in the agricultural fields consist of citrus, avocadoes, berries, and row crops. Occasionally celery is grown during the offseason of berry crops. Highway 101 cuts through the Mound Basin in a northwest-southeast direction. One other major highway (Highway 126) cuts through the basin and runs generally east-west.

2 GENERAL GEOLOGY

The groundwater basins managed by United Water are part of the Transverse Ranges geologic province where the mountain ranges and basins are oriented east-west rather than the typical northwest-southeast trend over much of California. These basins are located within the more regional Ventura Basin, which is an elongate east-to-west trending structurally complex syncline within the Transverse Range province (Yeats, et. al., 1981). The Santa Clara River Valley occupies the Ventura Basin, which is one of the major sedimentary basins in the geomorphic province. The total stratigraphic thickness of upper Cretaceous, Tertiary, and Quaternary strata exceeds 55,000 feet (Sylvester and Brown, 1988).

Active thrust/reverse faults border the basins of the Santa Clara River Valley contributing to the uplift of the adjacent mountains and down-dropping of the basins. This configuration creates the elongate mountains and valleys that dominate Santa Barbara and Ventura Counties. The basins are filled with sediments that were deposited in both marine and terrestrial settings. The basins on the coast, including the Mound Basin, are filled with recent sediments deposited on a wide delta complex that formed at the terminus of the Santa Clara River. Figure 2-1 is a regional geologic map showing the general geology of the region. Figure 2-1 shows the local formations which form the mountain ranges, surface geology, and the major faulting in relation to the United Water basins.

As discussed above, the geology associated with the Transverse Ranges is primarily east to west trending folds and faulting (fold axes trend east-west). As per the regional geology, the Mound Basin is characterized by a prominent syncline (Ventura syncline) whose axis trends east-west and plunges to the west.

The surface and shallow materials in the Mound Basin are characterized by Quaternary alluvium (Holocene and late Pleistocene). These are composed of lagoonal, beach, river/flood plain, alluvial fan, terrace, and marine terrace deposits. Underlying the Quaternary alluvium are the upper Pleistocene San Pedro formation (marine and continental clays, silts, sands and gravels) which hosts most of the aquifers in the area; the lower Pleistocene Santa Barbara formation (mudstone, shale and minor sandstone); and the lower Pleistocene Pico formation (marine mudstones, siltstones, sandstones, and conglomerates) (Mukae and Turner, 1975). The Pleistocene deposits outcrop in the hills bordering the Mound Basin to the north. The two mounds located in the south-central part of the basin, the namesake of the basin, are characterized by outcrops of the San Pedro formation.

2.1 MOUND BASIN FOLDING

Figure 2-2 is a generalized geology map of the Mound Basin. The geology as shown in Figure 2-2 is discussed in this section of this report. The Ventura syncline (called the Santa Clara River syncline by some researchers) axis trends through the Mound Basin in an east-west direction and the approximate location of the axis is indicated on Figure 2-2. The syncline plunges gradually to the west. The Montalvo anticline is approximately parallel to the Ventura syncline and is located south of the syncline near the present day southern structural boundary of the Mound Basin (Geotechnical Consultants, Inc., 1972). The southern leg of the Ventura syncline forms the northern leg of the Montalvo anticline. Some workers also place a parallel fault at the location of the Montalvo anticline (Mann, 1959; Fugro West, Inc., 1996). Seismic reflection data from Fisher et al (2005) does confirm that an anticline exists at that location. It is unlikely that the Montalvo anticline is a simple fold. Some faulting is involved on the northern flank of the Montalvo anticline (McGrath fault, Mound NW 3 fault, Mound NW 2 fault, Oak Ridge Fault).

2.2 MOUND BASIN FAULTING

The Mound Basin is characterized by several faults. The faults are discussed in the following sections.

2.2.1 VENTURA AND FOOTHILL FAULTS

The Ventura fault (Figure 2-2) is located in the northern section of the basin and trends east-west. It is a reverse fault that dips to the north at a high angle, with the up-thrown side on the north contributing to the Ventura foothills (Yerkes et al, 1987). Figure 2-3 is a cross-section interpretation showing the Ventura fault. The fault was mapped by the United States Geological Survey (USGS) near the base of the Ventura Foothills. The Ventura fault extends offshore where it is referred to as the Pitas Point fault by Greene et al (1978), however, the USGS and other workers still refer to it as the Ventura fault. The Foothill fault is also mapped as an east-west trending fault in the northeast section of the Mound Basin. It is not referenced in most publications for the geology of the area. However, it was included in the GIS coverage from the USGS website (United States Geological Survey, 2011). Yerkes et al (1987) do show an inferred fault at the approximate location of the Foothill fault where it is shown in Figure 2-2. However it is not shown on Figure 2-3. The assumed motion along the fault is that of a reverse fault with the up-thrown side to the north.

2.2.2 COUNTRY CLUB FAULT

The Country Club fault is an arc shaped fault that trends northwesterly along the eastern edge of the Mound Basin and mainly forms the structural boundary between the Mound Basin and the Santa Paula Basin to the east (Figure 2-2). It is a steeply dipping (almost vertical) reverse fault with some appreciable left-lateral displacement (Turner, 1975). United Water's inspection of oil well data indicate a displacement of 1,600 to 1,800, feet with the south side of the fault displaced

upward relative to the northern side which is consistent with the offset reported by other investigators [Fugro West (1996) indicates approximately 2,000 feet of offset; Geotechnical Consultants, Inc. (1972) shows approximately 1,700 feet of offset].

2.2.3 Oak Ridge fault/McGrath fault/Mound NW faults

An understanding of the location (Figure 2-3) and nature of the Oak Ridge fault, McGrath fault, Mound NW 2 fault and Mound NW 3 fault share a more complex development in historical literature. The Mound NW 2 fault and Mound NW 3 fault both are located adjacent to a topographic mound referred to as “pressure ridges”.

U.S. Geological Survey Bulletin 753 (USGS, 1924) does not extend the overall fault coverage map to the Mound Basin, although they produced a geology map of Los Angeles and Ventura Counties. This suggests that the Mound Basin was not studied at that time. In 1933 the Division of Water Resources Bulletin 46 (California Department of Water Resources, 1933) presents the results of a geological investigation of Ventura County, however, the Oak Ridge fault, McGrath fault, Mound NW 2 fault, or Mound NW 3 fault are not shown pertaining to the Mound Basin. In addition, the Ventura and Montalvo anticlines are not shown. The California State Water Resources Board Bulletin No. 12 (California State Water Resources Board, 1953) contains a geologic map which shows the Oak Ridge fault in the Santa Paula Basin only. It extends to another fault referred to as the Saticoy fault (predecessor in study of the modern Oak Ridge fault) partially extending into the Mound Basin (Figure 2-4). The Saticoy fault is mapped to the east side of the Mound Basin, however, if projected to the west it would trend through or just north of the Mound NW 2 and Mound NW 3 faults (and pressure ridges). The McGrath fault is not shown. The map does show the Montalvo anticline which is depicted as partially coincident with the Santa Clara River.

John F. Mann Jr. and Associates (1959) appears to replace the Montalvo anticline with the “Montalvo fault” on his map. However, he does refer to the Montalvo anticline in his text. The Saticoy fault, as per Bulletin 12, is included in this publication. The McGrath fault or the Mound NW 2 and Mound NW 3 faults (and pressure ridges) are not shown on maps or included in the text. His cross-section shows the Montalvo fault extending to the surface with the up-thrown side to the southeast (Figure 2-5). In 1972 Geotechnical Consultants, Inc. show the Oak Ridge fault extending in a general east-west direction across the entire Mound Basin. It is depicted as touching one Mound NW fault and pressure ridge. There is only one Mound NW fault and pressure ridge shown. The Montalvo anticline is also shown. In map view, they show the McGrath fault approximately coincident with the Montalvo anticline trending approximately parallel to the Oak Ridge fault. GTC’s McGrath fault is very similar to the Montalvo fault shown in Mann (1959). No Saticoy fault, or McGrath fault as shown in Figure 2-2, is included. In cross-section, the Oak Ridge fault is shown to partially extend upward into the San Pedro Formation and displaces less than 200 feet of the Santa Barbara formation adjacent to the San Pedro formation at a depth of 2,300 feet.

Turner and Mukae (1975) have the Oak Ridge fault extending through the Mound Basin in a general east-northeast orientation north of the pressure ridges (Figure 2-6). They show the

McGrath fault extending from the main part of the Oak Ridge fault. It connects with the Oak Ridge fault east of the pressure ridges. The McGrath fault section is north of the Santa Clara River for its entire length. The Montalvo anticline merges with the McGrath fault in the western portion of the Mound Basin. The Country Club fault also merges with the Oak Ridge fault. In cross-section, both the Oak Ridge and McGrath faults extend into the alluvial deposits in the area (Figure 2-7) with the southern side up-thrown for both faults. The Santa Barbara formation is not shown on their cross-sections as they only address the effective base of fresh water. However, the San Pedro formation and overlying alluvium are shown to extend across both faults for thicknesses between 1,000 and 1,600 feet according to the cross-sections.

Yerkes et al (1987) map the Oak Ridge fault extending through the Mound Basin in a general east-northeast orientation located north of the pressure ridges. They also show the McGrath fault as an unnamed fault which connects to the Oak Ridge fault west of the pressure ridges and curves westward extending south of the Santa Clara River (Figure 2-8). An oversize plate from Yerkes et al (1987) also shows the Oak Ridge fault at a different scale. From that scale it can be observed that the Oak Ridge fault is located directly north of the two pressure ridges located adjacent to the Mound NW 3 and Mound NW 2 faults. In fact the Oak Ridge fault actually "touches" the mound (pressure ridge) adjacent to Mound NW 2. Yerkes et al (1987) state that the Oak Ridge is a zone of faulting that forms the southern boundary of the Ventura synclinal trough in the western Ventura Basin (Mound structural basin) rather than the Montalvo anticline as mapped by earlier researchers. They state that the faults in the area are buried and known only from subsurface data. They describe the Oak Ridge as a steeply dipping reverse fault with stratigraphic separation of about 350 meters (1150 feet) at the base of the San Pedro formation. Yerkes et al describe the pressure ridges as two isolated, elongate northwest trending structural uplifts. They are described as compressional features and are compatible with left-lateral slip along the adjacent Oak Ridge fault. It suggests a significant strike-slip component along the Oak Ridge fault as well as a reverse fault uplift on the south side.

Yeats (1988) maps the Oak Ridge fault extending through the Mound Basin in a general east-northeast orientation north of the pressure ridges (Figure 2-9). He refers to the McGrath fault as the "Montalvo" fault and shows the fault extending southwestward in an arcuate shape extending from the Oak Ridge fault. It connects with the Oak Ridge fault west of the pressure ridges and trends south of the Santa Clara River where it goes out to sea. Both faults are mapped as concealed. The Yeats configuration of the Oak Ridge fault and McGrath fault (Yeats' Montalvo fault) agrees with the Yerkes et al (1987) which is used for Figure 2-2. United Water uses that configuration. Yeats contains two cross-sections (A-A' and B-B') over the Oak Ridge fault and McGrath fault (Montalvo fault) (Figure 2-10). Cross-section A-A' is oriented north-northwest and crosses both the Oak Ridge fault and the McGrath fault. Cross-section B-B' is also oriented north-northwest and crosses the Oak Ridge fault in the vicinity of the pressure ridges. Cross-section A-A' shows that the McGrath ("Montalvo") fault actually merges with the Oakridge fault at a depth of approximately 2 kilometers (6,562 feet) (Figure 2-11). The Oak Ridge fault is shown as a reverse fault with the up-thrown side on the south side. The McGrath fault is also a reverse fault with the up-thrown side on the south side. Therefore, the area between faults as they appear in map view is actually up-

thrown in whole. Both cross-sections indicate that the top of the Oak Ridge fault exists at a depth of 1.0 to 1.5 kilometers bgs (3,300 feet to 4,900 feet). Yeats et al (1982) contends that the upper edge of the Oak ridge fault is buried by Quaternary sediment 1,250 meters thick (4,100 feet) in the Ventura Basin near Ventura, California. This is much deeper than the aquifer systems in the San Pedro formation.

Fisher et al (2005) conducted a high resolution and medium resolution marine seismic reflection survey over the Oak Ridge fault and the McGrath fault offshore south of Ventura, California. Using data from Huftile and Yeats (1995), Fisher et al show the Oak Ridge fault upper edge greater than a kilometer (3,300 feet) deep as measured under the continental shoreline where it goes out to sea. Seismic reflection data obtained from approximately 6 kilometers (~19,700 feet or 3.7 miles) as well as 9 kilometers (~29,500 feet or 5.6 miles) offshore image the Oak Ridge fault. These data are interpreted to image an unconformity, at a depth estimated to be approximately 80 meters (265 feet) below the sea floor that is probably at the base of the upper Pleistocene and Holocene strata which is not offset by the Oak Ridge fault. The upper edge of the Oak Ridge fault extends to the unconformity, however, the unconformity and strata above it are not offset. The McGrath (Montalvo) fault is also interpreted by Fisher et al (2005) to be truncated by an unconformity below the sea floor approximately 3 kilometers (9,850 feet or 1.9 miles) offshore.

3 HYDROSTRATIGRAPHY

In the Mound Basin, alluvial deposits and the San Pedro formation represent the principal water bearing strata. Underlying deposits, which include the Santa Barbara and Pico formations, are considered non-water bearing in the Mound Basin area even though they yield a limited amount of water for domestic wells elsewhere in Ventura County.

Figure 3-1 is a schematic cross-section of the Mound Basin taken from Greene (1978). Although the faulting may not be consistent with the latest understanding of the basin, it shows the general formations within the basin discussed in the following paragraphs of this report. It also shows the Montalvo anticline on the right hand side of the figure. Figure 3-2 shows the relationship between the major hydrostratigraphic units (i.e., aquifers and aquifer systems) and the geologic formations and their ages as typically defined for the region. In general the Oxnard aquifer and Mugu aquifer zones comprise the Upper Aquifer System (UAS) with the Lower Aquifer System (LAS) containing the Hueneme, Fox Canyon, and Grimes aquifers. These hydrostratigraphic units extend into the Mound Basin from adjacent basins, however, they change character (e.g., lithology, thickness, degree of interbedding) in places. Generalized conceptual groundwater flow paths are depicted in Figure 3-3. Figure 3-4 is a southwest to northeast cross-section, across the Oxnard Plain, located southeast and adjacent to the Mound Basin. The Grimes Canyon aquifer is not shown on the cross-section.

3.1 UPPER AQUIFER SYSTEM

The UAS is composed of Holocene (Oxnard aquifer) and late Pleistocene (Mugu aquifer) alluvium separated by an unconformity that functions as a clay aquitard (Figure 3-2). The boundary between the UAS and LAS is an unconformity.

Undifferentiated younger alluvium (Holocene Oxnard aquifer zone) and older alluvium (late Pleistocene Mugu aquifer zone) comprise the water bearing alluvial deposits in the UAS in the Mound Basin. The younger alluvium in the Mound Basin is composed of flood plain and active river deposits in the vicinity of the Santa Clara River, and fan deposits which mantle much of the remaining portion of the basin. These deposits are predominately interbedded, lenticular clays with some silts, sands, and gravels. Geotechnical Consultants, Inc. (1972) report a maximum thickness of approximately 290 feet near the southwest corner of the Mound Basin. These deposits unconformably overlie the older, late Pleistocene alluvium. In the nearby Oxnard Plain Basin, the younger alluvium is reportedly nearly 250 feet thick on average (Turner, 1975) and contains a permeable coarse-grained unit at its base (Oxnard aquifer). As the Oxnard aquifer zone in the Mound Basin is dominated by clay deposits, the coarse grained units tend to be more sparse and lenticular in nature.

Undifferentiated older alluvium (late Pleistocene) unconformably overlies the late Pleistocene San Pedro formation. Older alluvium can be divided into an upper and lower portion. The upper portion consists mainly of confining zones (clay and silty clay) with minor amounts of sand and gravel. Interstratified sand and gravel, with variable amounts of clay, comprise the lower portion of these deposits. In the Mound Basin this coarse-grained portion is thickest near the Santa Clara River and becomes generally thinner to the north toward the foothills. The coarse grained strata at the base of the older alluvium in the Mound Basin are considered equivalent to the Mugu Aquifer, which has been traced into the Mound Basin from the Oxnard Plain Basin. Most wells in the Mound Basin contain perforations in the Mugu Aquifer. Older alluvium reported thicknesses are variable ranging from approximately 125 feet (Geotechnical Consultants, Inc., 1972) in the eastern part of the basin to about 450 feet (Turner, 1975) near the coast. Borehole geophysical logs reviewed for this investigation (Figures 3-5, 3-6, and 3-7) suggest Mugu hydrostratigraphic unit thicknesses up to about 425 ft.

3.2 LOWER AQUIFER SYSTEM

The Hueneme and Fox Canyon aquifers are part of the late Pleistocene San Pedro formation with the Grimes Canyon aquifer being part of the early Pleistocene Santa Barbara formation.

The San Pedro formation deposits are upper Pleistocene in age and underlie the alluvial deposits in the Mound Basin along a marked angular unconformity. Exposures of the San Pedro formation occur in the foothills which form the northern boundary of the basin. They attain a maximum thickness of 2,300 feet in this region (Geotechnical Consultants, Inc., 1972). The thickness of the San Pedro formation is considerably less at the southern edge of the Mound Basin as a result of

complex folding and faulting and subsequent erosion in that area (Montalvo anticline). This is evidenced in oil well geophysical logs inspected by United Water. The maximum thickness of the San Pedro formation occurs at the axis of the Ventura syncline near the center of the basin. Oil well data show that the maximum thickness is approximately 4,500 feet (Yerkes et al, 1987; Fugro West, 1996).

Upper portions of the San Pedro formation contain variable amounts of clay, silty clay, and sand. A series of interbedded water-bearing sands in this section form the time equivalent of the Hueneme aquifer in the Oxnard Plain Basin. Structural complexities and erosion have removed a portion of these beds in the southern part of the Mound Basin. In the central and northern part of the basin e-log signatures indicate changes in the aquifer units compared to the Oxnard Plain. However, thick sections of the Hueneme aquifer (or its time equivalent) do occur in the Mound Basin, as oil well e-logs interpreted by United Water indicate variable amounts of aquifer materials. Some areas appear to be characterized by significant clays. Most of the deeper wells in the Mound Basin are perforated in the Hueneme aquifer.

Lower portions of the San Pedro formation consist principally of sand and gravel zones with variable thicknesses of interstratified clay and silt. In a northerly direction across the Mound Basin these coarser grained water bearing strata are somewhat lenticular and generally become thinner (Mann, 1959, Geotechnical Consultants, Inc., 1972). This predominantly sand and gravel zone located at or near the base of the San Pedro formation is known as the Fox Canyon Aquifer in the Oxnard Plain Basin and extends into the Mound Basin. These deposits occur at great depths in the Mound Basin and are generally not targeted for water production.

The Fox Canyon Aquifer is continuous and traceable across the Oxnard Plain. As discussed above these beds apparently partially pinch out and become more lenticular in a northerly direction across the Mound Basin. Exposures near the base of the San Pedro formation in the foothills on the north side of the Mound Basin do not indicate the same aquifer thickness, or sediment coarseness, as at the type location of the Fox Canyon zone on the south flank of South Mountain, located several miles southeast of the basin. Nevertheless, in the Mound Basin (and surrounding areas) the distinct borehole geophysical log signature of the Fox Canyon Aquifer can be used as an aid in defining the base of the San Pedro formation.

United Water created several cross-sections by correlating borehole geophysical data from oil wells and some water wells. Figure 3-5 is a location map for two cross-sections that cross the Mound Basin in a general southwest-northeast (Cross-section J-J'; Figure 3-6) and north-south orientation (Cross-section P-P'; Figure 3-7). Both cross-sections illustrate the spatial relationships between the hydrostratigraphic units in the Mound Basin. On Section J-J' the large stratigraphic offset between the second and third well on the southwest side of the profile likely represents the McGrath fault. At that location, there appears to be approximately 700 feet of throw on the top of the Santa Barbara formation with the up-thrown side on the south. It has put some Santa Barbara formation in contact with the San Pedro formation. However, there is still approximately 1,200 feet of San Pedro formation and alluvium above the Santa Barbara formation. Interestingly, offset across the Oak

Ridge fault is not readily apparent which may be a function, at least in part, of the log spacing (i.e., wells are far apart). The Oxnard and Mugu alluvial aquifers do not appear to have been offset by either the McGrath or Oak Ridge faults. Overall, the UAS and a significant portion of the LAS hydrostratigraphic units are continuous across these faults.

On the northeast half of Cross-section J-J', the depth to the bottom of the Hueneme aquifer zone and Fox Canyon aquifer zone (San Pedro formation) in the Ventura syncline are not resolved by the well data (the wells are not deep enough). The Hueneme and Fox Canyon aquifer zones are deeper than the available well log data. The northern leg of the Ventura syncline is very steep on the northeast side of the profile as it extends upward to form the foothills.

On the southern portion of Cross-section P-P' the Fox Canyon aquifer zone extends upward and is in contact with the Mugu aquifer. This is likely the expression of the Montalvo anticline. Part of the extreme upward extension of the Fox Canyon aquifer zone in that area may be due to the Oak Ridge fault. There is approximately 200 feet of offset in the Mugu aquifer zone between wells 02N22W08L01S and 02N22W08P04S which may be caused by the Oak Ridge fault or related splays. Typically the UAS aquifers are not offset by the fault except for this location. The Hueneme aquifer zone is missing between Wells 2N22W17G01S and 2N22W17Q04S. Geotechnical Consultants Inc. (1972) also indicate that structural complexities and erosion have removed the Hueneme aquifer zone in the southern part of the Mound Basin. However, it is present further to the south. The contact between the Fox Canyon aquifer (beneath the Oxnard Plain) and the thick section of Mugu aquifer might serve a source of recharge to LAS aquifers in the Mound Basin.

3.3 IMPACT OF STRUCTURAL FEATURES ON HYDROSTRATIGRAPHY

The hydrostratigraphy of the Mound Basin has been impacted by the development of the structural features such as folding (e.g., Venture syncline, Montalvo anticline) and/or faulting (e.g., Country Club fault, Oak Ridge fault, McGrath fault) that created the Mound structural basin. Some researchers have suggested that the major faults within the basin or basin bounding faults function as impediments to groundwater flow and in some cases as barriers to flow. In most cases, researchers have proposed that low permeability geologic deposits have been uplifted into a juxtaposed position with the aquifers. Review of the readily available literature (Section 2) on the structural geology provided insight into data used to develop the historical perspectives.

The top of the Montalvo anticline has been eroded and the truncated edges of the Hueneme aquifers may be in hydraulic communication with the shallower aquifer zones in that area. Such a contact likely serves as a source of recharge to aquifers in the Mound Basin under certain water level conditions (Fugro West, 1996).

No readily available research on the influence the faults themselves have on groundwater flow has been identified. Their impact on groundwater has not been quantified.

3.3.1 Country Club fault

The Country Club fault has been speculated to be significant barrier to groundwater flow on the eastern boundary of the Mound Basin. However, it only displaces a portion of the low permeability Santa Barbara formation against the aquifer rich San Pedro formation. GTC (1972) shows approximately 1,300 feet of the San Pedro formation and alluvium exists above the up thrown Santa Barbara formation at that location. Fugro West (1996) shows approximately 1,500 feet of San Pedro formation and alluvium on top of the up thrown Santa Barbara formation at that location.

With the San Pedro formation on both sides of the Country Club fault above the displaced Santa Barbara formation, the Country Club fault zone likely conducts groundwater flow. Approximately 1,500 feet of San Pedro formation and younger Quaternary alluvium is continuous across the top of the Country Club fault forming a section that is possible for groundwater flow and recharge to the Mound Basin. The deeper section of the fault where the Santa Barbara formation is in contact with the San Pedro formation may act as a groundwater flow barrier only at depths below a minimum of 1,500 feet. The fault is not considered to extend upward through the alluvium (GTC, 1972).

3.3.2 Oak Ridge fault / McGrath fault / Mound WN faults

Mann (1959) depicts (Figure 2-5) the low-permeability Santa Barbara formation plotted adjacent to the San Pedro formation for approximately 500 feet, at a depth of 900 feet below ground surface (bgs). Therefore, there would be some hydraulic connection in the San Pedro formation (aquifers of the San Pedro formation) for water to recharge or flow on both sides of the “Montalvo fault” for a thickness of 900 feet.

GTC (1972) shows that hydraulic connection could occur for a significant thickness (~2,300 feet) on both sides of the Oak Ridge fault. GTC’s McGrath fault extends upward through the San Pedro formation however it does not penetrate the 400 feet of alluvium above it. The fault does displace 500 to 600 feet of Santa Barbara formation adjacent to the San Pedro formation at a depth of 800 to 1,100 feet (depending on which of the cross-sections used). Accordingly, there may be significant hydraulic connection between the aquifers of the San Pedro formation across GTC’s McGrath fault. There is a thickness of 800 feet to 1,100 feet of San Pedro formation and alluvium overlying the highest up-thrown section of Santa Barbara formation. Therefore it is likely that there is flow in that zone and recharge to the Mound Basin.

Turner and Mukae (1975) cross sections show the San Pedro formation and overlying alluvium extending across both the Oak Ridge and McGrath faults for thicknesses of between 1,000 and 1,600 feet. Therefore there could be hydraulic connection between the aquifers of the San Pedro formation across both faults. Mapping in the California DMG Open File Report 76-5 (California Division of Mines and Geology, 1975) is very similar to Turner and Mukae (1975) as far as the surface mapping of the faults is concerned. However, the western section of the McGrath fault is located south of the Santa Clara River. In addition, the eastern section of the McGrath fault does not connect with the Oak Ridge fault. It is mapped to end before it merges with the Oak Ridge fault.

Cross-Section D-D' from Yerkes et al (1987) (Figure 2-3) is a full cross-section that extends north-south from the Ventura foothills past the Oak Ridge fault and shows insignificant stratigraphic offset along the Oak Ridge fault (approximately 100 feet). The cross-section shows the San Pedro formation as having a thickness of approximately 1,500 feet on both sides of the Oak Ridge fault overlying the low permeability Santa Barbara formation. This is a significant thickness for possible groundwater flow and recharge.

Yeats et al (1982) depict the San Pedro formation and most of its aquifers as continuous across the top of the Oak Ridge fault and extending between the Oxnard Plain Basin and the Mound Basin unimpeded by the Oak Ridge fault along the southern boundary of the basin. The McGrath fault (Yeats Montalvo fault) extends upward to shallower depths close to the land surface. However, the McGrath fault only traverses a small portion of the southern boundary of the Mound Basin. The shallower aquifer systems of the Oxnard Plain and Forebay Basins extend between the basins across the top of the fault. This configuration, for both faults, suggests hydraulic connection and flow to the Mound Basin from the Oxnard Plain Basin and Forebay Basin.

The seismic data presented in Fisher (2005) suggests that a 265 feet thickness of aquifer materials (below the sea floor) exist continuously across the top of the Oak Ridge fault several miles offshore (3.7 and 5.6 miles).

4 WATER LEVELS

Groundwater elevation records exist for nearly sixty wells located within the Mound Basin. A number of key wells have water levels dating to the late 1920s, allowing an evaluation of long-term water level trends within the basin. However, the distribution of wells is heavily skewed towards the southern half of the basin, with relatively few wells existing north of Telephone Road. In the western portion of the basin wells are concentrated along Olivas Park Drive and near the railroad tracks south of Highway 101. This distribution of active and historic wells complicates the assessment of potential mountain-front recharge to the basin from the north. The southern and eastern boundaries of the basin are defined by structural features, and water level records from adjacent areas help assess the nature of the basin boundaries in these areas. Water level trends for many wells within the basin are similar, with evidence of recharge from adjacent basins to the east and south. The main groundwater flow pattern is down the axis of the basin from east to west. The slope of the potentiometric surface within the basin is quite flat during dry periods and the gradient increases somewhat following periods of above-average rainfall. During dry periods, groundwater elevations in many wells fall below sea level.

A major structural feature of the Mound Basin is the Ventura syncline, with the axis following an alignment similar to that of Highway 126. Several wells are located near the axis of this syncline, providing water level information in the center of the basin. Recharge on the north flank of the structure is believed by some to be likely, where the San Pedro formation crops out in the foothills (Geotechnical Consultants, Inc., 1972). The influence of faulting along the northern margin of the basin is undetermined, but may limit the potential for recharge from the adjacent uplands. Water

level records are known to exist for only one well in the northern portion of the Mound Basin (well 02N23W01P01S, total depth 300 feet). Water level records are only available for the mid-1970s, when recorded water levels were about 100 feet higher than in other wells from the central portion of the basin. Monitoring well 02N22W07M03S was constructed in 1995, located near the intersection of Highways 101 and 126, and screened from 210-270 feet below grade. Groundwater elevations in this well are similar to those recorded earlier in well 02N23W01P01S, and show very little seasonal or annual variability (Figures 4-1 and 4-2). Samples from the monitoring well show water quality to be consistently very poor, supporting the water level record as evidence of a perched groundwater system (of unknown extent) in this vicinity. Water levels in the aquifer units that may exist on the north flank of the Ventura syncline are not known to exist. Test holes drilled near the mouth of Lake Canyon (near Foothill Road and Victoria Ave) in the early 1970s apparently did not penetrate productive aquifer units and were not completed as production wells.

The eastern boundary of the Mound Basin sits adjacent the western Santa Paula basin. This boundary between sub-basins of the Ventura Central basin is generally defined by the concealed trace of the Country Club fault (Turner, 1975 and Geotechnical Consultants, Inc. 1972). The geology of the western Santa Paula basin is structurally complex, and faulting and folding in this vicinity may complicate groundwater flow within the regional groundwater flow system down the Santa Clara River valley. Groundwater elevations in the western Santa Paula basin generally range from 80 to 140 feet above sea level, and individual wells in this area exhibit somewhat muted water level variability, common to groundwater discharge areas of the other sub-basins of the valley. Groundwater elevations in three wells (02N22W09K05S, -09L03S and -09L04S) near Kimball Road in the eastern Mound Basin are similar to those recorded in the western Santa Paula basin, and are some 40 to 80 feet higher than other nearby wells (Figure 4-4). The high heads in these three deep wells may suggest some aquifer zones have a better connection to the Santa Paula basin. A fourth well located south of the Oak Ridge fault and in section 02N22W09 has a record of groundwater elevations in the 1970s approximately 20 to 30 feet higher than nearby wells. However, recorded groundwater elevations in shallower wells in the eastern Mound Basin are often 80 to more than 100 feet lower than those in western Santa Paula. This differential in head produces a large hydraulic gradient across the basin boundary, and likely results in groundwater flow from the Santa Paula to the Mound Basin. The magnitude of this flow, however, remains unquantified.

Along its southern margin, the Mound Basin sits adjacent to the Oxnard Forebay in the east and the Oxnard Plain to the west. A number of past researchers adopted the Montalvo anticline as the southern boundary of the Mound Basin, and this same feature has been mapped by others as the Montalvo fault or McGrath fault (Mann, 1959 and Geotechnical Consultants, Inc. 1972). More recently, others have refined the existence and location of the Oak Ridge fault about 4,000 feet to the north (Figure 2-2 geology section), and argue this is a more appropriate southern boundary for the Mound “structural” basin (Yerkes et al, 1987, Yeats et al, 1988). This more northern interpretation of the basin structural boundary leaves few production wells in the central portion of the Mound Basin. Historic water level records exist for a few wells located in the area north of the Oak Ridge fault, but the amount of water produced from these older wells is unknown. In the early

1980s municipal pumping in section 02N22W08 increased rapidly, reaching 3,000 acre-feet in 1984 and averaging slightly more than this amount annually through the end of 2010. Groundwater elevations around 40 feet above sea level were common in this area throughout the 1970s, but rare in years since (Figure 4-1). Regardless of this change in pumping in the area, a long-term profile of groundwater elevations from selected wells located near the axis of the basin shows a fairly consistent and gradual decline in heads from east to west [from the Kimball Road area to the coast near Ventura Harbor (Figures 4-5 and 4-6)]. Significant agricultural pumping also exists in the areas east and northeast of the harbor.

The annual water level responses for the wells located south of the Oak Ridge fault are similar, with the more eastern wells (up-gradient wells) having higher heads than the wells closer to the coast (Figures 4-7 and 4-8). Deeper wells throughout the basin tend to have lower groundwater elevations, but recorded water levels in most Mound Basin wells tend to converge during dry periods. In periods of drought, water elevations in many wells in the central portion of the basin fall below sea level. Contouring of water levels in the central portion of the basin is difficult given the poor distribution of wells and a common variability in water levels among nearby wells of up to 20 feet.

Comparison of water level records from the northern Forebay/Oxnard Plain and the area between the Montalvo Anticline and the Oak Ridge fault of Yerkes and Yeats appear to support the appropriateness of the more-northern boundary. Contouring of available groundwater elevations from wells south of the Oak Ridge fault generally show a relationship with those from adjacent areas to the south, namely, the former “Zone C” area north of the Santa Clara River and the northern Oxnard Plain in areas south of the Santa Clara River (Figures 4-7 and 4-8; Appendix B). Wells located north of the Montalvo anticline and closest to the Forebay (e.g., well 02N22W16K01S) predictably exhibit the greatest annual variability, but the range of recorded water levels is less than that in wells in the main recharge areas of the Forebay. Groundwater flow to the Mound basin from the Forebay and northern Oxnard Plain has been noted in older reports, but also noted was reduced opportunity for recharge north across the Montalvo anticline during times of depressed groundwater elevations on the Oxnard Plain (GTC, 1972; Fugro, 1996). United Water’s contouring of water levels north of the Montalvo anticline support these prior findings, showing good agreement with water levels in the northern Forebay and Oxnard Plain in the spring of some recent wet years (e.g., 2001, 2005). Contouring also suggests that during drier periods the southern strip of the Mound basin (located south of the Oak Ridge fault and north of the Montalvo anticline) exhibits heads that are commonly 5 to 15 feet lower than those to the south, with the head differential between the basins increasing towards the coast.

The contouring of past water level conditions is complicated at times by sparse data. Increased collection of water level records is recommended in this greater area in order to better define groundwater gradients between these adjacent basins. The recent installation of monitoring wells north of the Santa Clara River near the northwestern margin of the Forebay should be helpful in better defining the flow of groundwater from the Oxnard Forebay to areas north of the Montalvo anticline. However, relatively few wells exist along the southeastern portion of the Mound basin, an

area of sparse well records and known structural complexity. In recent times no active production wells have been located within a mile of the coast, so in 1995 United Water and the City of Ventura jointly funded the installation of three monitoring wells at Marina Park near the north side of Ventura Harbor to assess groundwater conditions near the ocean. Artesian conditions are common in the shallowest of these wells, screened 170 to 240 feet below the land surface. Heads 20 feet above the land surface are commonly recorded, suggesting recharge from the Ventura foothills to the north. In fall 2004 water levels in most wells in the western Mound Basin were below sea level, but heads in this well remained high. No active wells in the area are screened in this shallow aquifer zone. A deeper well at Marina Park (screened 480-660' deep) commonly displays weak artesian conditions, and recorded heads six feet below sea level in 2004. The deepest well at this site rarely has artesian flow, but often has groundwater elevations above sea level. In the agricultural area east of Ventura Harbor, production wells record water levels below sea level in dry periods (Figure s 4-9 and 4-10). Heads of 25 feet below sea level were recorded here in 1991, and 14 feet below sea level in 2004.

As discussed in this chapter and the hydrostratigraphy chapter (Section 3), the Mound Basin is structurally complex. The current distribution of wells and water level records within and surrounding the basin allows an imperfect understanding of groundwater source and movement in some locations. Available information indicates the Mound Basin receives groundwater recharge from both the Santa Paula basin to the east and the Oxnard Forebay/ Oxnard Plain to the south. Overall, water levels in many wells respond in similar fashion to wet and dry periods. Gradients within the basin remain fairly flat most of the time. Water levels tend to vary among nearby wells, with deeper wells often having lower groundwater elevations. Groundwater production is concentrated in several areas with the basin, creating the potential for pumping interference in some water level measurements. In some production wells, the large distance to water may lead to occasional errors in water level measurement.

5 GROUNDWATER EXTRACTION

Much of the Mound groundwater basin lies within the boundaries of the City of Ventura. The Downtown, Midtown and West Side areas of the City fall within the boundaries of Casitas Water District, and water supplied to these areas source from Lake Casitas and various City wells located near the community of Casitas Springs. Areas south and east of Midtown Ventura fall within the boundary of United Water Conservation District. The City chose to concentrate Mound Basin pumping in the area near the Ventura County Government Center. Deep municipal wells were constructed here in 1975, 1994 and 2000, and since 1982 the great majority of municipal pumping in this central portion of the basin has been from the City's wells. The City also operates high-capacity production wells near the San Buenaventura Golf Course on the Oxnard Plain, and pumps water north to businesses and residents located in the Mound Basin. Other areas in the eastern portion of the City receive water from a production well in the Santa Paula basin.

Historically, agricultural pumping has been the majority water user in the Mound Basin, and agricultural pumping totaled nearly 70 percent of reported pumping in calendar year 2010. Agricultural pumping is concentrated in three main areas of the basin: farmland near Olivas Park Drive in the south, the agricultural areas east of Ventura Harbor, and the so-called Serra area extending southeast from the southern terminus of Kimball Avenue (Figure 5-1). A fourth agricultural area, located north of Hwy 126 and west of Kimball Avenue, is served by water imported from the Santa Paula basin. These areas of agricultural land use have not been incorporated by the City and are not served by the City's potable water system.

The distribution of historic pumping between agricultural and municipal uses in the Mound Basin is displayed in Figure 5-2. The city's pumping generally increased through the 1980s, and was variable in the 1990s. Municipal pumping peaked in 2003 at over 5,500 acre-feet, and has declined fairly steadily in recent years. Since the mid-1980s agricultural pumping has averaged nearly 4,200 acre-feet per year, with peak annual production of 5,850 AF recorded in 1990. The above pumping totals are for the Mound Basin defined as the area north of the Montalvo anticline. If the Mound Basin were defined as the area north of the Oak Ridge fault, pumping along Olivas Park Drive would be included with Oxnard Plain pumping totals. In this case, 2010 pumping would total 4,630 AF, with agricultural usage totaling 64 percent of the reported pumping.

6 WATER QUALITY

While the quality of the groundwater produced by most wells within the Mound Basin is suitable for municipal and agricultural uses, the basin is not known for the high quality of its groundwater. The Geotechnical Consultants, Inc. (1972) investigation of the Mound Basin noted structural complexity and the lenticular nature of many San Pedro Formation sediments within the basin, and suggested connate waters continue to impair water quality in many zones. Structural deformation and the less-continuous nature of highly permeable deposits within the basin (compared to nearby basins) have likely inhibited the flushing of poor-quality waters from the basin. Water quality is variable between wells, and many records indicate somewhat elevated concentrations of TDS, sulfate, hardness and other analytes. Water quality appears to be relatively stable among many of the Mound basin wells having long-term water quality records. Available records from wells near the coast do not show evidence of saline intrusion.

Relatively few dedicated monitoring wells exist in the Mound Basin. Six monitoring wells, jointly funded by United Water and the City of Ventura, were installed in 1995. One nest of wells exists at Marina Park, at the north side of the Ventura Harbor. Water quality in these three wells has been fairly stable since the wells were installed. The deepest well, screened 970 to 1070 feet bgs, routinely records TDS concentrations near 1,300 mg/l and sulfate concentrations of approximately 500 mg/l. A shallower well, screened between 480 and 660 feet below the surface, records slightly better water quality, with TDS around 900 mg/l and sulfate around 400 mg/l. The shallowest well at this location, well 02N23W15J03S, is screened from 170 to 240 feet bgs has the poorest water quality. In this shallow well TDS concentrations are above 3,000 mg/l and chloride values average

nearly 100 mg/l. As noted in the previous section on water levels, strong artesian heads are consistently recorded in this well. The high heads in this well suggest offshore groundwater gradients in this vicinity. Near-shore submarine canyons, such as those that exist near Port Hueneme and Point Mugu, do not incise the offshore portion of the Mound groundwater basin. The absence of near-shore canyons, high heads in coastal wells and the lack of active production wells near the coast results in a minimal threat of saline intrusion under current basin conditions.

A second cluster of three monitoring wells was installed at Camino Real Park in the central portion of the basin. Sampling of these wells has resulting in the only water quality records known to exist for wells located north of Highway 126. As with the Marina Park wells, mineral content is slightly higher in the deeper San Pedro unit (screened 1,200 to 1,280 feet bgs) than in a shallower zone (screened 710 to 780 feet bgs). In the deeper screened interval TDS concentrations of 1,100 mg/l are commonly recorded. TDS is generally less than 1,000 mg/l in the shallower screened well CP-780 (Figure 6-1). Sulfate anions account for about half of the total mineral content of the water as is typical for other wells in the basin.

The shallowest of the three wells at the Camino Real Park site (screened 210 to 280 feet bgs) records some of the worst groundwater quality in the basin. TDS in this well sometimes exceeds 5,000 mg/l. Chloride and nitrate are also found at high concentrations in this well. These analytes are rarely elevated in other Mound Basin wells. Groundwater elevations are very stable in this well and are also much shallower than in other nearby wells. The anomalous groundwater elevations and water quality from this well suggest perched groundwater conditions, or an aquifer zone otherwise isolated from aquifer units utilized for groundwater production elsewhere in the basin.

The two newest monitoring wells in the Mound Basin were installed near Kimball and Telegraph Roads in 2008 as part of a siting study for a potential new production well for the City of Ventura (Hopkins Groundwater Consultants, Inc., 2008). Limited samples exist for these wells to date. The shallower well (screened 480 to 510 feet bgs) records very poor water quality. A recent sample recorded TDS of 6,300 mg/l, sulfate of 3,700 mg/l and hardness of 2,650 mg/l. Nitrate and chloride concentrations were also high. The deeper well (screened 890 to 950 feet bgs) records water quality more typical of wells within the basin. Both of these wells have groundwater levels higher than some other surrounding wells. It is unclear at this time whether the higher heads are related to groundwater recharge from the nearby Santa Paula basin, or associated with aquifer zones that are poorly connected with other permeable zones within the stratigraphic section that are currently utilized for groundwater production.

Municipal pumping in the Mound basin is concentrated in section 02N22W08 with production wells located around the perimeter of the Ventura County Government Center. The City's Victoria 1 well was constructed in 1975 with five screened intervals within the depth range of 460 to 1,405 feet below ground surface. Water quality was very consistent in this well from the early 1980s through the 1990s, with TDS commonly measured near 1,500 mg/l. In the late 1990s production shifted to the new Victoria 2 well and sampling of Victoria 1 became infrequent as the well was maintained in standby status. A few samples in 2001 and 2002 did however show a distinct increase in dissolved

mineral content, with TDS peaking above 2,000 mg/l and sulfate approaching 1,200 mg/l. The nearby Victoria 2 well (02N22W08F01S) has two screened intervals (580-640 and 900-940 feet bgs). Water quality records from this well show a steady long-term decline. Early TDS concentrations of less than 1,000 mg/l slowly increased to values of 1,400 to 1,800 mg/l common to recent samples (Figure 6-2). A third well, Mound 1, was constructed in 2000 (screened 580 to 650 feet bgs) and began reporting production in 2003. Water quality records from 2006 to 2011 show fairly consistent TDS concentrations of around 1,800 mg/l, with some samples exceeding 2,000 mg/l. The cause of the water quality changes in this vicinity is not readily apparent. The multiple screened intervals in the Victoria 1 well do however provide an opportunity for depth-dependent water quality sampling. Sampling devices are now available to measure both water quality and groundwater production from various depths within an active production well. This type of information might assist the designers of future wells in this area in avoiding aquifer zones of poor water quality.

Water quality samples from wells in an area of former municipal pumping, the Montalvo area in the southern portions of Section 02N22W17, record a period of significant deterioration in water quality. Quality problems began in the early 1970s and continued through the 1980s. Pumping records are not available prior to 1980, so it is unclear if water quality changes in this vicinity were related to an increase in groundwater pumping in the 1970s. A peculiarity of these records is that chloride concentrations rose along with TDS and sulfate.

A map showing recorded TDS concentrations in Mound basin wells from 2011 is shown as Figure 6-3. The map plots TDS (by summation) from production well samples collected by the Groundwater Section of the Ventura County Watershed Protection District, as well as TDS (by residue) as sampled by United Water and the City of Ventura. It is easily seen that without the sampling by the County's Groundwater Section, coverage in the basin would be very poor. The distribution of sampled wells within the basin for 2011 is better than in most prior years. TDS in the production wells ranged from 1150 to over 2,200 mg/l. Also shown is sulfate sample results from 2011 (Figure 6-4). These two maps show that sulfate commonly contributes roughly half the TDS in these samples, and water quality results are often variable among nearby wells.

Mapping the maximum values of all available water quality samples for Mound basin wells reveals that many of the highest chloride concentrations are recorded in wells located near mapped faults in the southern portion of the basin (Figure 6-5). Many of these high values are likely associated with times of drought, but some may be outlier records from individual wells. The maximum-recorded chloride concentrations from the 2011 calendar year are shown in Figure 6-6. One production well located near the intersection of highways 101 and 126 recorded chlorides above 100 mg/l, a target water quality threshold for many agricultural operations.

Many of the active wells in the basin are operated for agricultural water supply and sampling of these wells tends to be less consistent than in the public supply wells. If samples are collected, the results often are not shared with regulators or water management agencies. A good water quality record does exist for well 02N22W16K01S. This well is located east of Harmon Barranca and just

north of the mapped location of the Montalvo anticline axis. Water quality records for this well exist for the years 1953 through 1997. The water quality record shows some variability (upward deflections) but no clear trending over the period of record. This well is screened from approximately 290 to 350 feet bgs. Water quality in this well is relatively good, with most recorded TDS concentrations less than 1,200 mg/l. In the western basin near Ventura Harbor, well 02N23W14K01S provides another example of a well with good water quality for the period of record from 1933 to 1981. Concentrations for most analytes are fairly stable, with TDS concentrations averaging less than 1,200 mg/l (Figure 6-7). This agricultural well is screened from 475 to 915 feet bgs. One outlier record of elevated chloride exists from 1962. This outlier of 376 mg/l is shown just inland of Ventura Harbor in Figure 6-5. Otherwise the records from this coastal production well show no evidence of saline intrusion.

7 DISCUSSION

There are a limited number of wells within the Mound Basin. Wells are absent along the northern portions of the basin, and the western extent of the basin also lacks wells as this area is supplied by surface water and groundwater from Ventura River valley. Some public supply wells exist in the central portion of the Mound basin but significant quantities of groundwater are imported from Oxnard Plain to the south, in part due to the better water quality associated with those wells. The amount of data available for characterization of basin conditions is somewhat limited. The water supply scenario for the Mound Basin is atypical for the region, with groundwater imports from three adjacent basins. The other basins managed by United Water are dominated by agricultural land use with some urban environment. The Mound Basin is dominated by the urban environment of the City of San Buenaventura and surrounded by some agricultural lands. Pumping records indicate that agricultural pumping often exceeds municipal pumping in the Mound basin.

The Mound basin is a complex basin due to its physical and geologic setting. Characteristics of the Mound Basin are different than most of the other basins that are managed by United Water. Despite its unique characteristics the Mound Basin shares similar hydrogeologic dynamics and processes with the other basins in the Santa Clara River Valley and Oxnard Plain.

The present day boundaries of the Mound Basin consist of: the Ventura foothills/Ventura fault to the north, the Country Club fault to the east, the Pacific Ocean to the west, and the Montalvo anticline to the south. The Oak Ridge fault runs sub-parallel to the Montalvo anticline approximately one half to one mile north of the anticline. Although the Montalvo anticline is presently used for the southern boundary it has been suggested that perhaps the Oak Ridge fault should be used for the southern basin boundary. Yerkes et al (1987) state that the Oak Ridge is a zone of faulting that forms the southern boundary of the Ventura synclinal trough in the western Ventura Basin (Mound groundwater basin) rather than the Montalvo anticline. Since the basin is characterized by faults along the northern and eastern boundaries it is arguable that the southern boundary should be defined by a fault, forming a consistent structural architecture to the basin rather than a geographical basin for groundwater management. Groundwater elevations in the zone between the

Oak Ridge fault and the Montalvo anticline are responsive to water levels in the Oxnard Forebay, especially during periods of above-average recharge in the Forebay.

There are some appreciable offsets of geologic formations across the faults bounding the Mound Basin. Several previous studies by others and recently reviewed borehole geophysical data suggest that the low-permeability Santa Barbara formation does not extend to sufficiently shallow depths to impede groundwater flow across the faults or above the faults. In most cases the faults do not extend close enough to the surface to disturb San Pedro or alluvial sediments. In those cases, there is a significant thickness of the San Pedro formation (aquifer materials) existing on both sides of the faults. The degree of aquifer offset is site-specific along the trace of the faults, however, there are significant data to suggest that the UAS and to a somewhat lesser degree the LAS, are continuous across most of the basin-bounding faults. This implies that the hydrogeological boundaries of the basin are not necessarily coincident with its' structural boundaries and that there is hydrologic connection between the Mound basin and the adjoining groundwater basins.

The nature of the faults themselves as an impedance to groundwater flow is not known. However, groundwater flow and basin recharge across these zones is most probable. Recharge from the Oxnard Plain basin, Forebay basin, and Santa Paula basin into the Mound Basin is likely occurring across the geologic features that currently delineate the Mound basin. Groundwater flow within the basin is generally east-to-west, and groundwater flows from recharge areas to surrounding down-gradient areas. These recharge and flow dynamics are consistent with the accepted and well-documented groundwater flow systems in the Oxnard Forebay/Oxnard Plain and other coastal California basins.

In the Mound Basin water levels in many wells respond in similar fashion to wet and dry periods. Gradients within the basin remain fairly flat most of the time and water levels tend to vary somewhat among nearby wells. Deeper wells often have lower groundwater elevations. Records of groundwater samples from Mound basin wells reveal that salt concentrations are somewhat elevated compared to adjacent basins, but the water is generally suitable for municipal and agricultural uses. Although groundwater flow may occur through areas where interconnected or continuous aquifer materials exist, the less-continuous lens-like nature of some highly-permeable deposits within the basin (compared to nearby basins) have likely inhibited the flushing of poor-quality waters from the basin (possible connate waters). Active production wells are not currently located near the coast, and available records from coastal wells do not show evidence of saline intrusion.

Since there is somewhat limited data for characterization of the Mound basin, it is recommended that some additional studies be performed to better define basin conditions. One study would be to assess and better characterize the Country Club fault. Geophysical surveys (TDEM) can be utilized across the assumed location of the Country Club fault. Since the Santa Barbara formation is easily recognizable in electric logs (very low resistivity), its depth along a profile or profiles extending from the Santa Paula Basin into the Mound Basin may be defined using this technique. From that data

the actual location of the Country Club fault and the throw on the fault might be resolved. This would provide information regarding the thickness of the San Pedro formation above the up-thrown Santa Barbara formation. Once those data are resolved a pump test could be conducted with a pumping well on one side of the fault and observation wells on both sides of the fault. This type of study can furnish information on flow dynamics on both sides of the fault and across and/or over the fault. A similar study could also be conducted in the vicinity of the Oak Ridge fault.

Additional study is also warranted in the southern portion of the basin, in the greater area surrounding the Montalvo anticline and the Oak Ridge fault. This area of geologic complexity likely provides significant recharge to the Mound basin. The complexity of the zone appears to influence water quality as well, with some of the basin's highest historical chloride concentrations located in this area. A number of active wells currently exist in this area, but data collection from these wells has been poor or inconsistent to date.

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9 APPENDIX A – GENERAL FIGURES

Figure 1-1: Map of Basins Managed by United Water Conservation District.

Figure 1-2: Map Showing Boundaries of the Mound Basin.

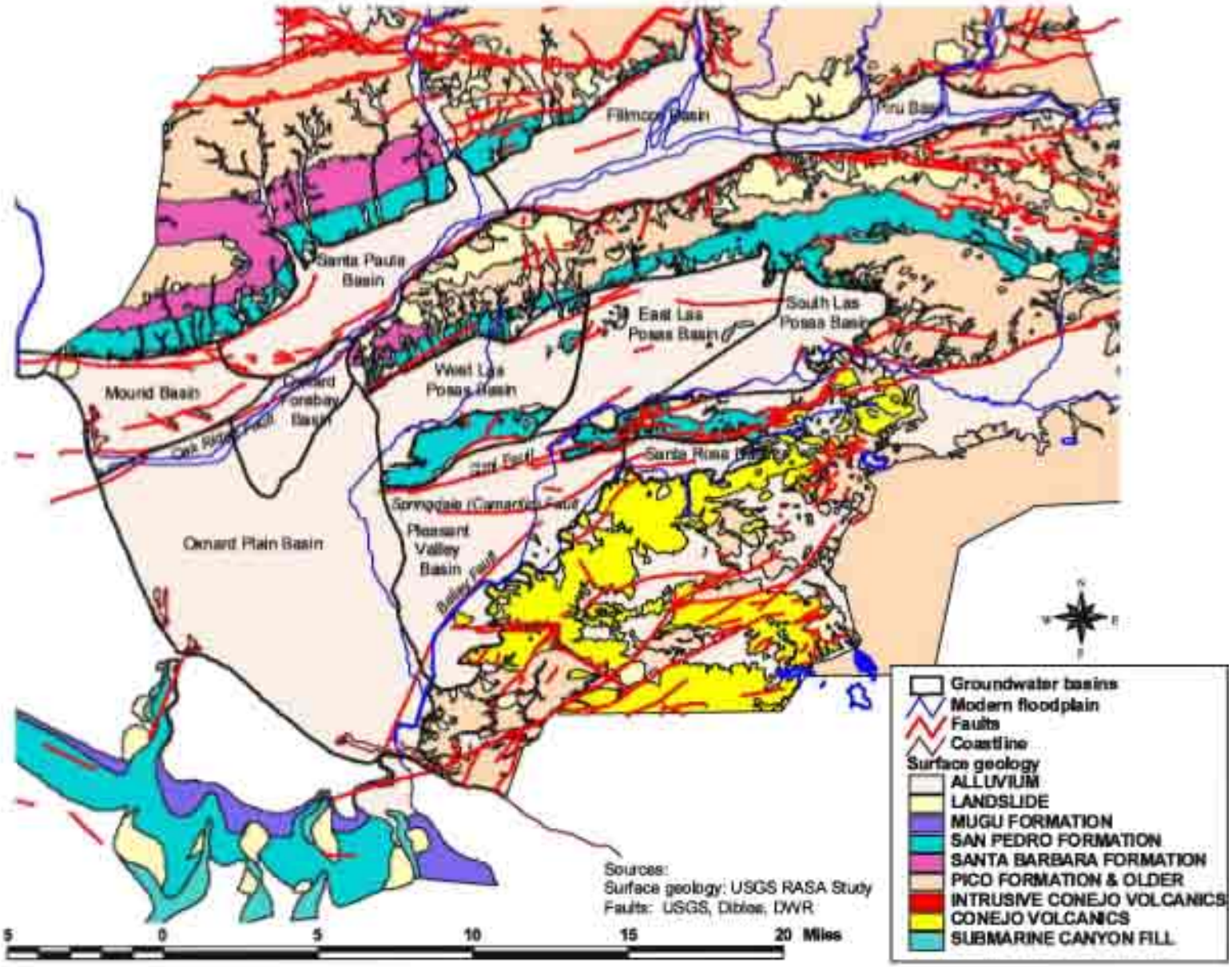


Figure 2-1: Overall geologic map showing groundwater basins including the Mound Basin.

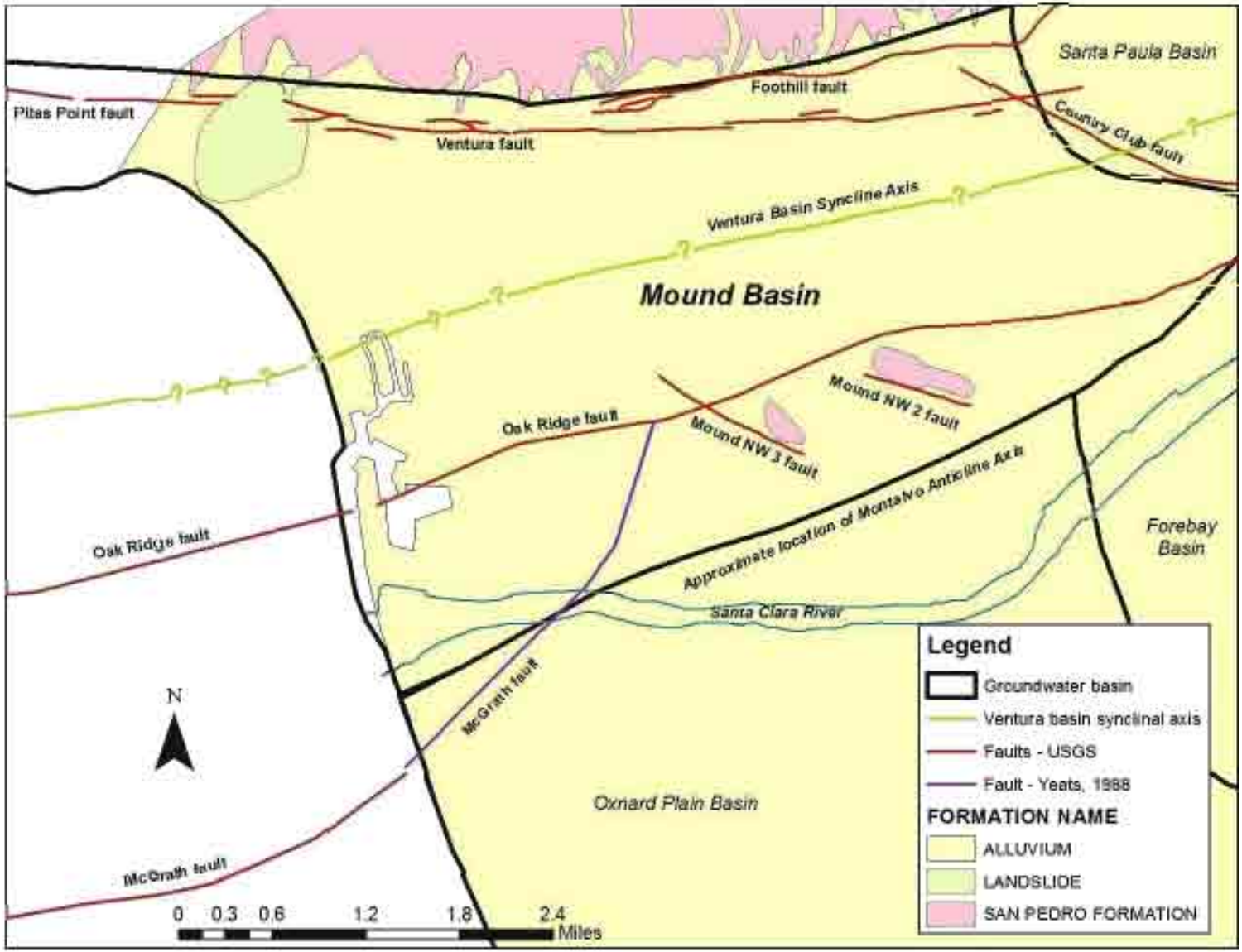


Figure 2-2: Generalized geologic map of the Mound Basin.

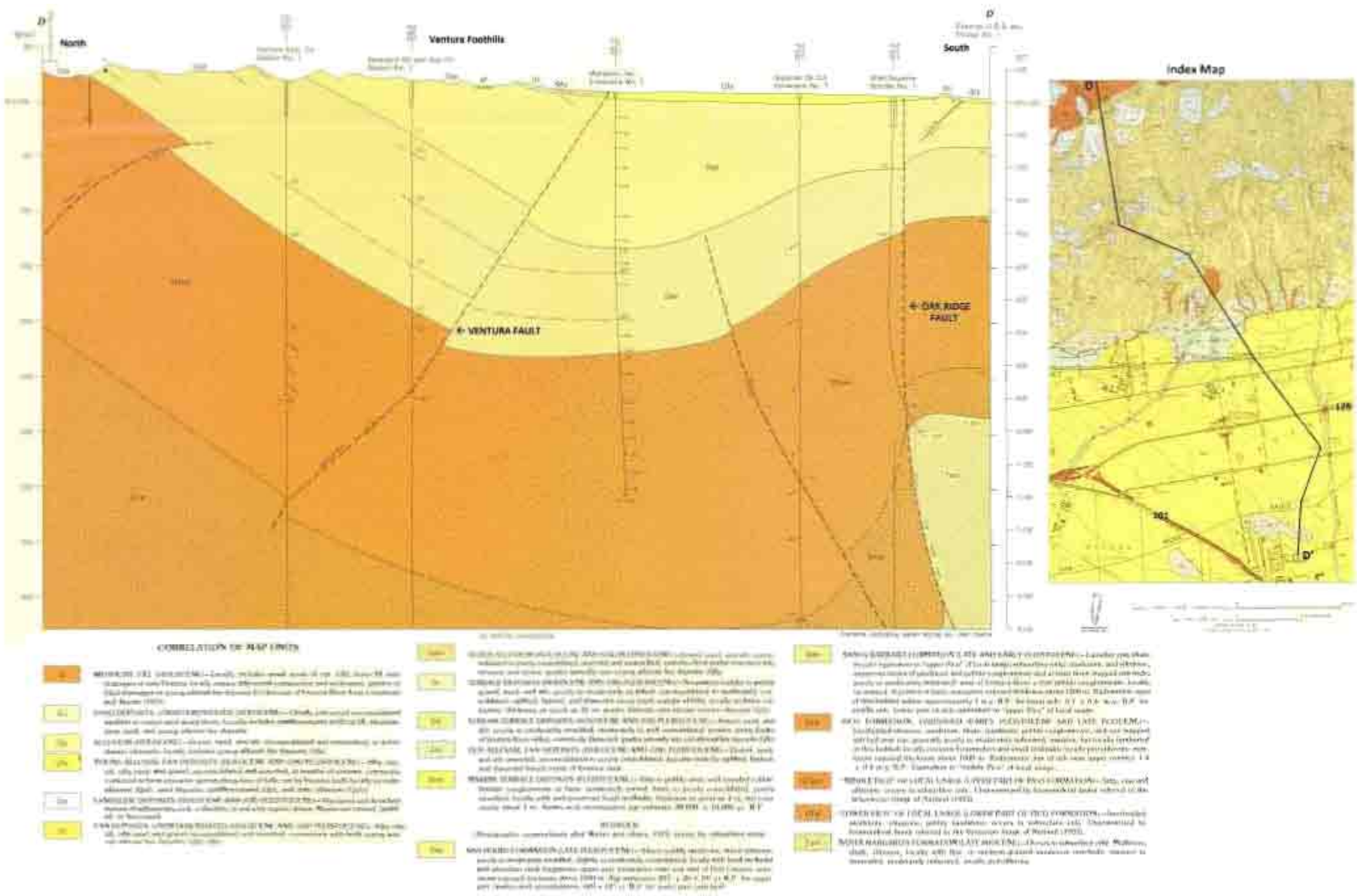


Figure 2-3: Cross-section of the Mound Basin showing the Ventura fault and Oak ridge fault interpretations (Yerkes et al, 1987).

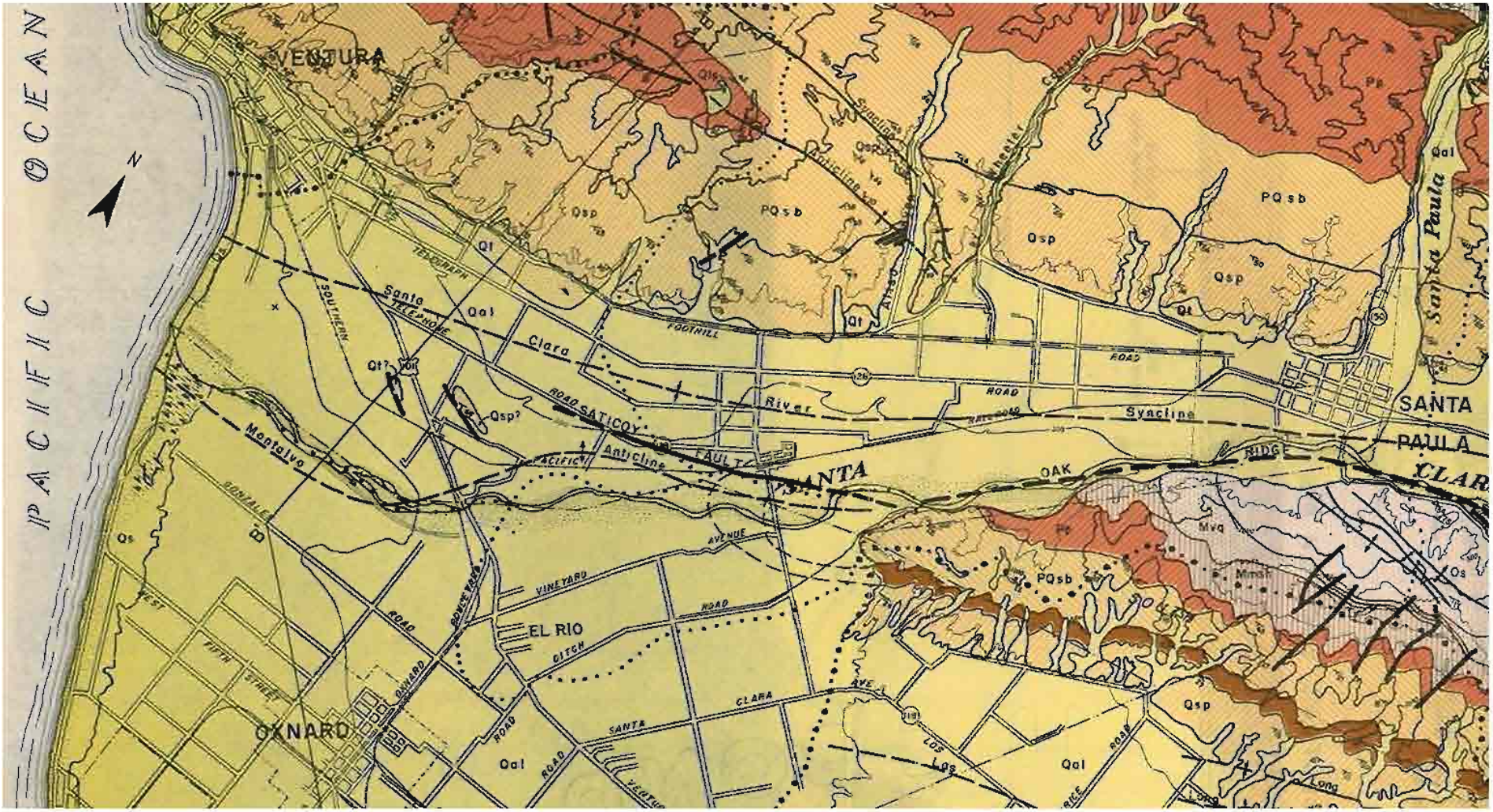
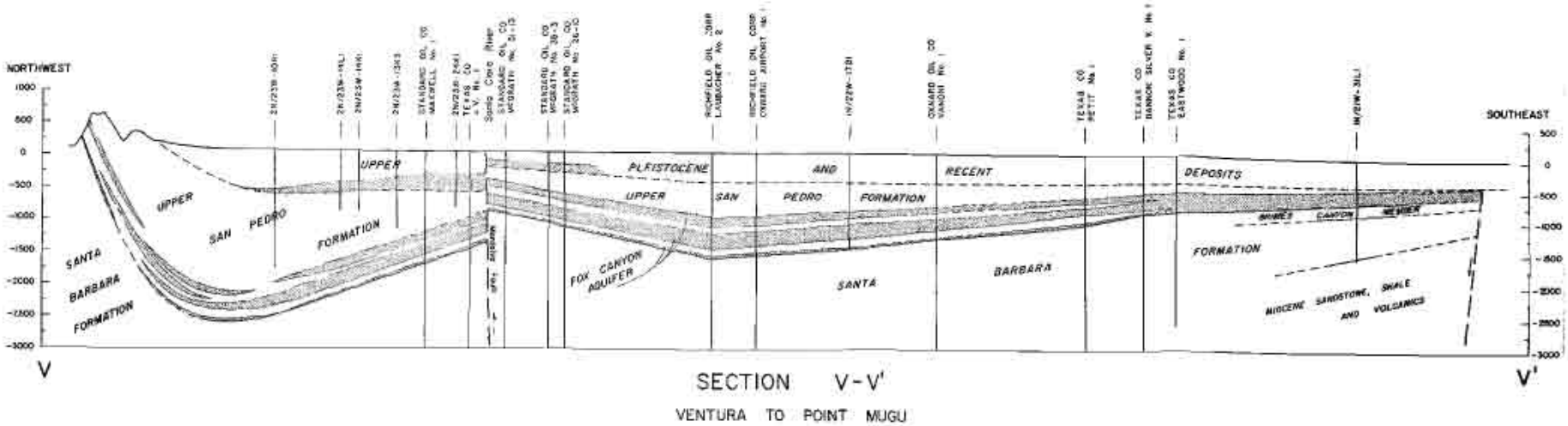


Figure 2-4: Map showing Oak Ridge fault near Santa Paula leading to the "Saticoy Fault" on the eastern side of the Mound Basin (California State Water Resources Board, 1953).



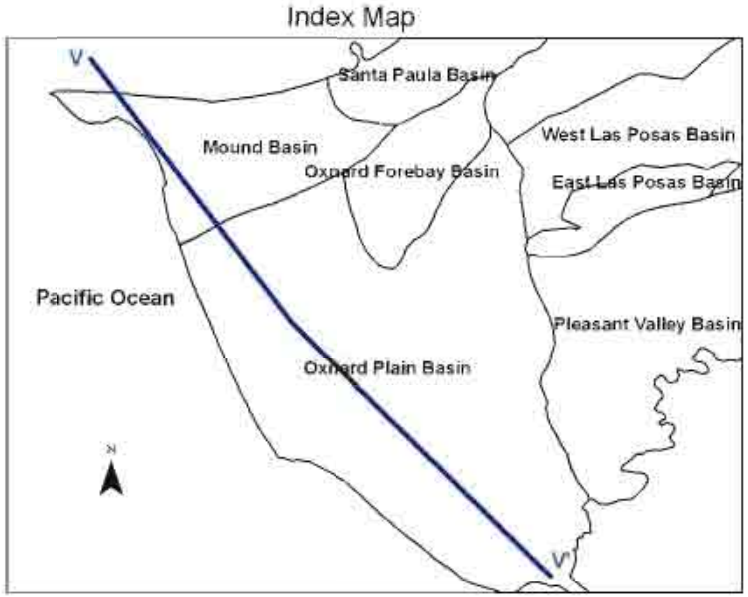


Figure 2-5: Cross-section taken from Mann (1959). The Montalvo fault is shown to form the southern boundary of the Mound Basin. Note that the Ventura fault is not shown.

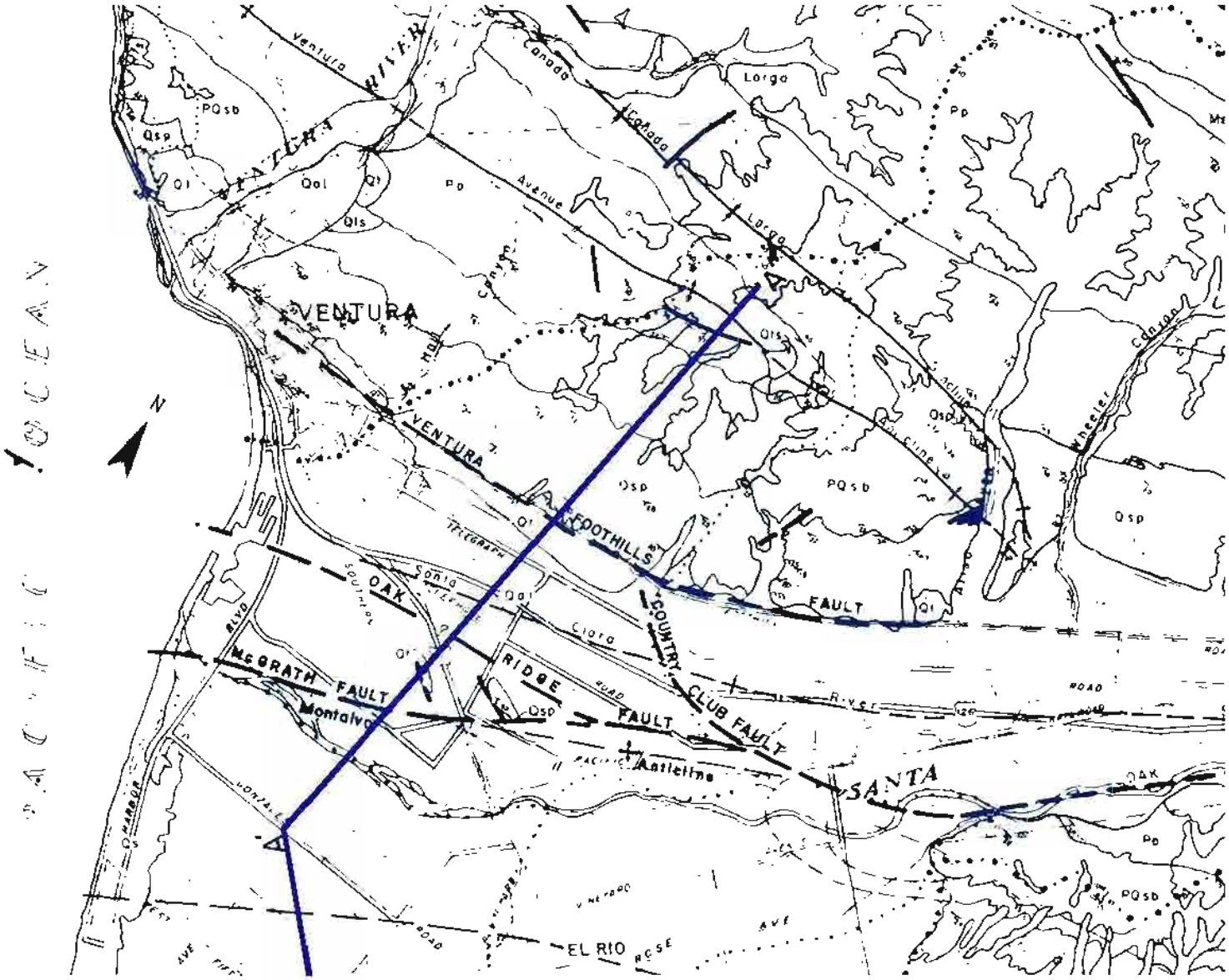


Figure 2-6: Turner and Mukae (1975) map showing Oak Ridge fault and McGrath fault. The Montalvo anticline is shown which forms the southern boundary of the Mound Basin. The location of cross-section A-A' is also shown.

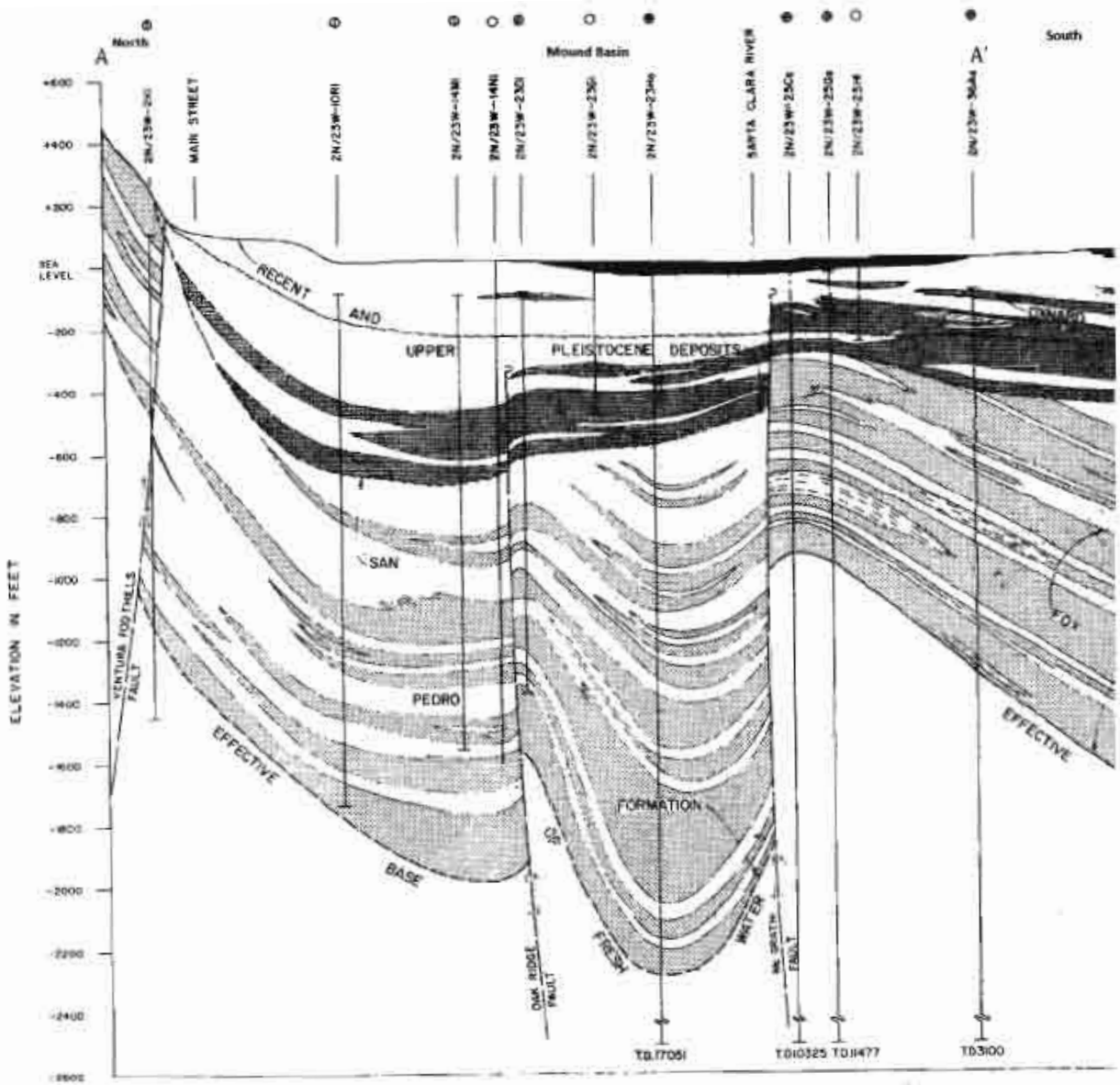


Figure 2-7: Turner and Mukae (1975) cross-section A-A' of Mound Basin near the coast showing the Oak Ridge fault and McGrath fault.

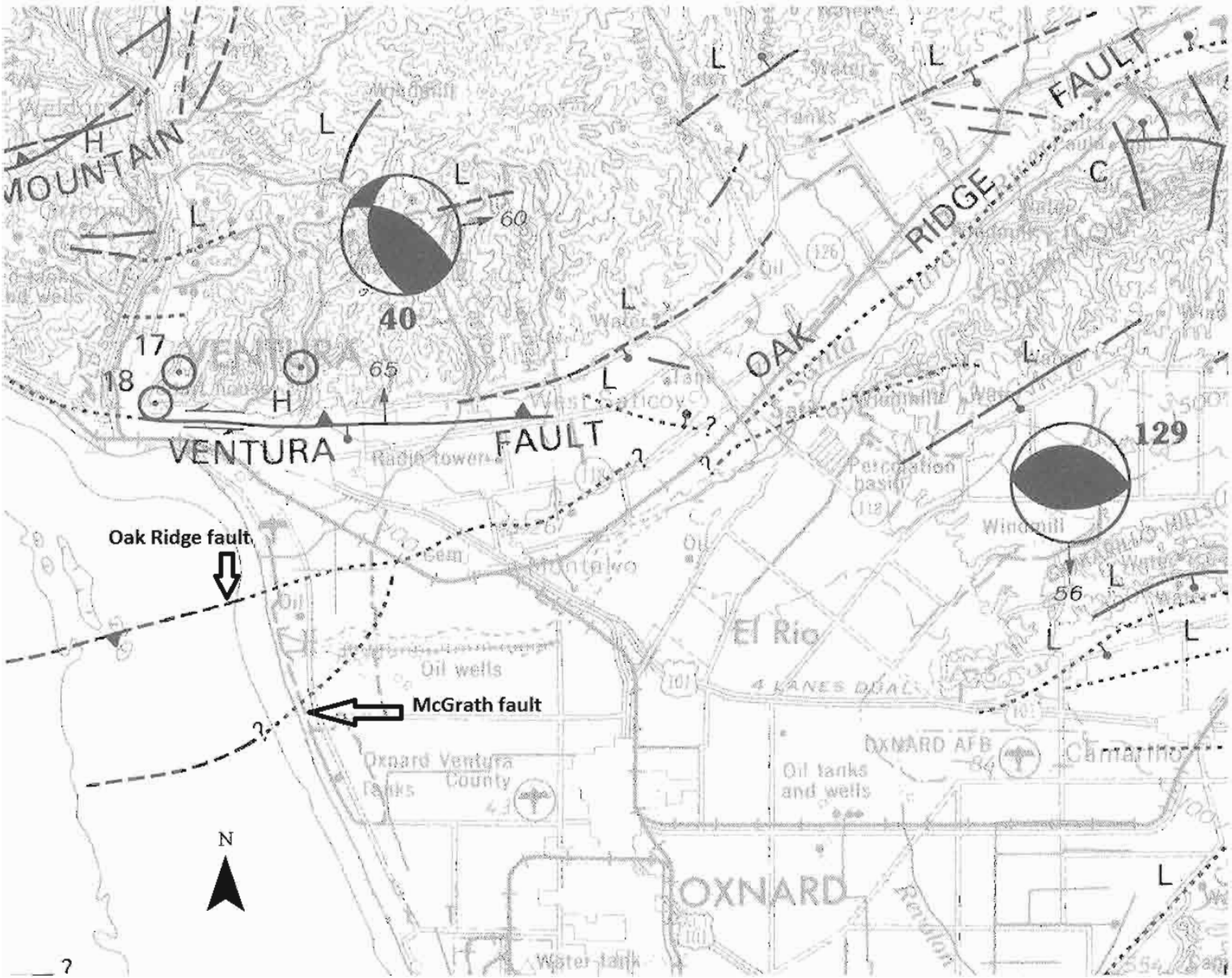


Figure 2-8: Yerkes et al (1987) map showing the Oak Ridge fault and McGrath fault.

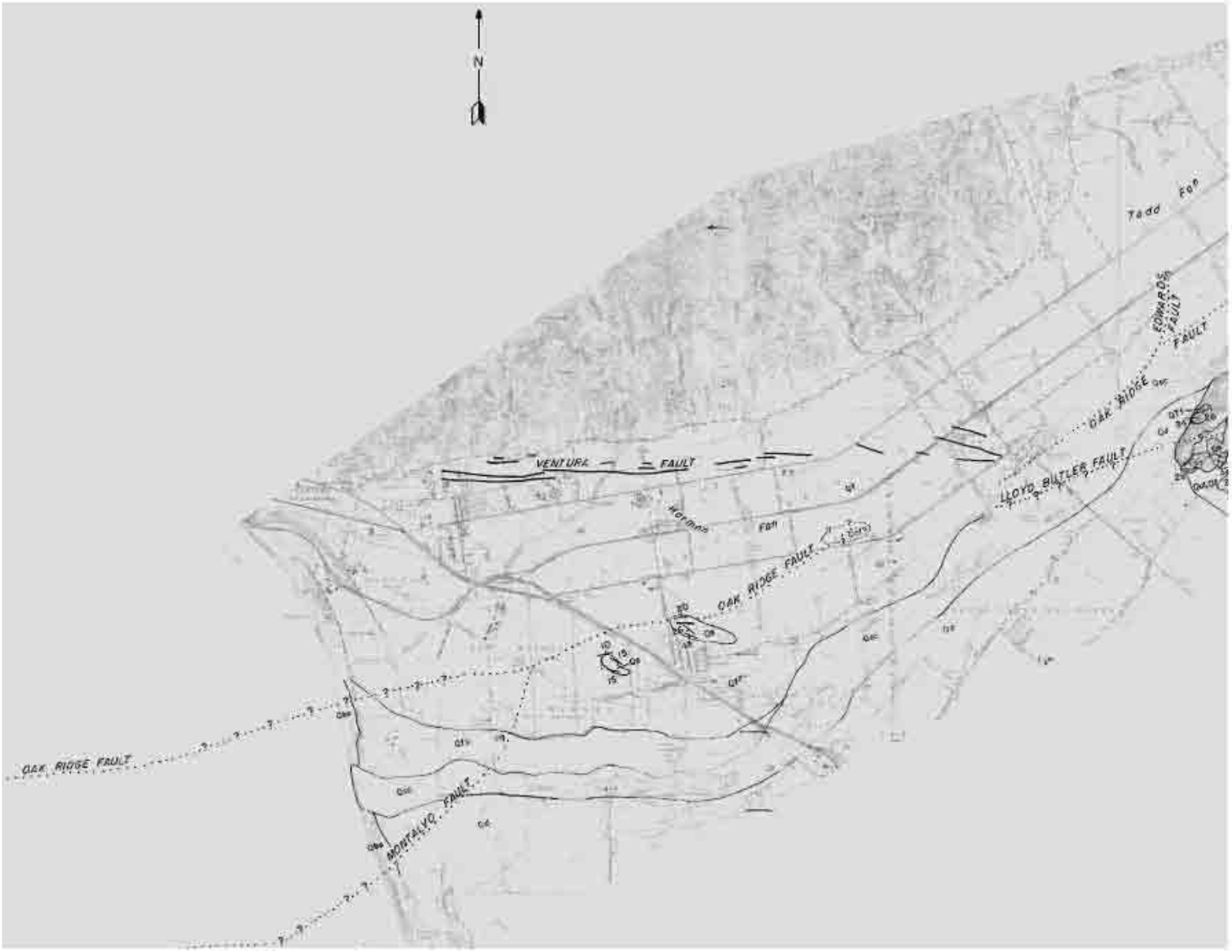


Figure 2-9: Yeats et al (1988) map showing the Oak Ridge fault and McGrath fault. Yeats refers to the McGrath fault as the "Montalvo" fault.

Figure 2-10: Yeats et al (1988) map showing Cross-sections A-A' and B-B' locations over the Oak Ridge fault and McGrath fault ("Montalvo" fault).

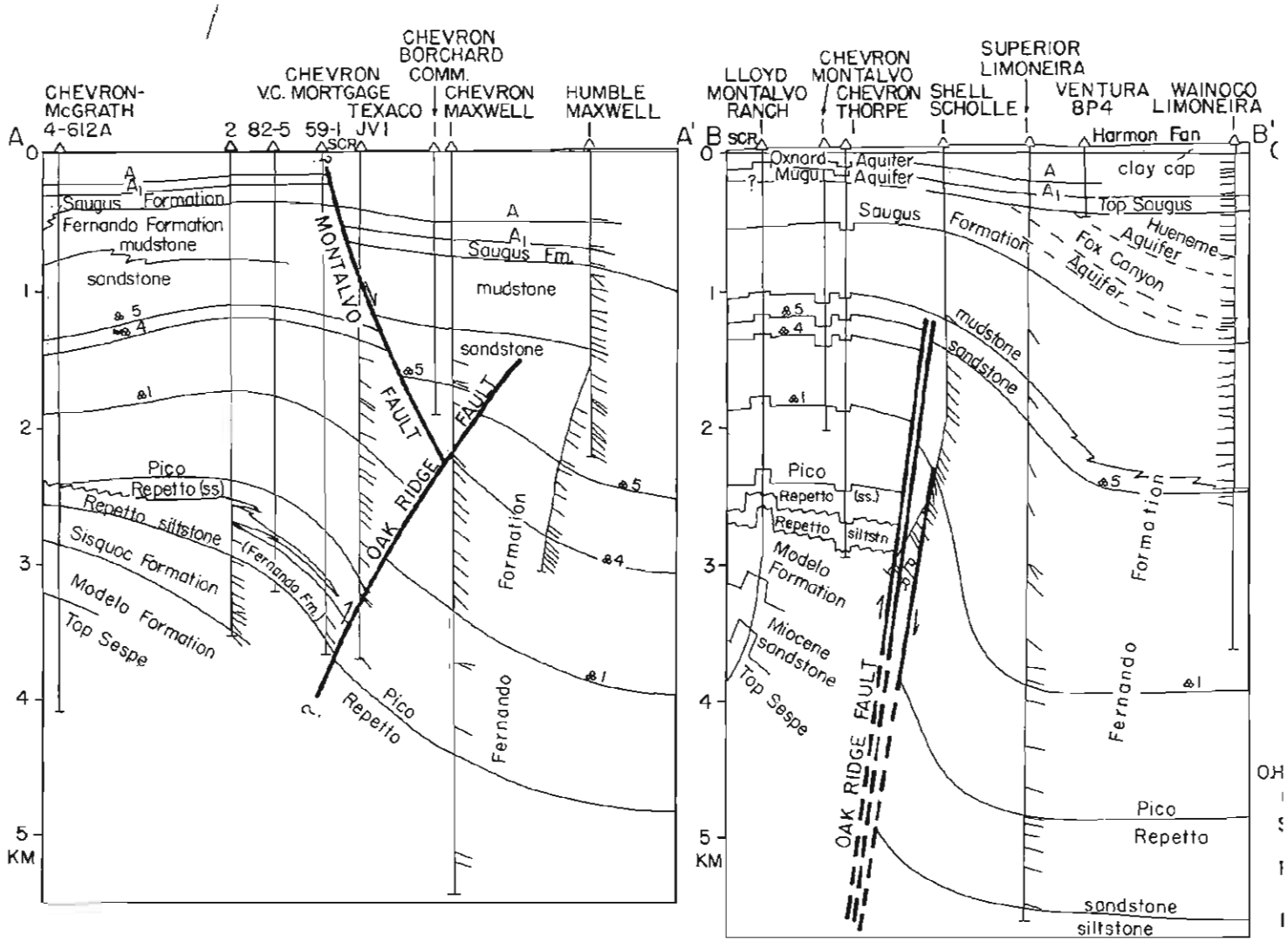
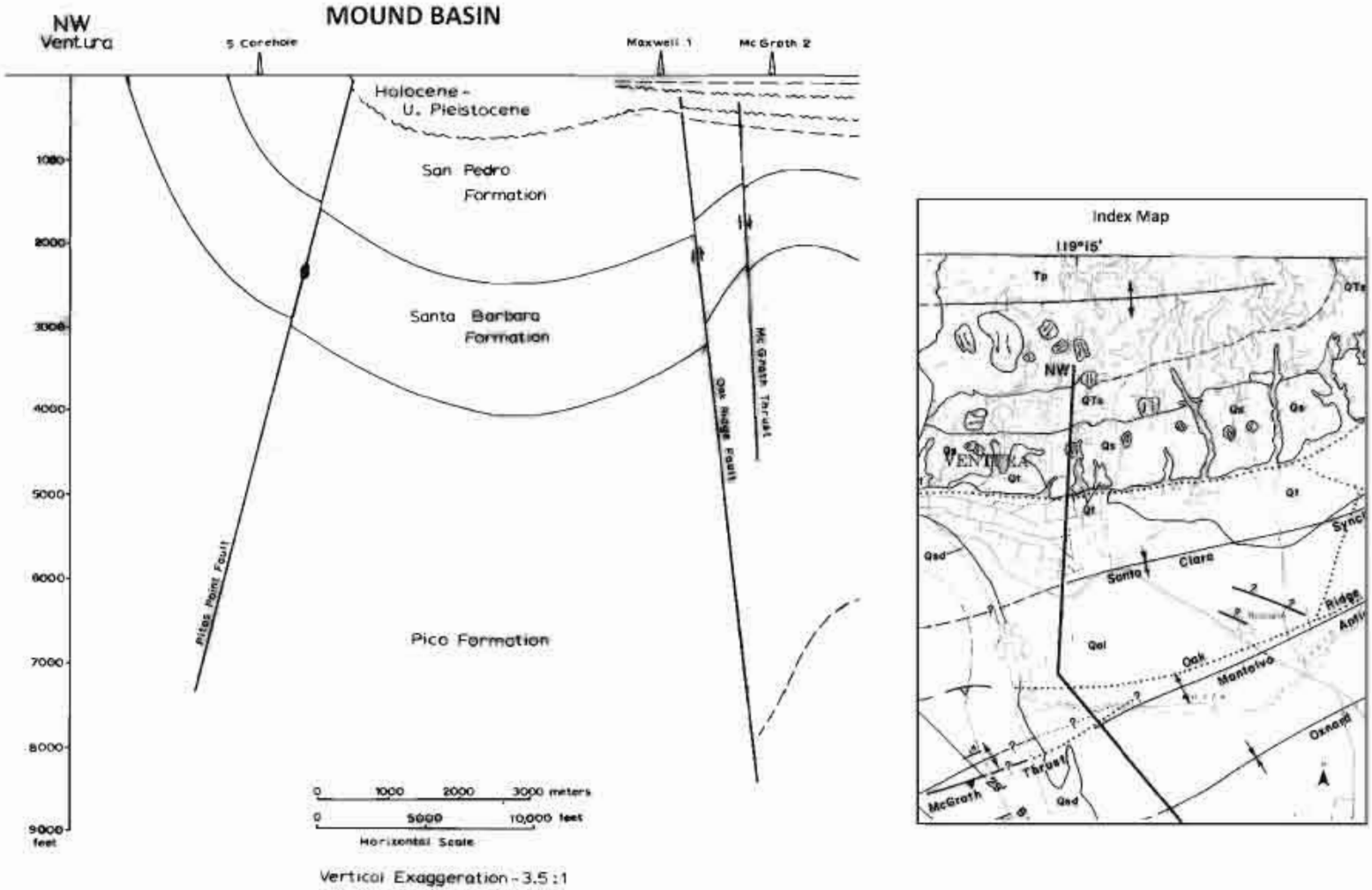


Figure 2-11: Yeats et al (1988) Cross-sections A-A' and B-B' over the Oak Ridge fault and McGrath fault ("Montalvo" fault).



Generalized onshore stratigraphic cross-section across the coastal portion of Oxnard Plain. See Plate 2 for areal extent and orientation of cross-section. (Modified after Paschall and others, 1956; State of California, 1965; Ogle, 1969; Turner, 1971, oral commun.)

Figure 3-1: Schematic Cross-Section of the Mound Basin taken from Greene et al (1978).

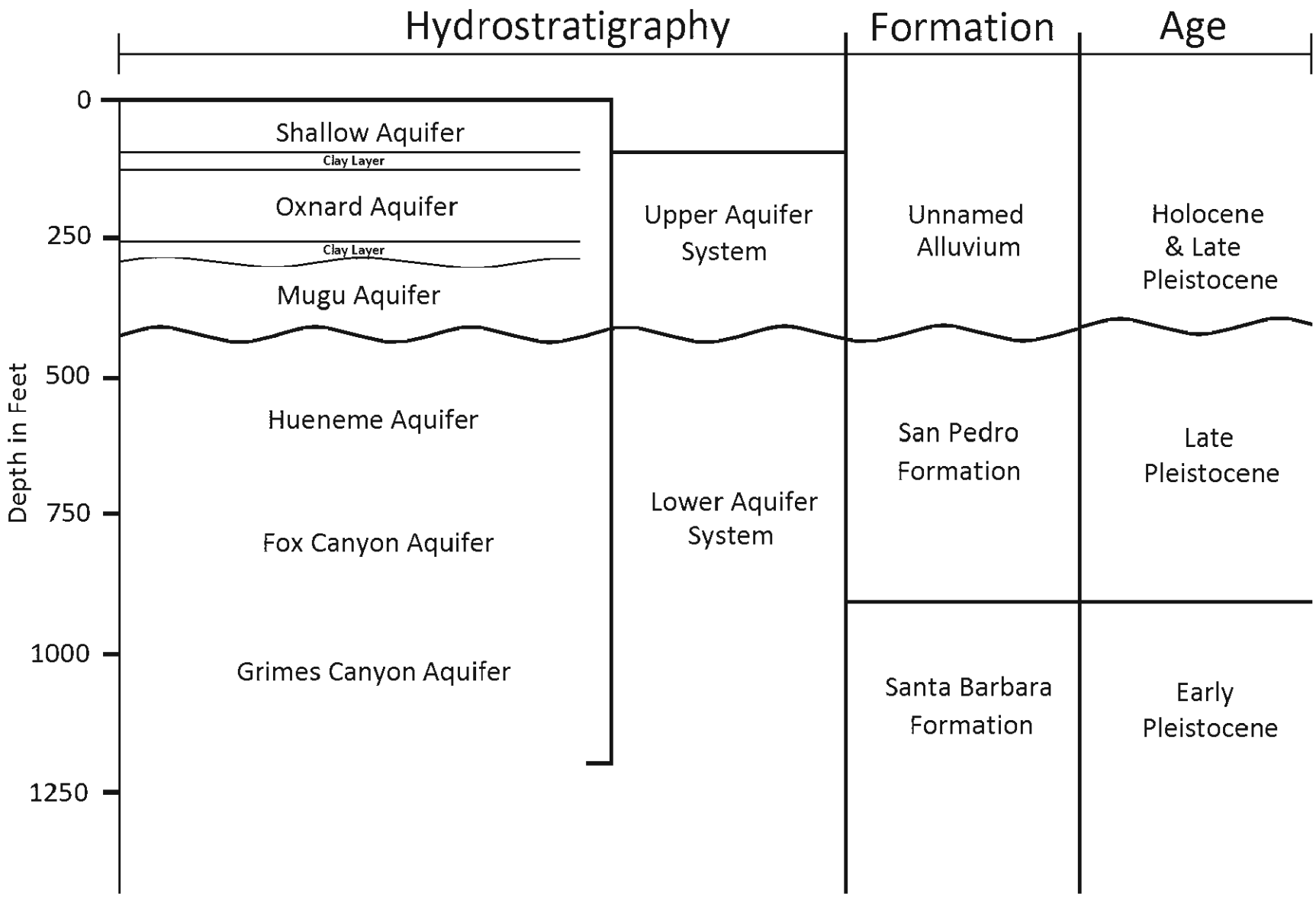


Figure 3-2: Schematic diagram of general aquifer systems.

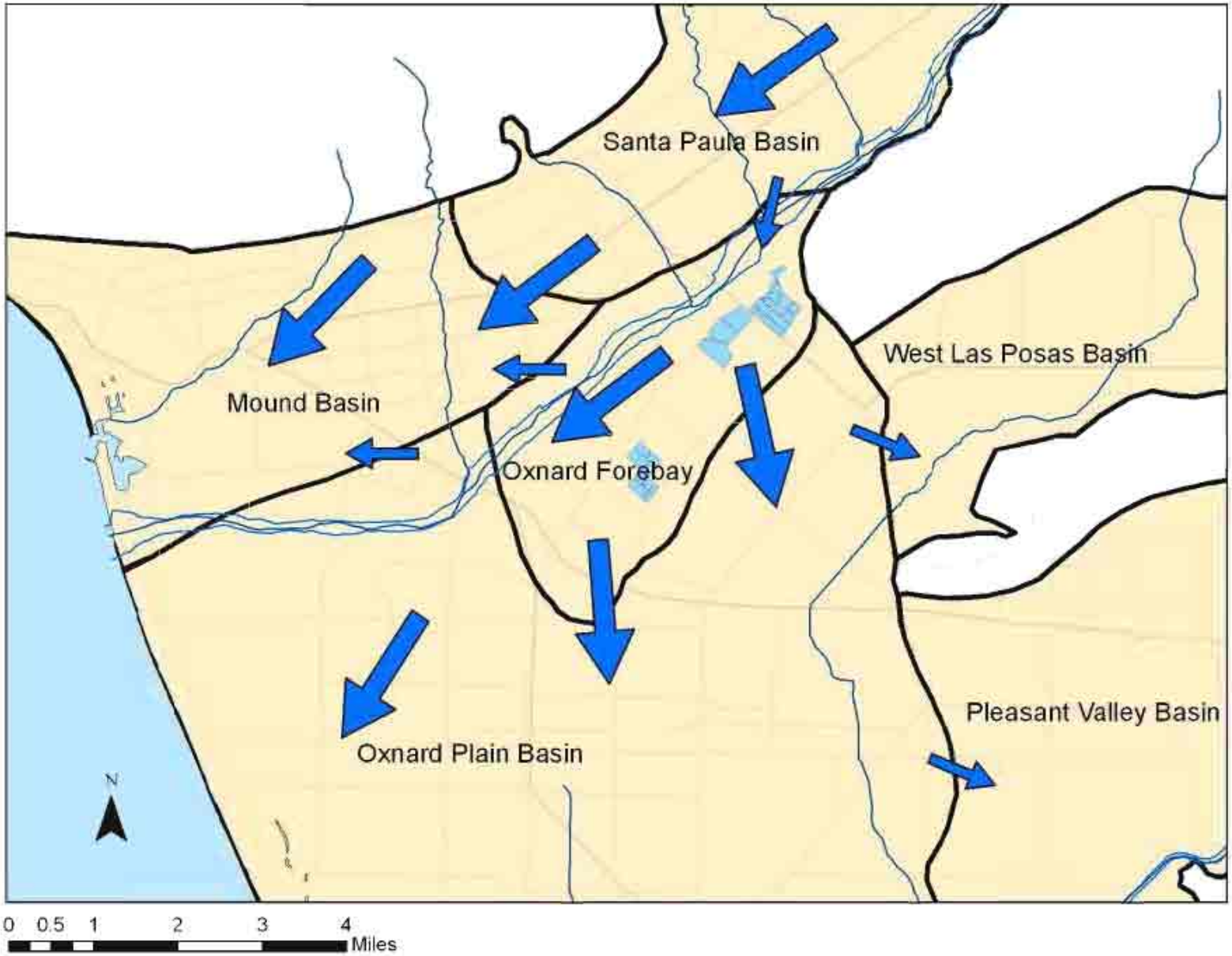


Figure 3-3. Generalized conceptual groundwater flow paths.

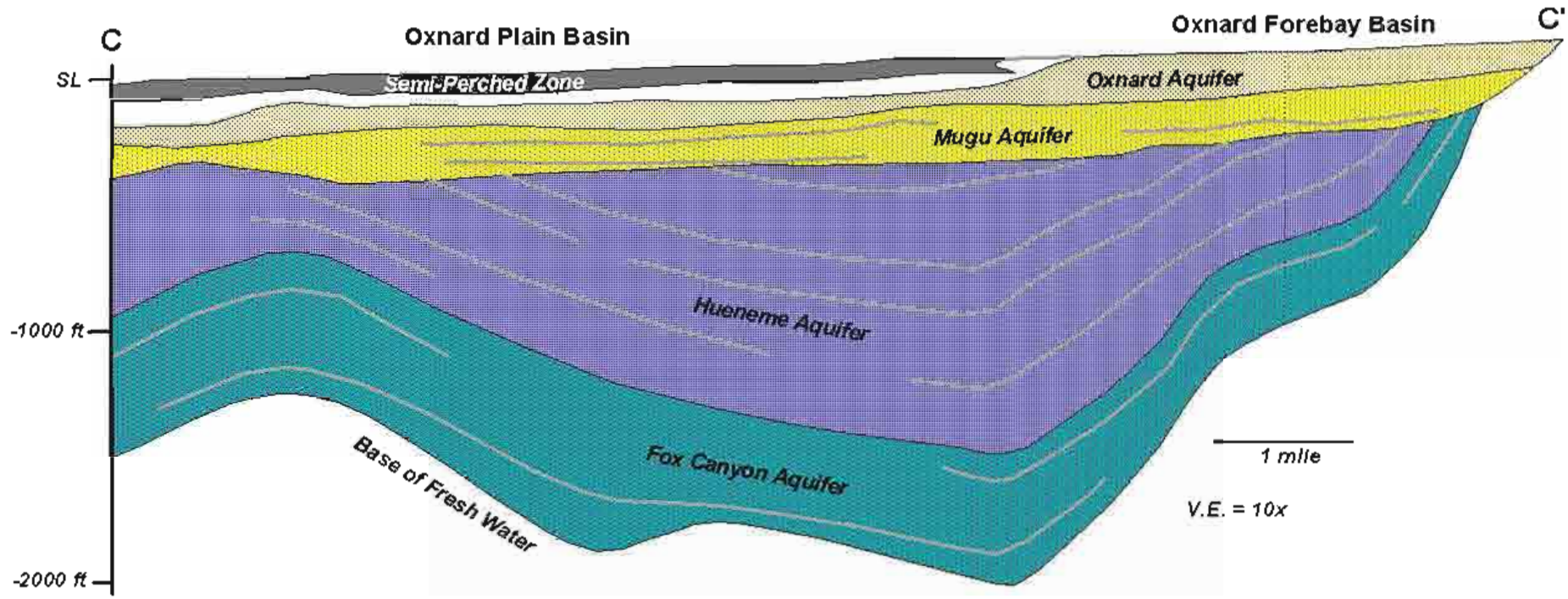


Figure 3-4: Schematic Cross-Section of Aquifer Systems in the adjacent Oxnard Plain south of the Mound Basin.

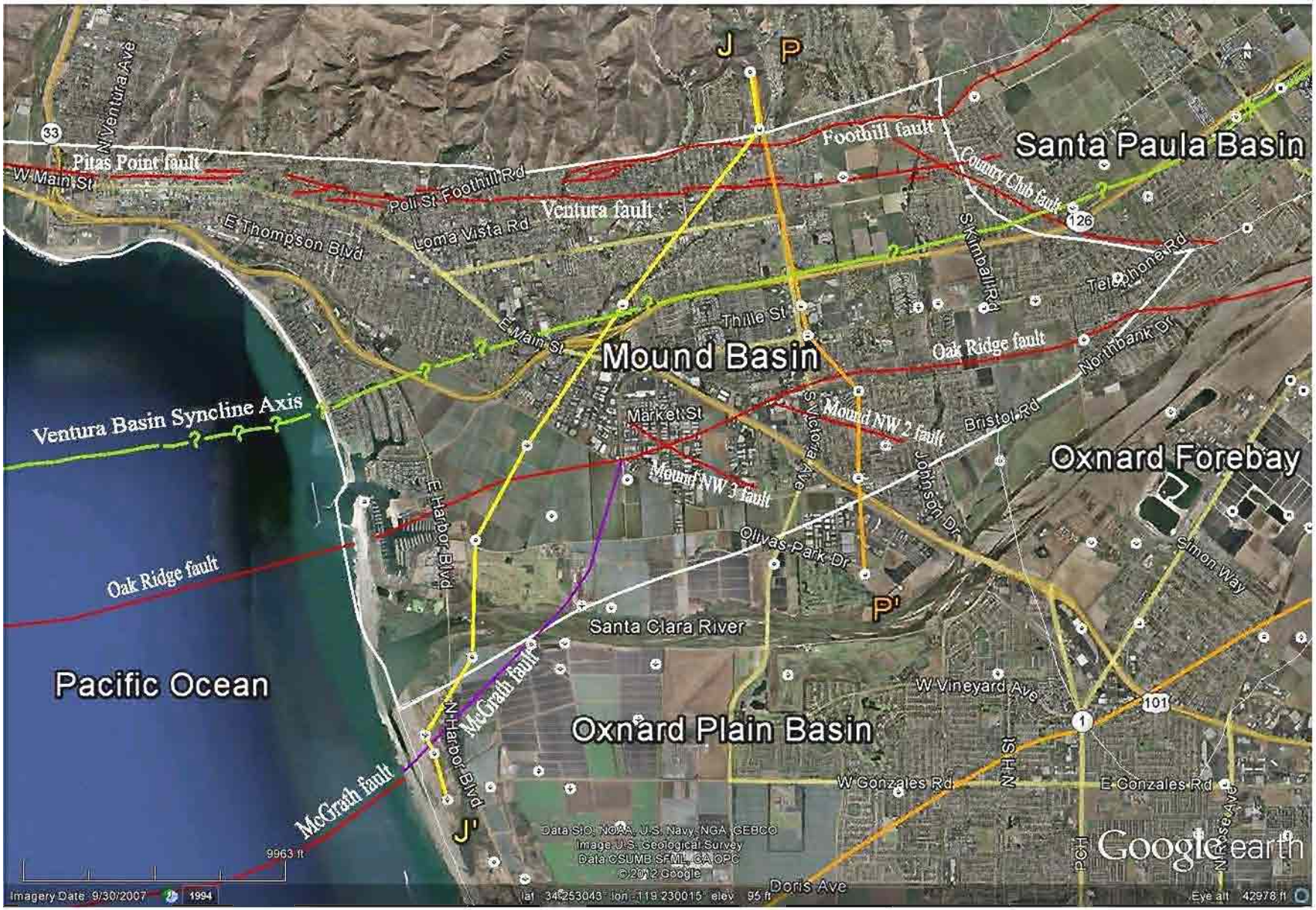


Figure 3-5: Location Map for United Water Cross-Sections J-J' and P-P'.

Cross-Section J-J'

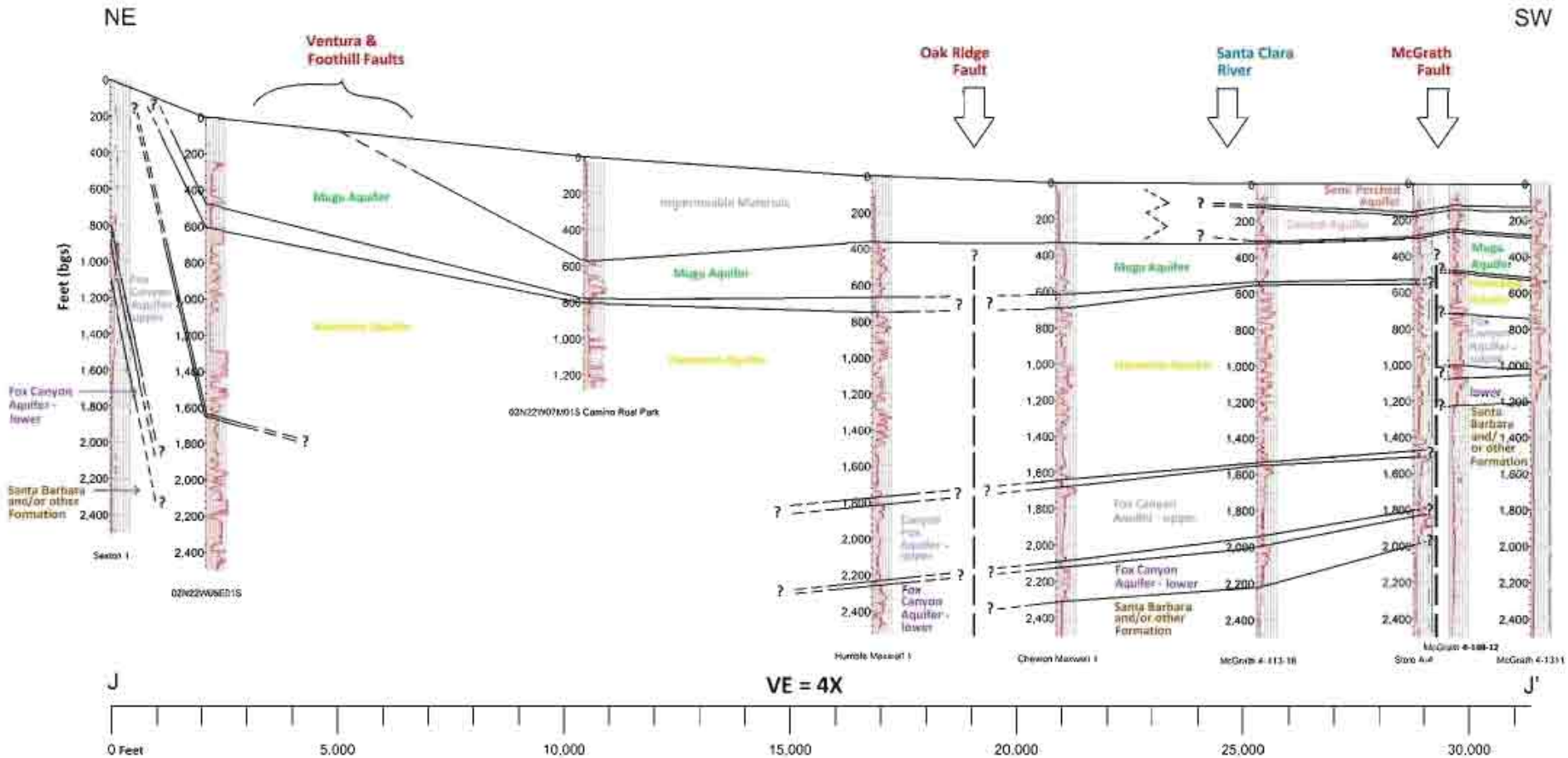


Figure 3-6: United Water Cross-Sections J-J'.

Cross-Section P-P'

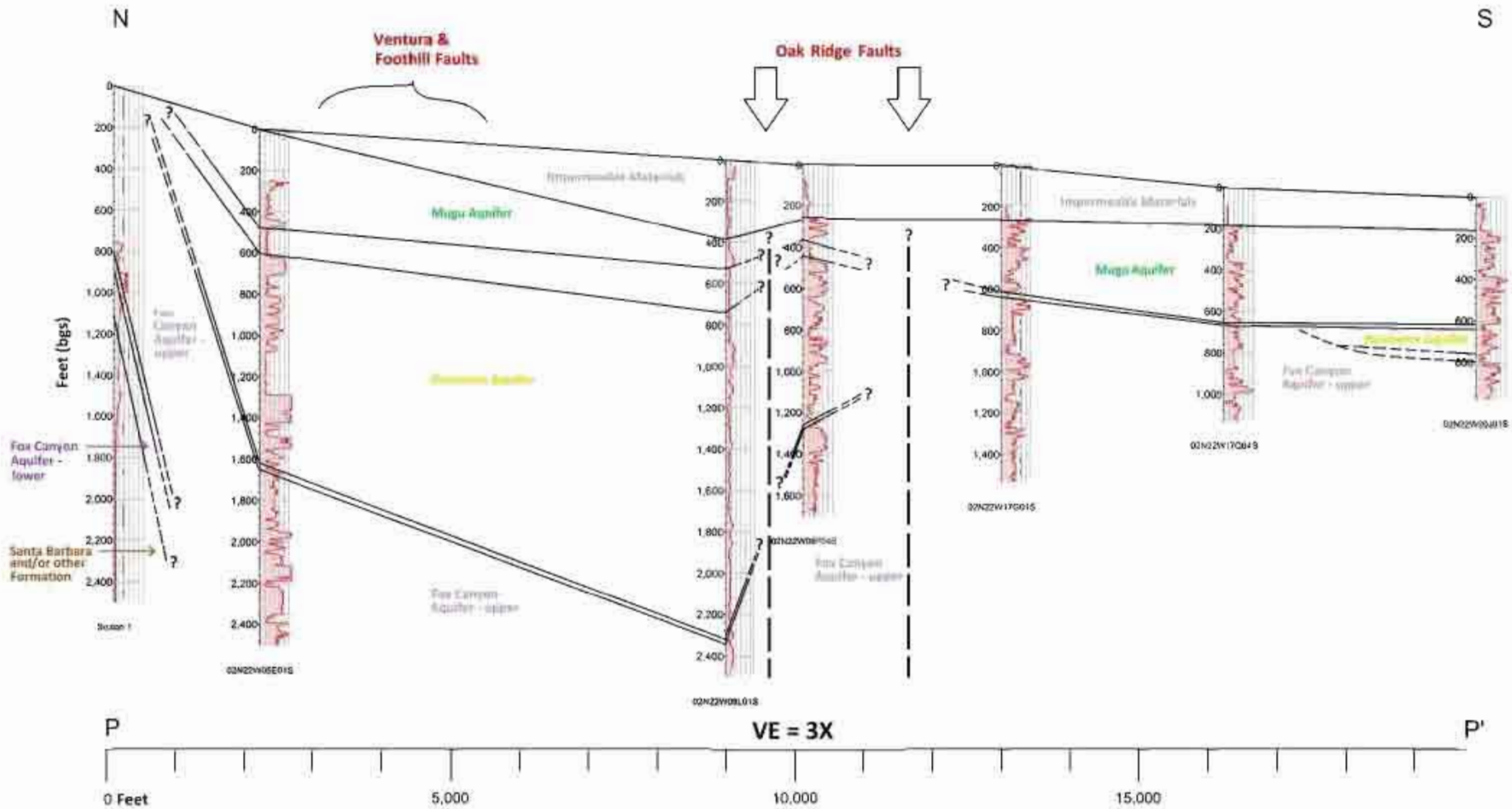


Figure 3-7: United Water Cross-Sections P-P'.

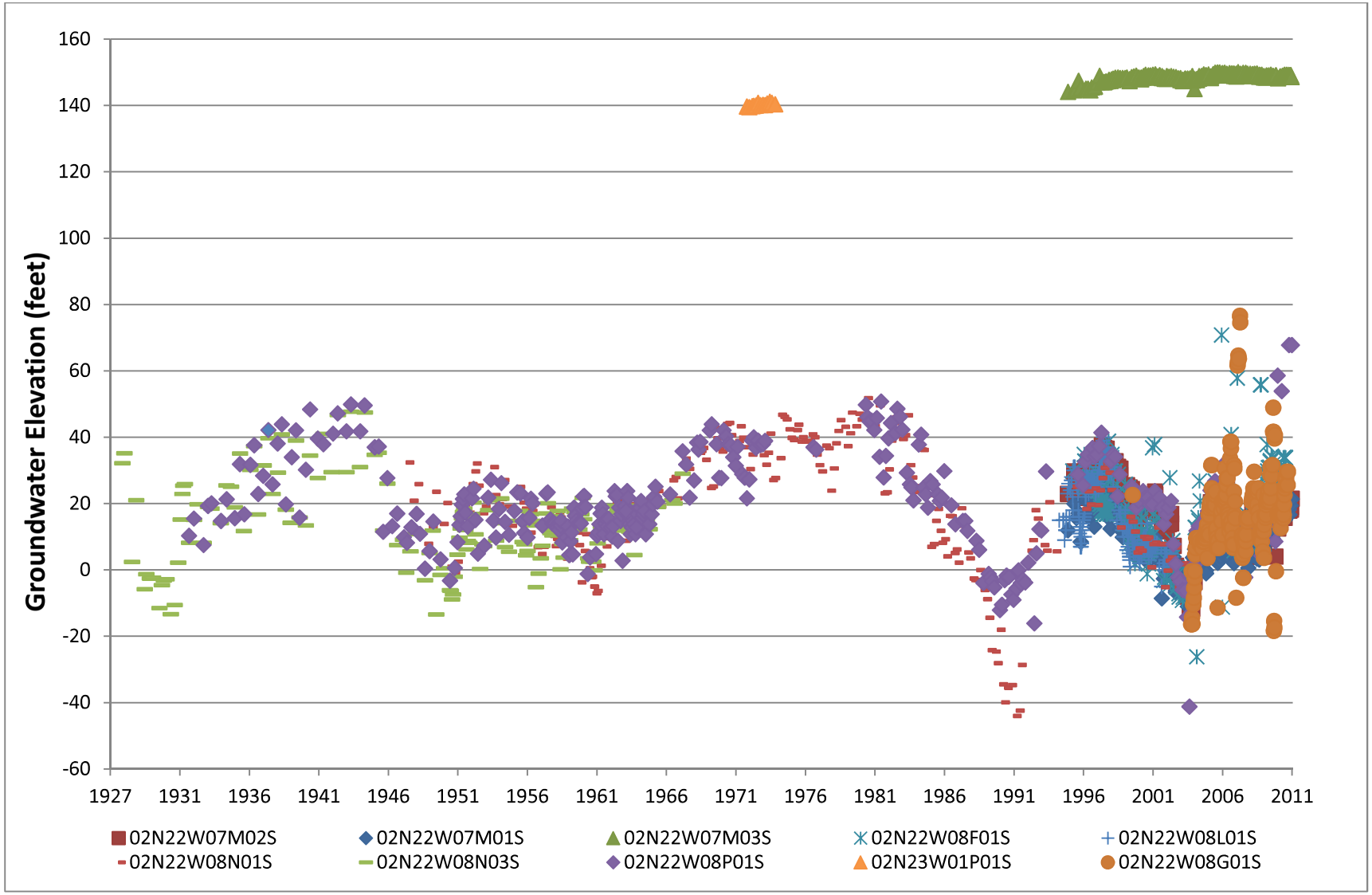


Figure 4-1. Recorded groundwater elevations, north and central Mound basin.

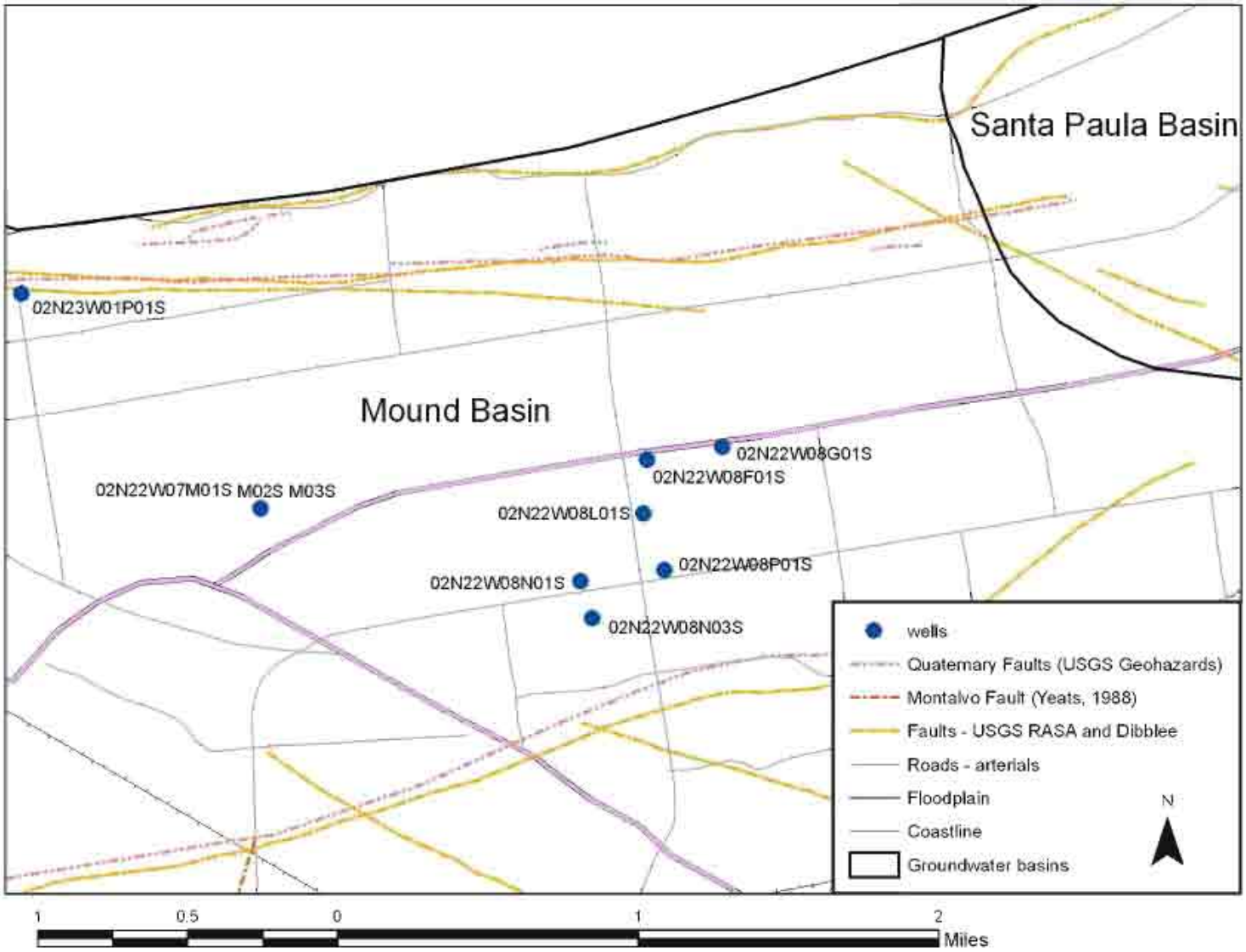


Figure 4-2. Location map for north and central Mound basin wells with WLE records.

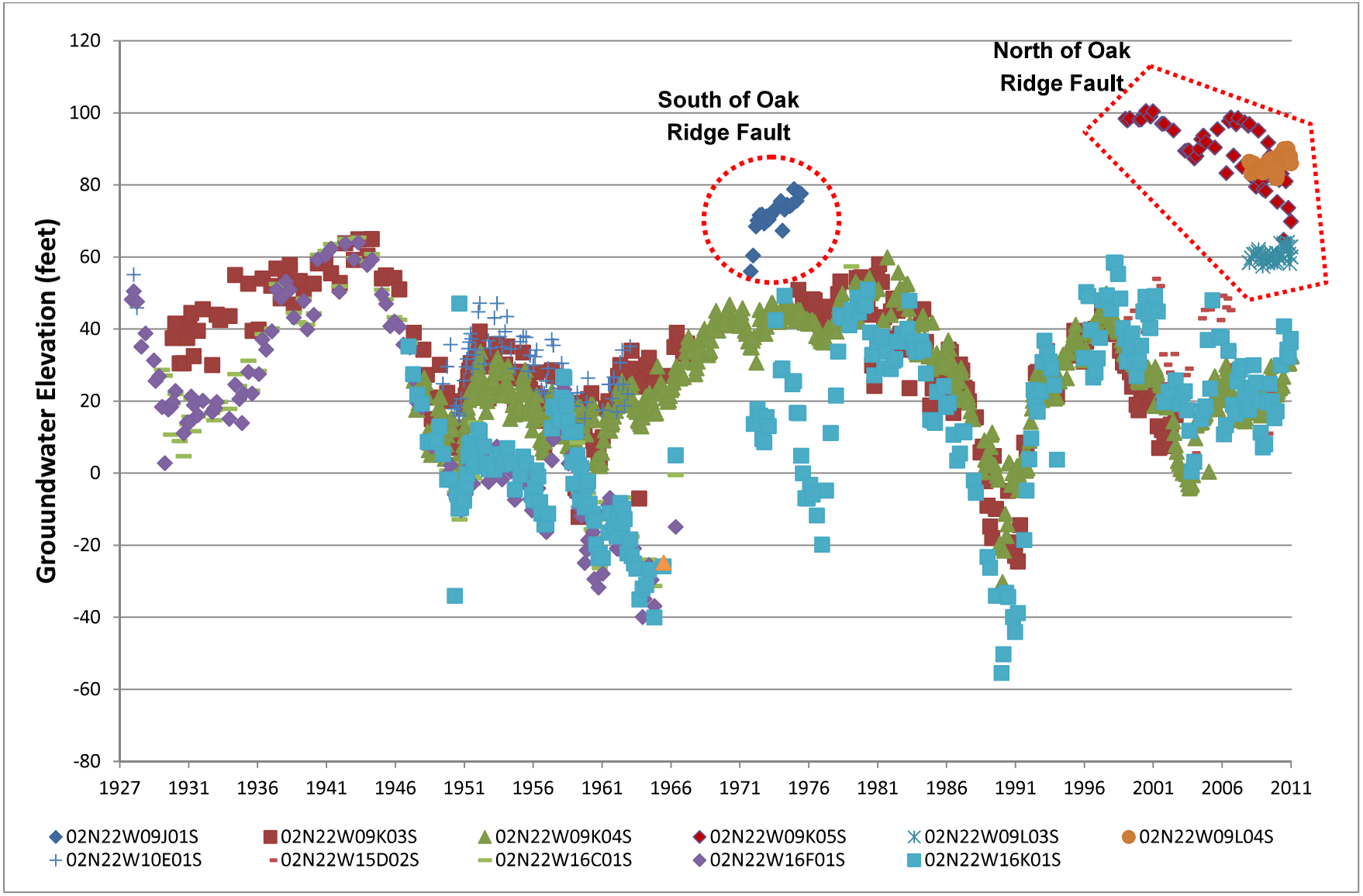


Figure 4-3. Recorded groundwater elevations, eastern Mound basin.

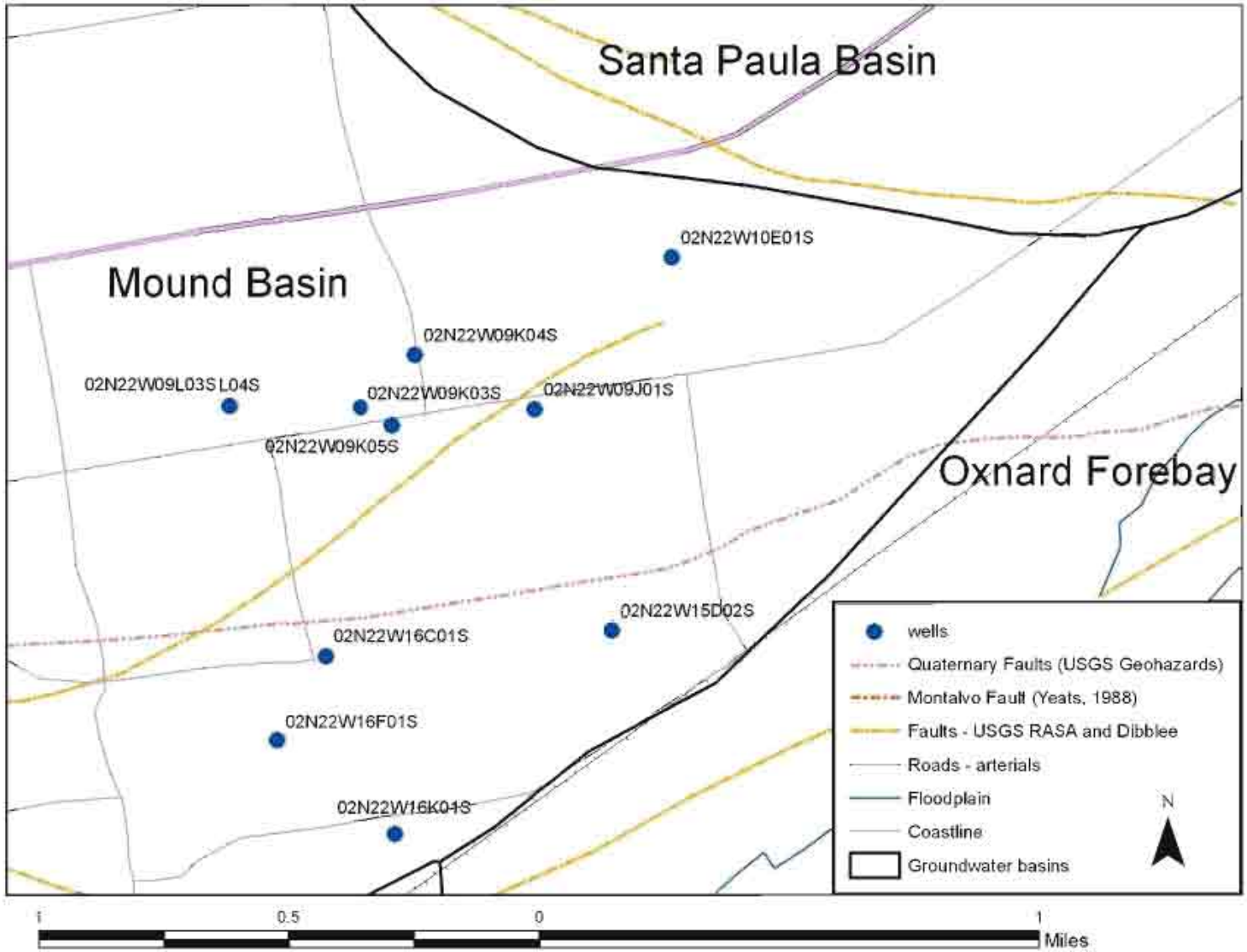


Figure 4-4. Location map for eastern Mound basin wells with WLE records.

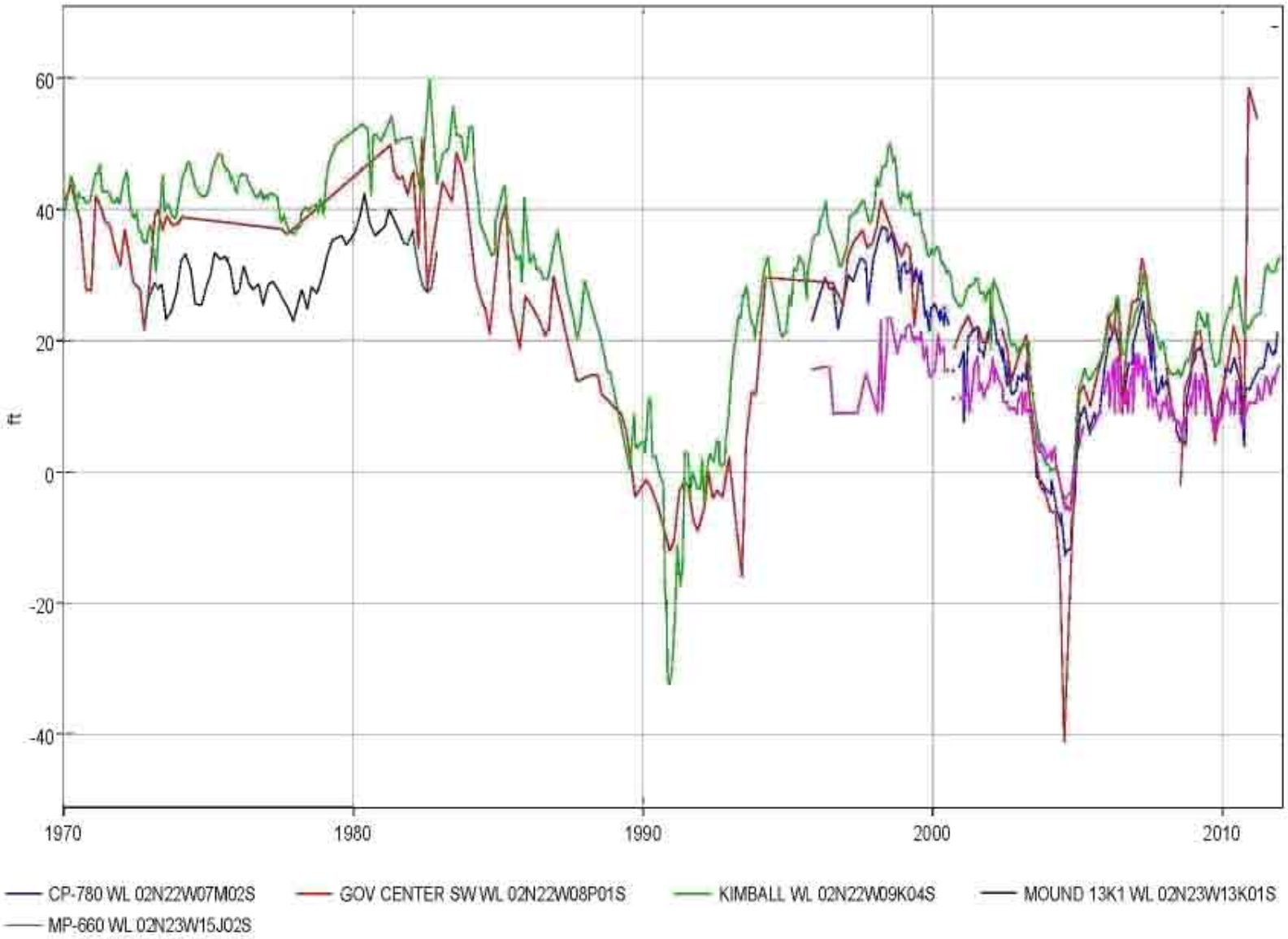


Figure 4-5. Recorded groundwater elevations, central Mound basin.

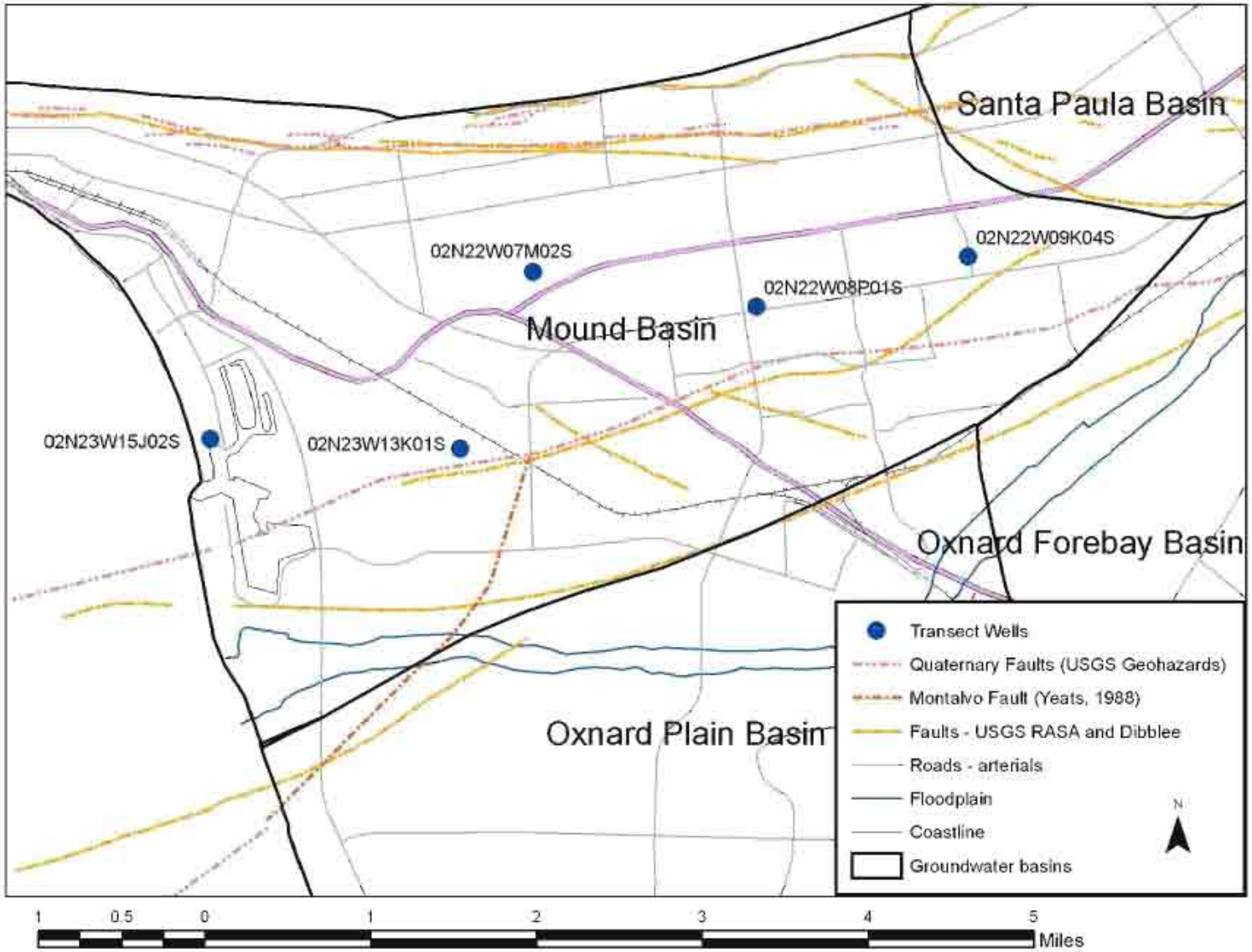


Figure 4-6. Location map for central Mound basin wells with WLE records.

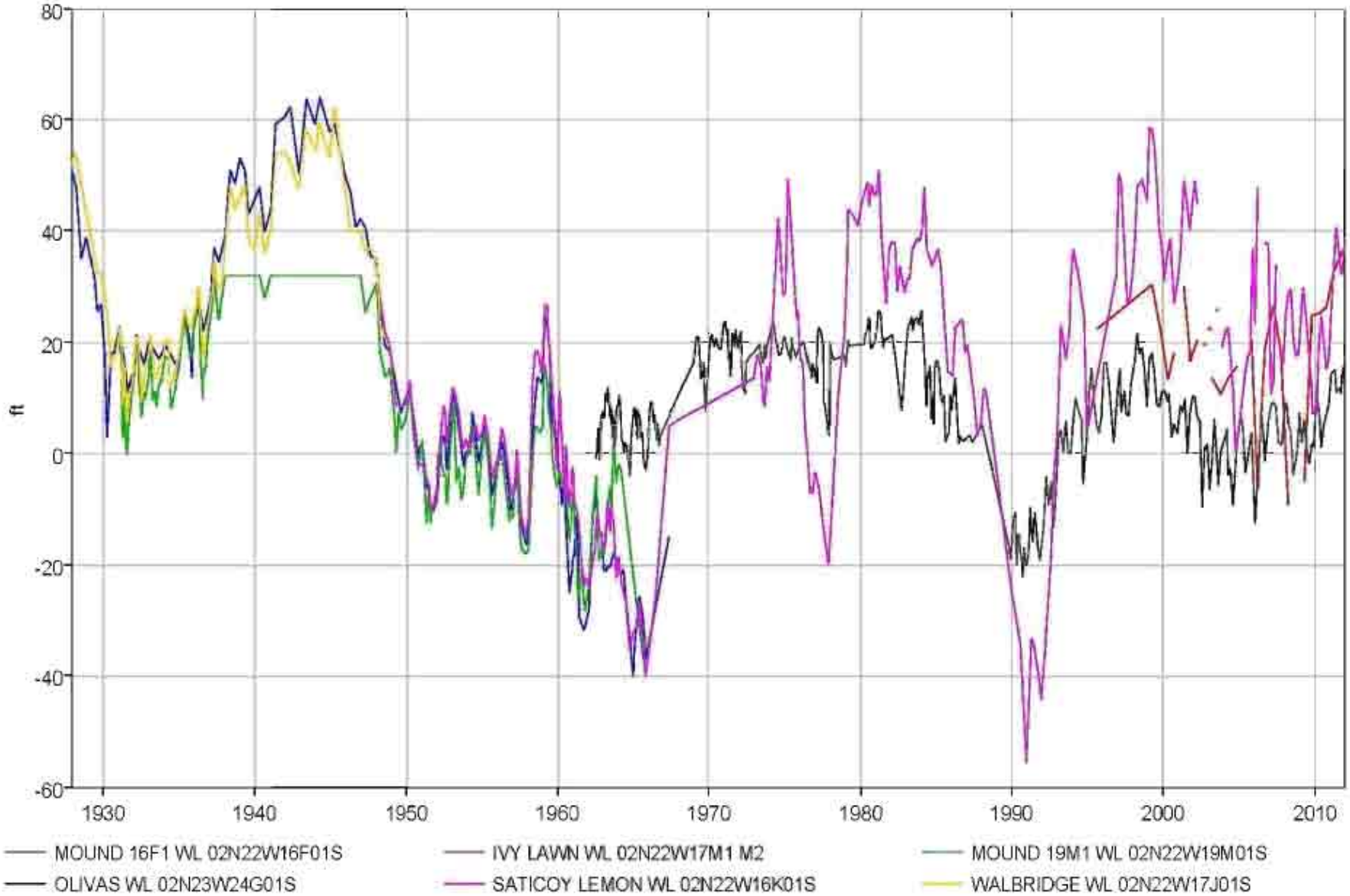


Figure 4-7. Recorded groundwater elevations, southern Mound basin.

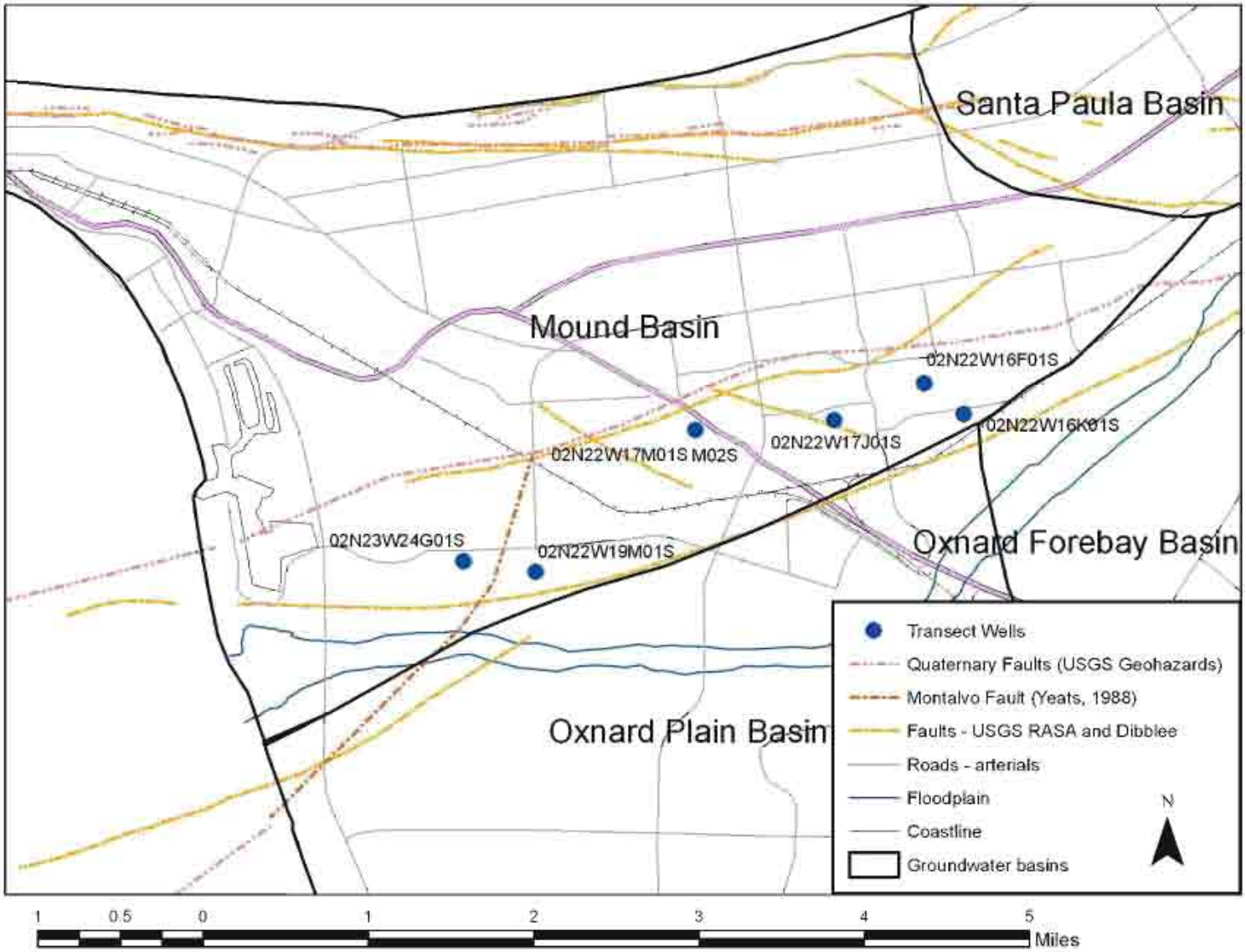


Figure 4-8. Location map for southern Mound basin wells with WLE records.

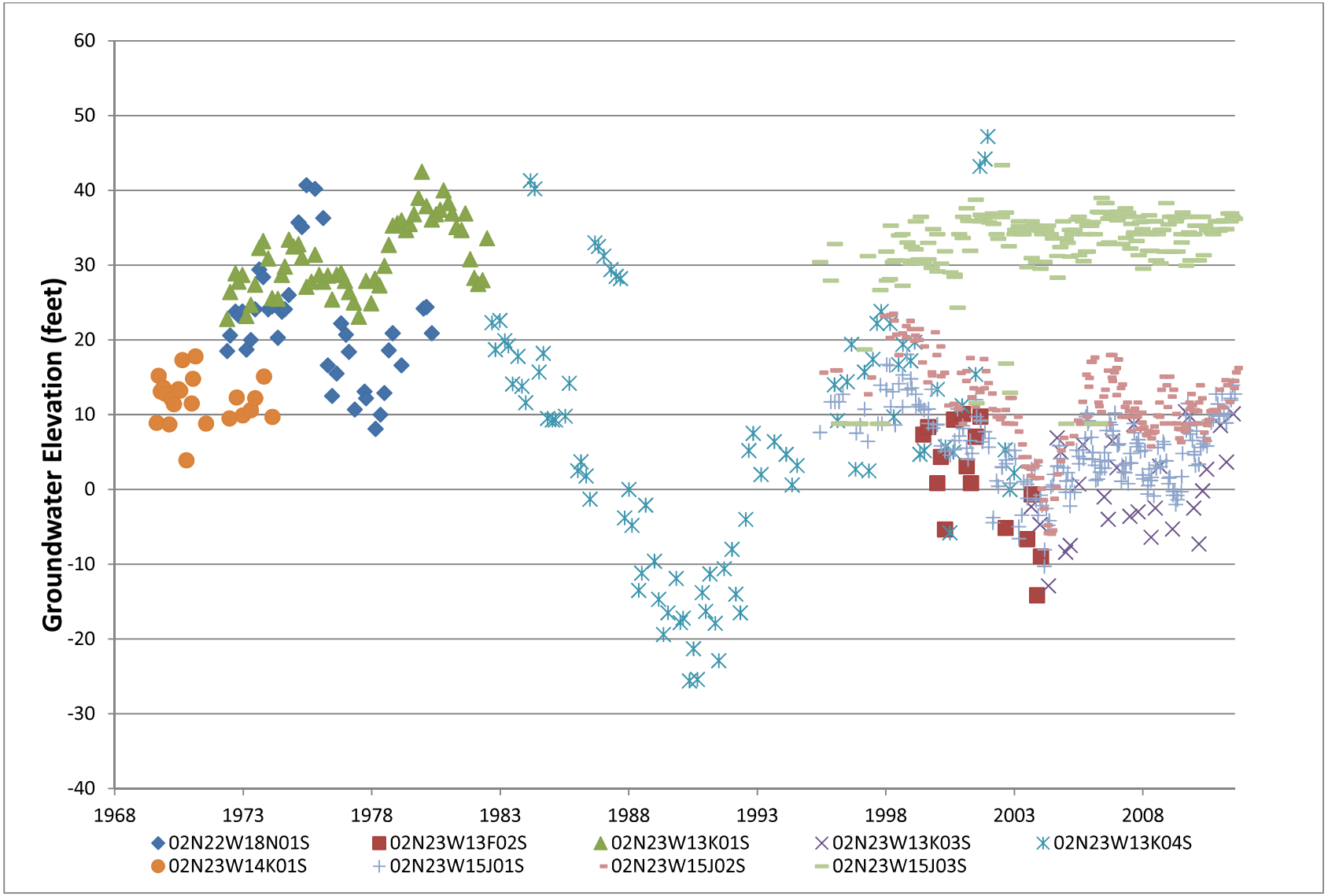


Figure 4-9. Recorded groundwater elevations, western Mound basin.

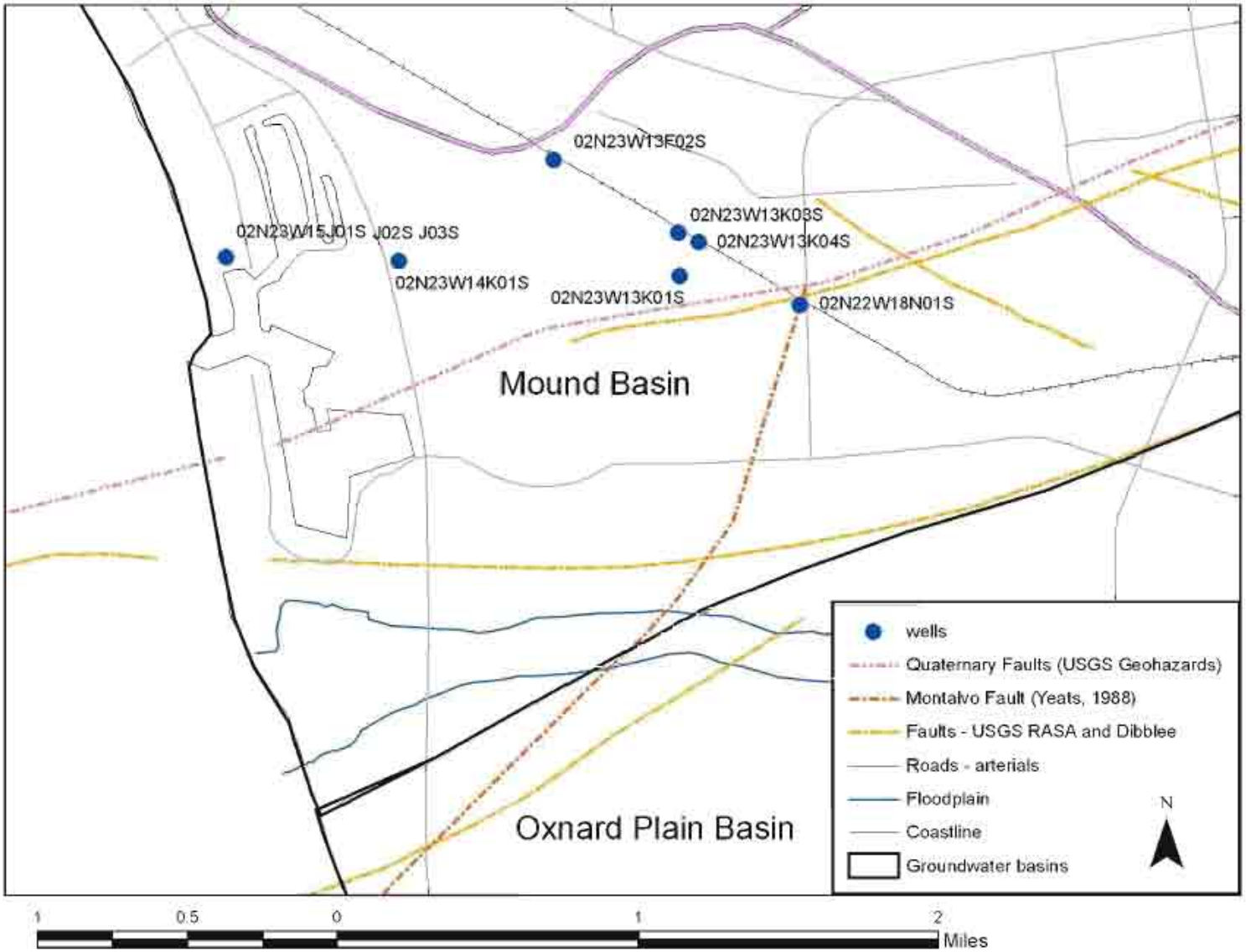


Figure 4-10. Location map for western Mound basin wells with WLE records.

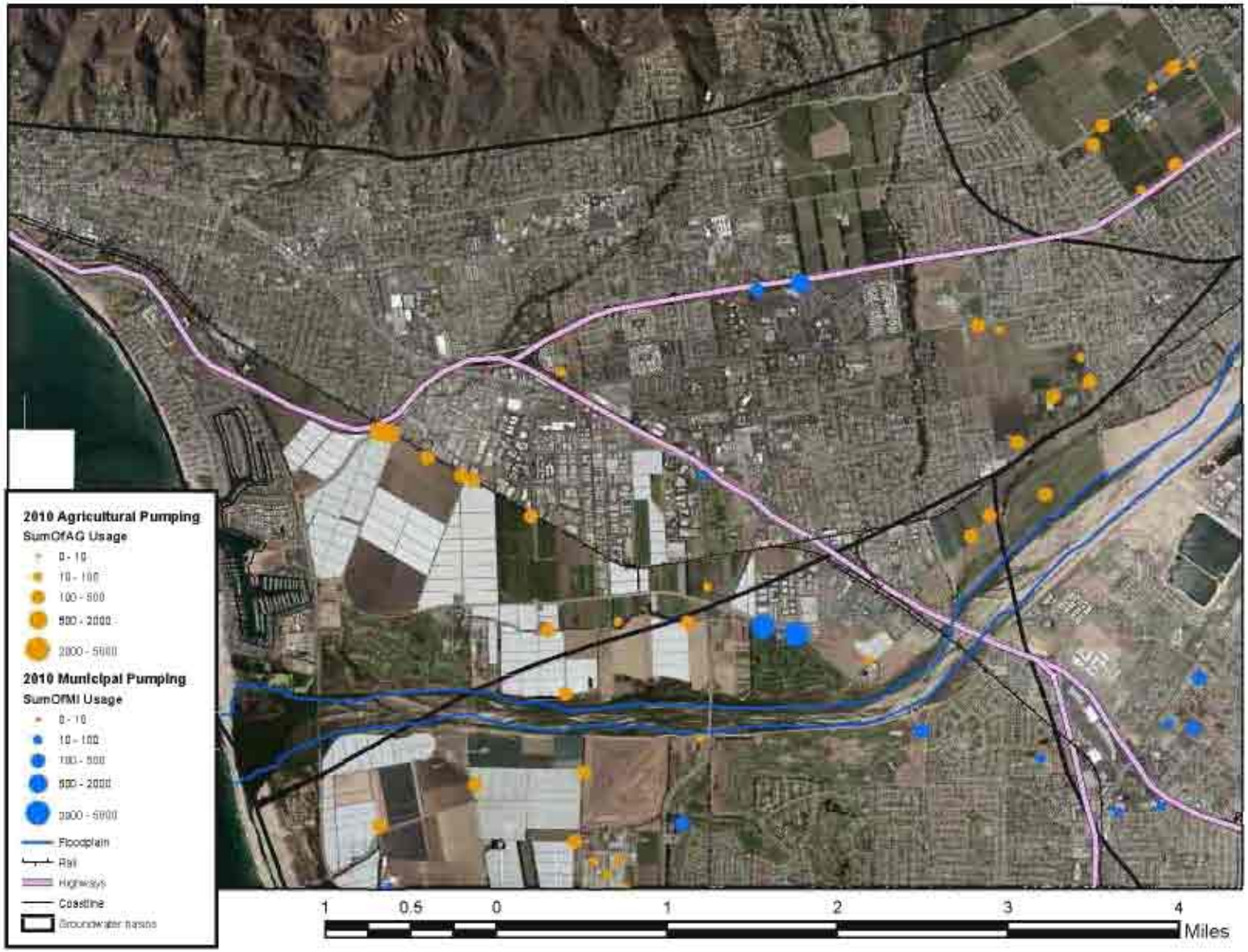


Figure 5-1. Distribution of Mound basin pumping, 2010 calendar year.

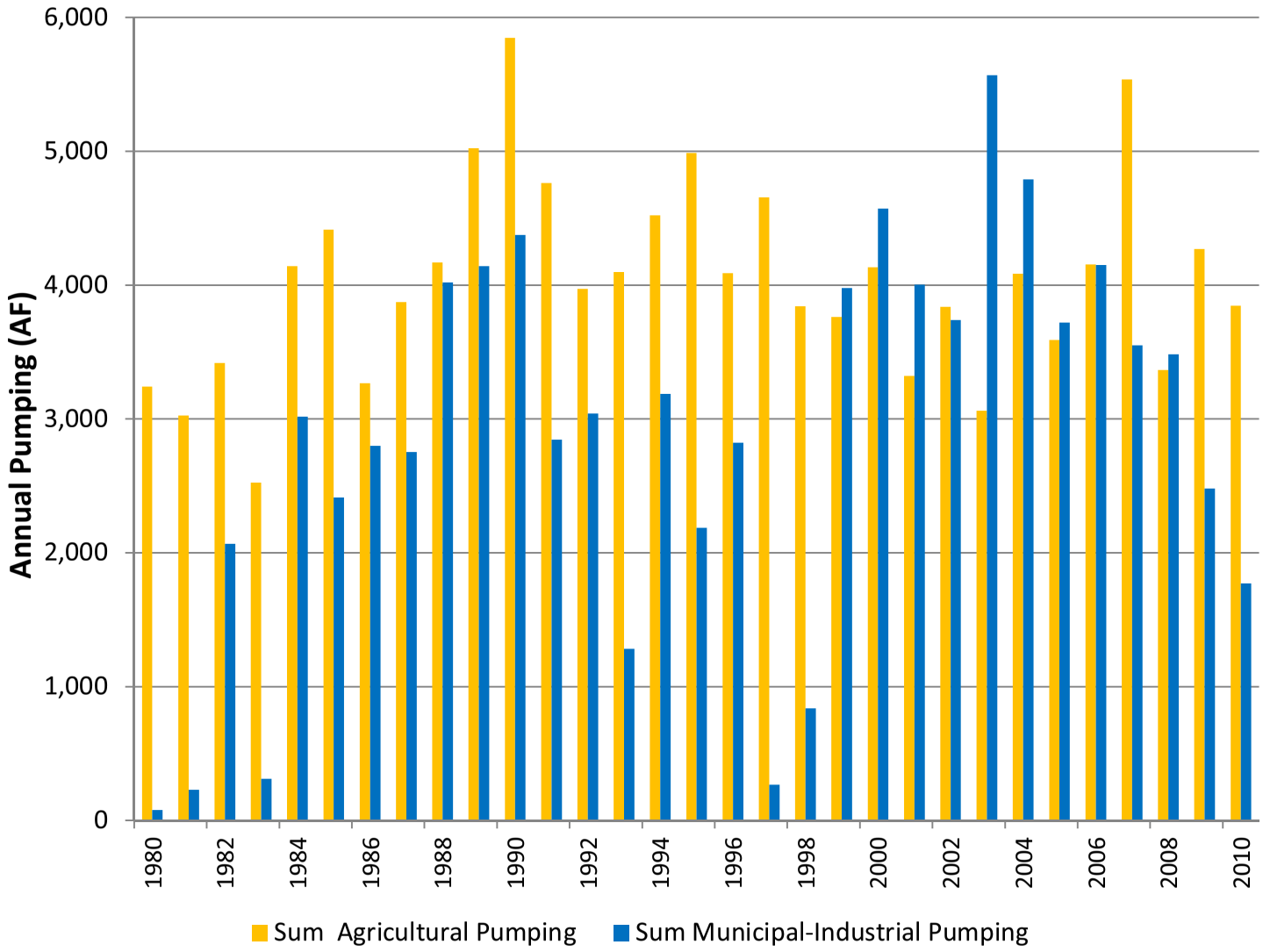


Figure 5-2. Annual Mound basin pumping totals by water use.

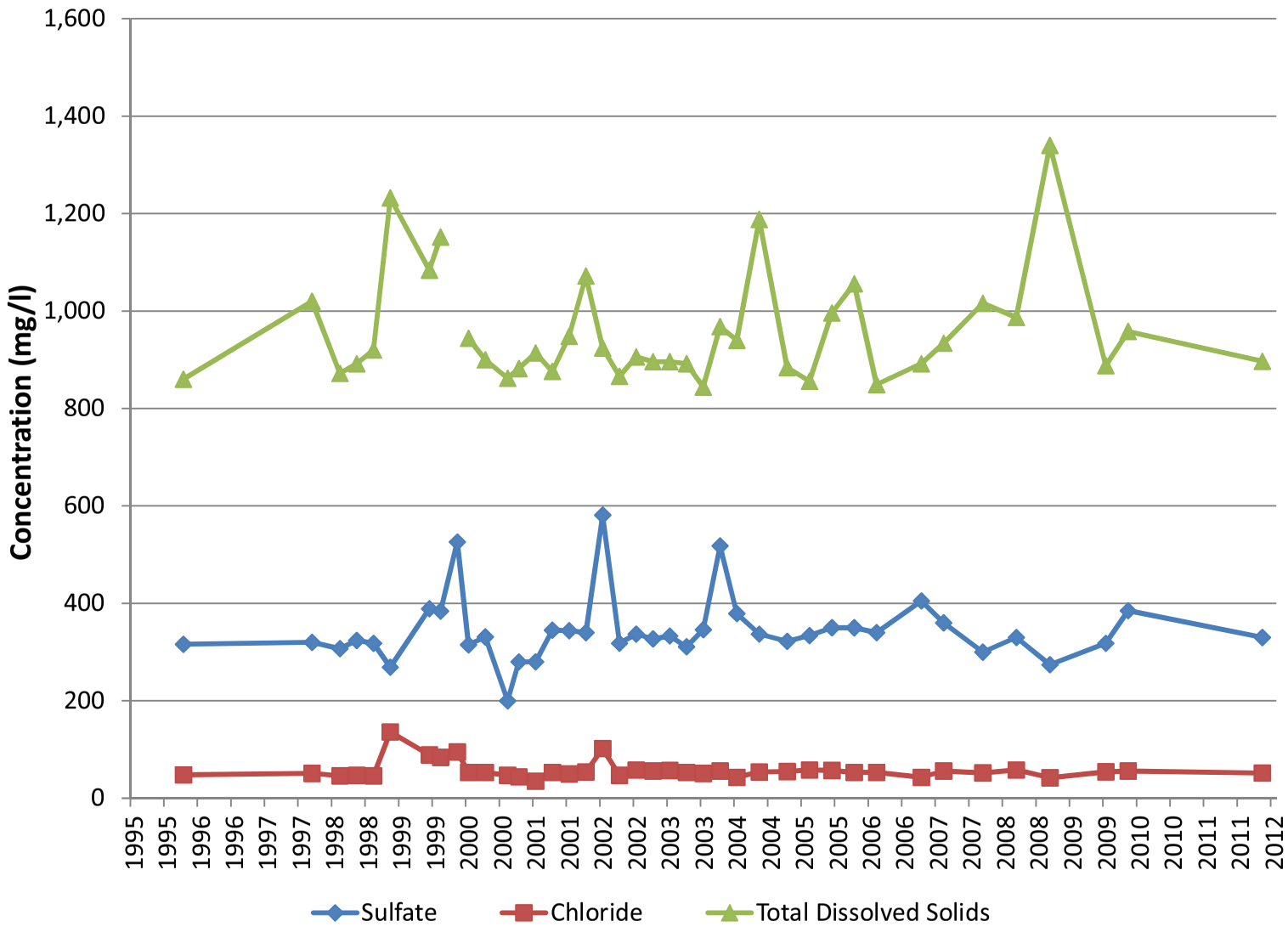


Figure 6-1. Well 02N22W07M02S water quality records (monitoring well CP-780).

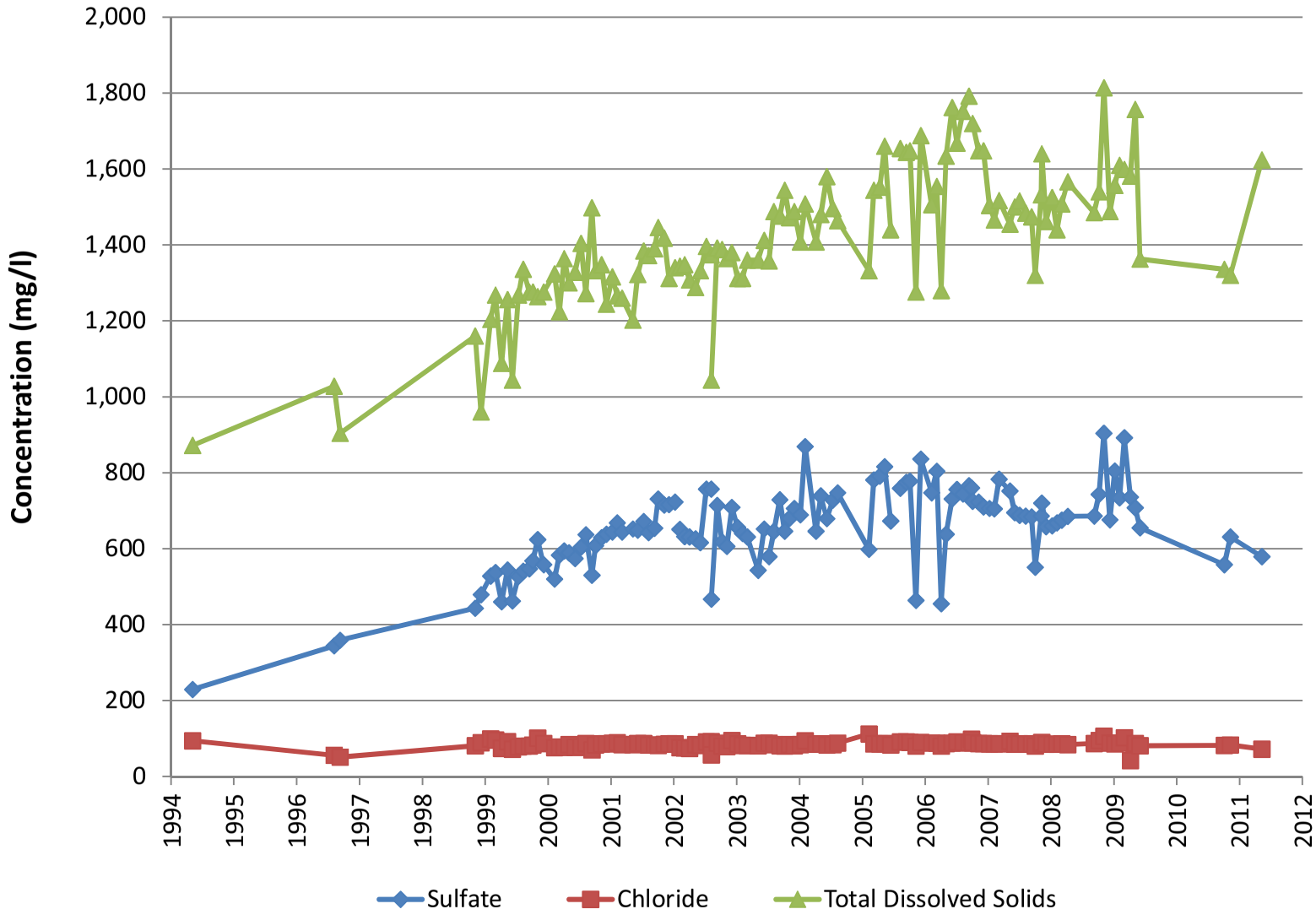


Figure 6-2. Well 02N22W08F01S water quality records (Victoria 2).

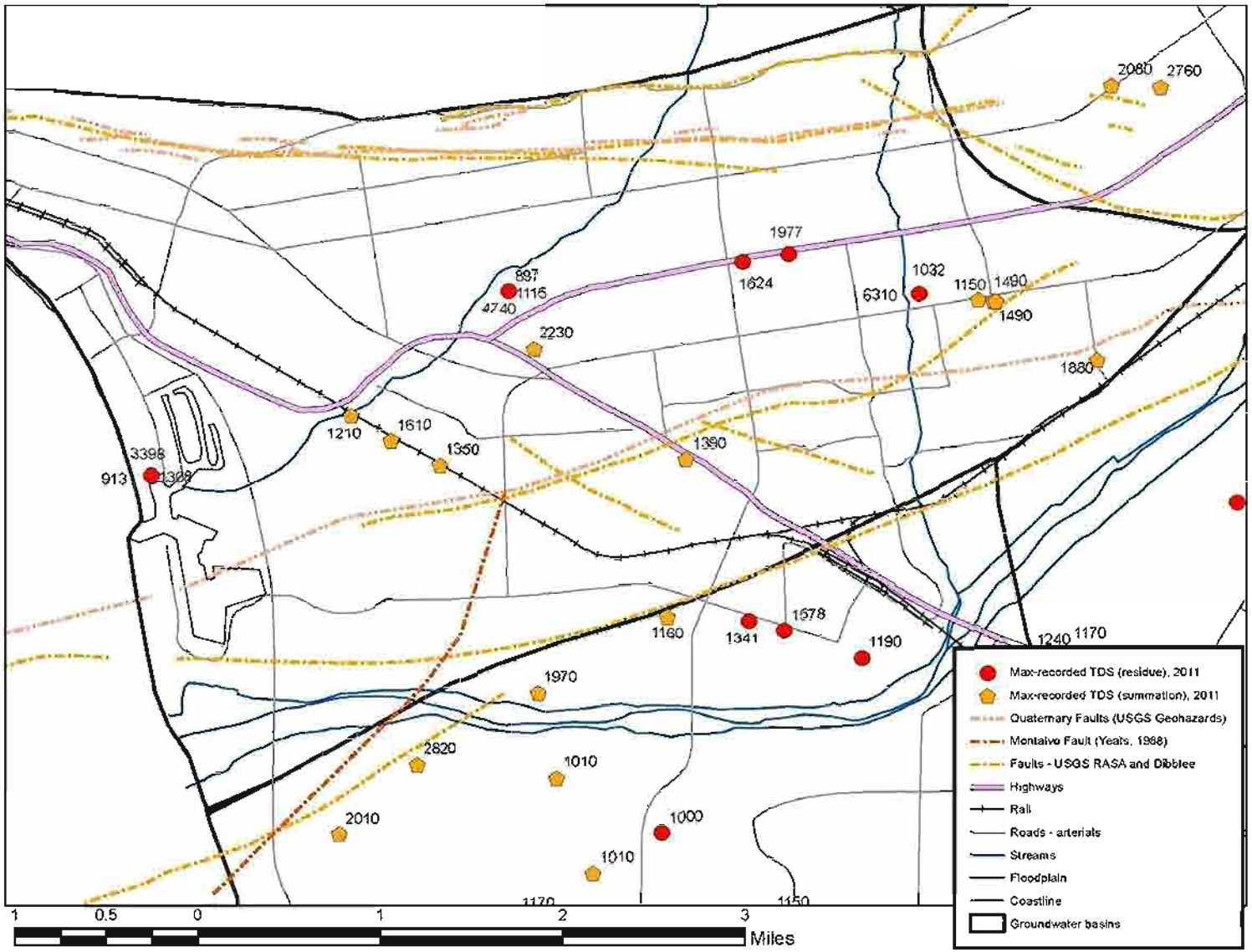


Figure 6-3. Maximum-recorded Total Dissolved Solids in 2011.

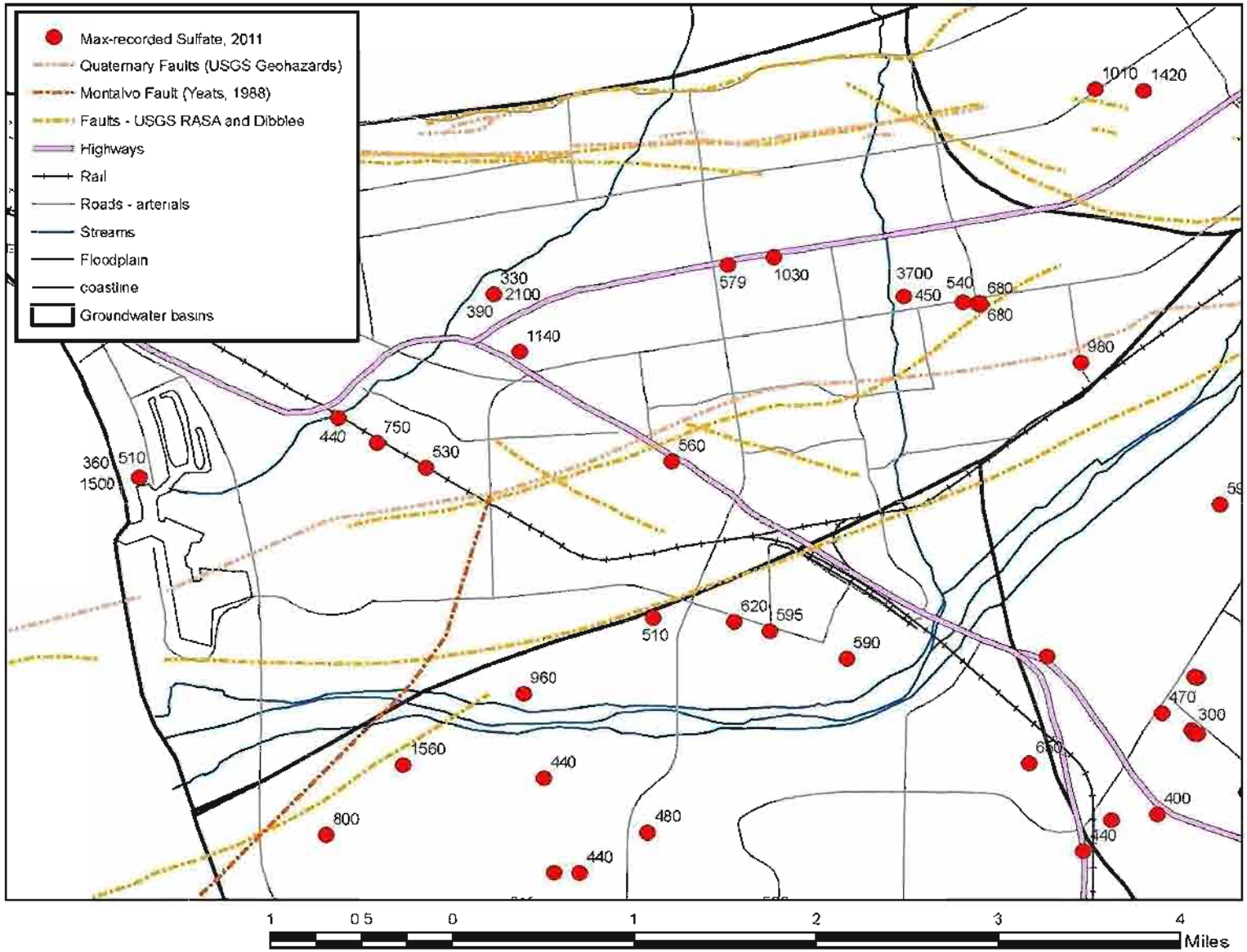


Figure 6-4. Maximum-recorded sulfate concentration in 2011.

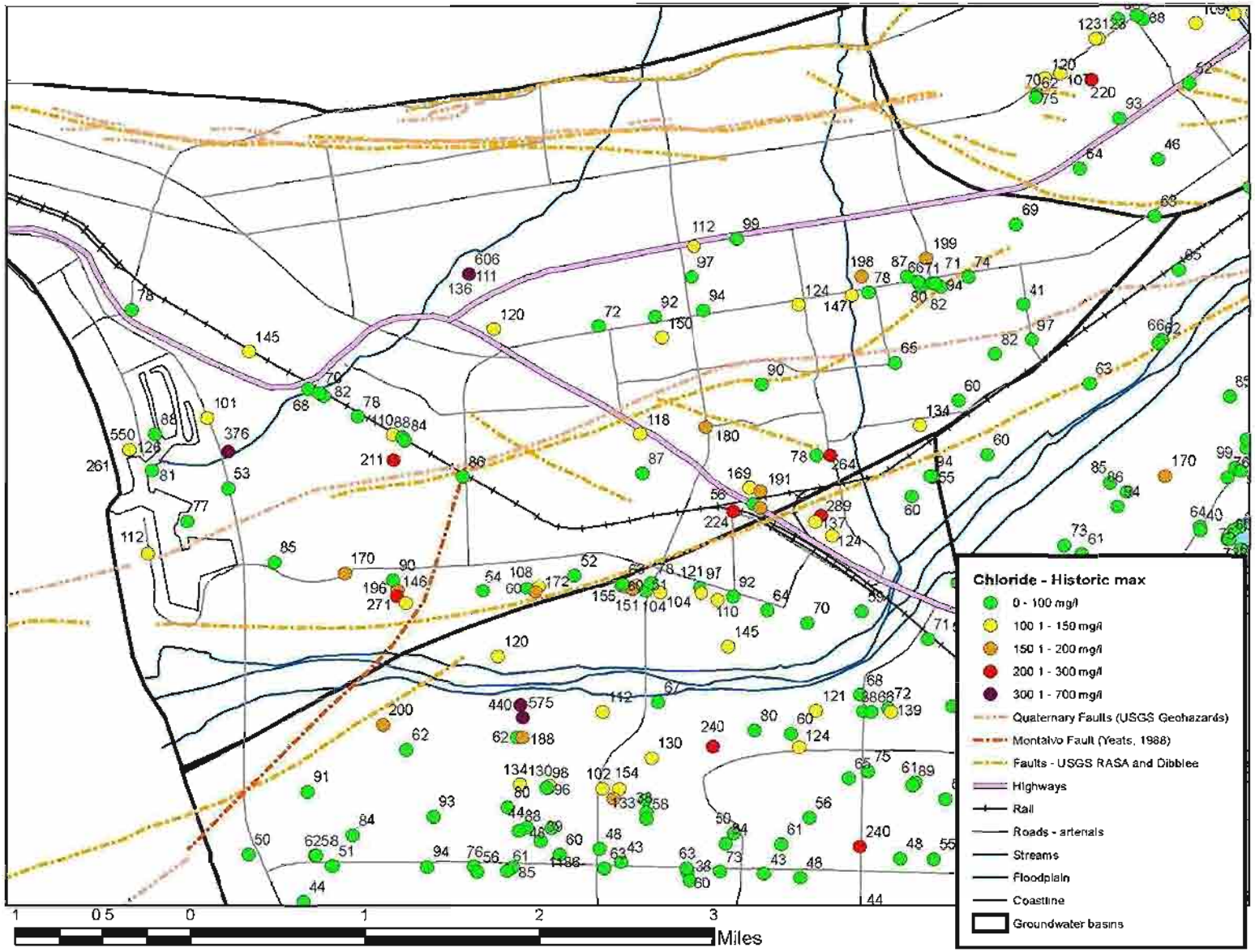


Figure 6-5. Maximum-recorded chloride concentration, all historic records.

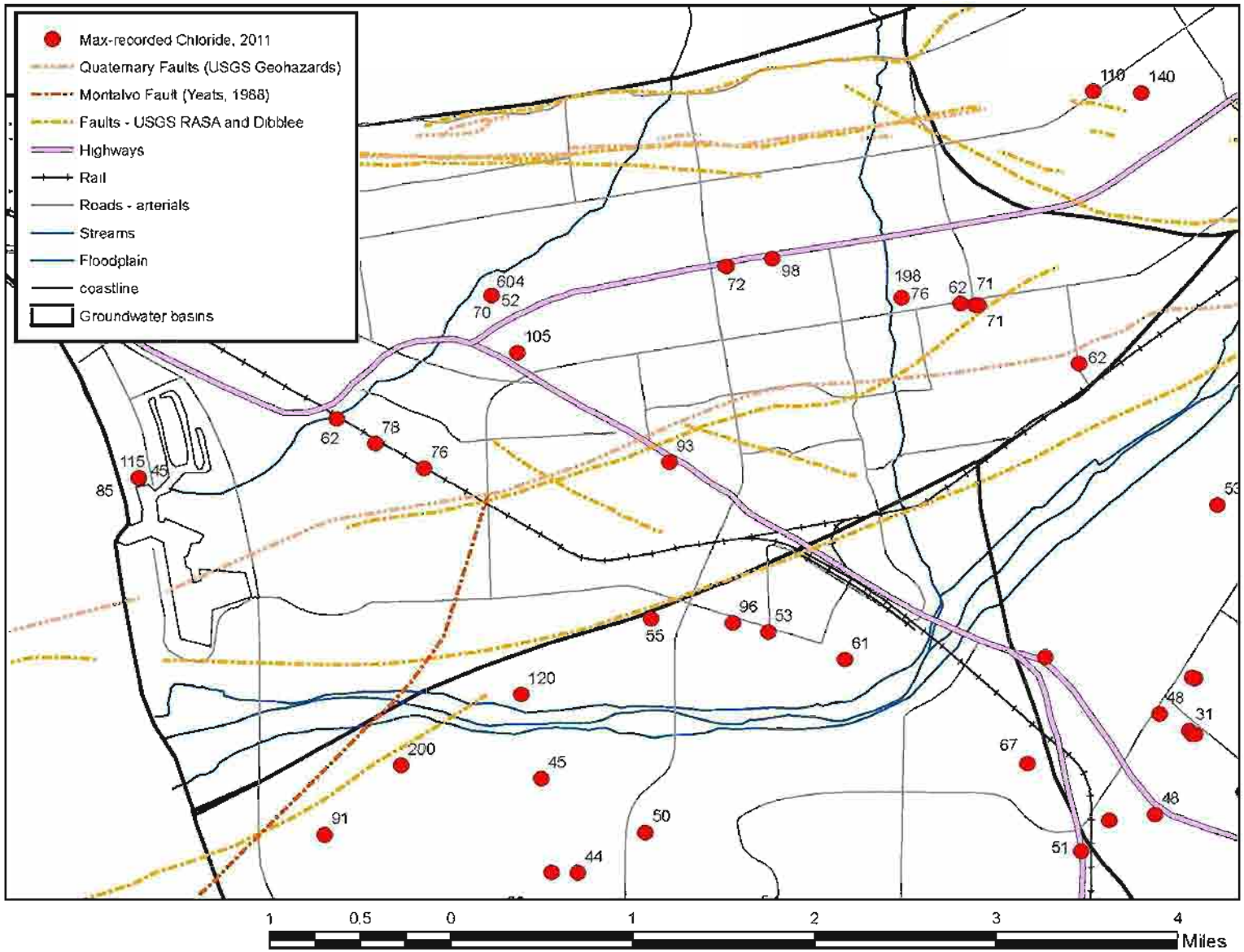


Figure 6-6. Maximum-recorded chloride concentration in 2011.

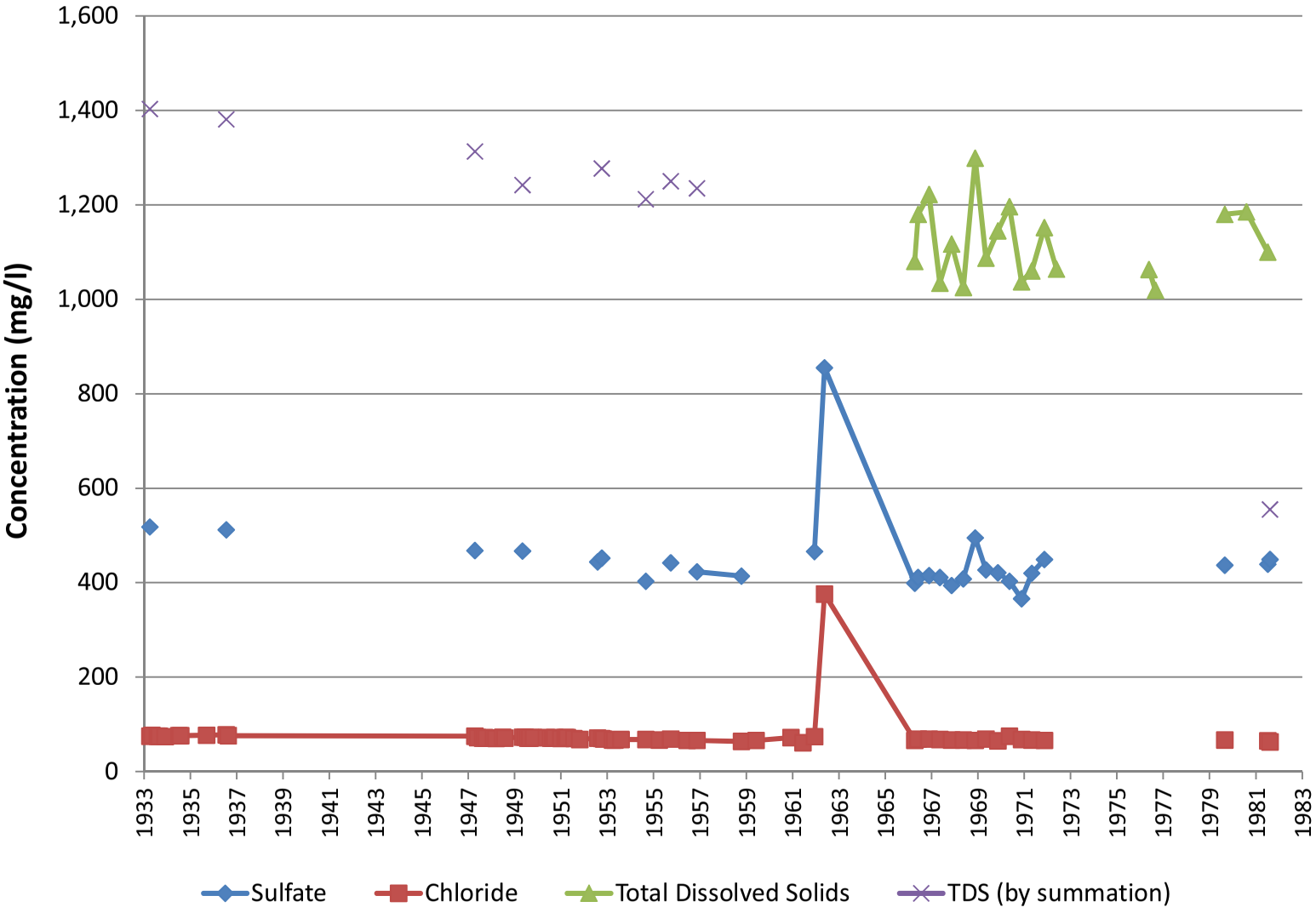
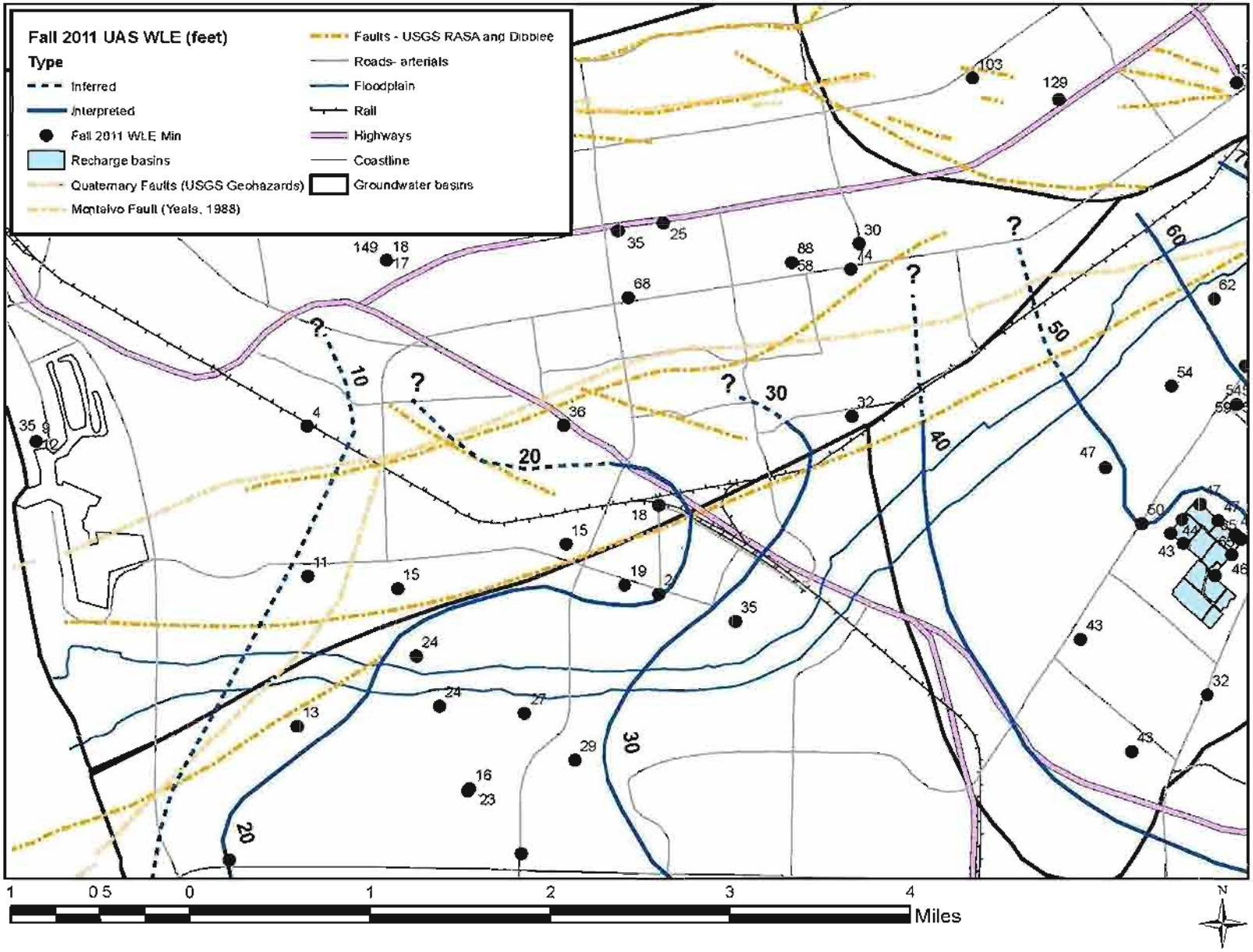
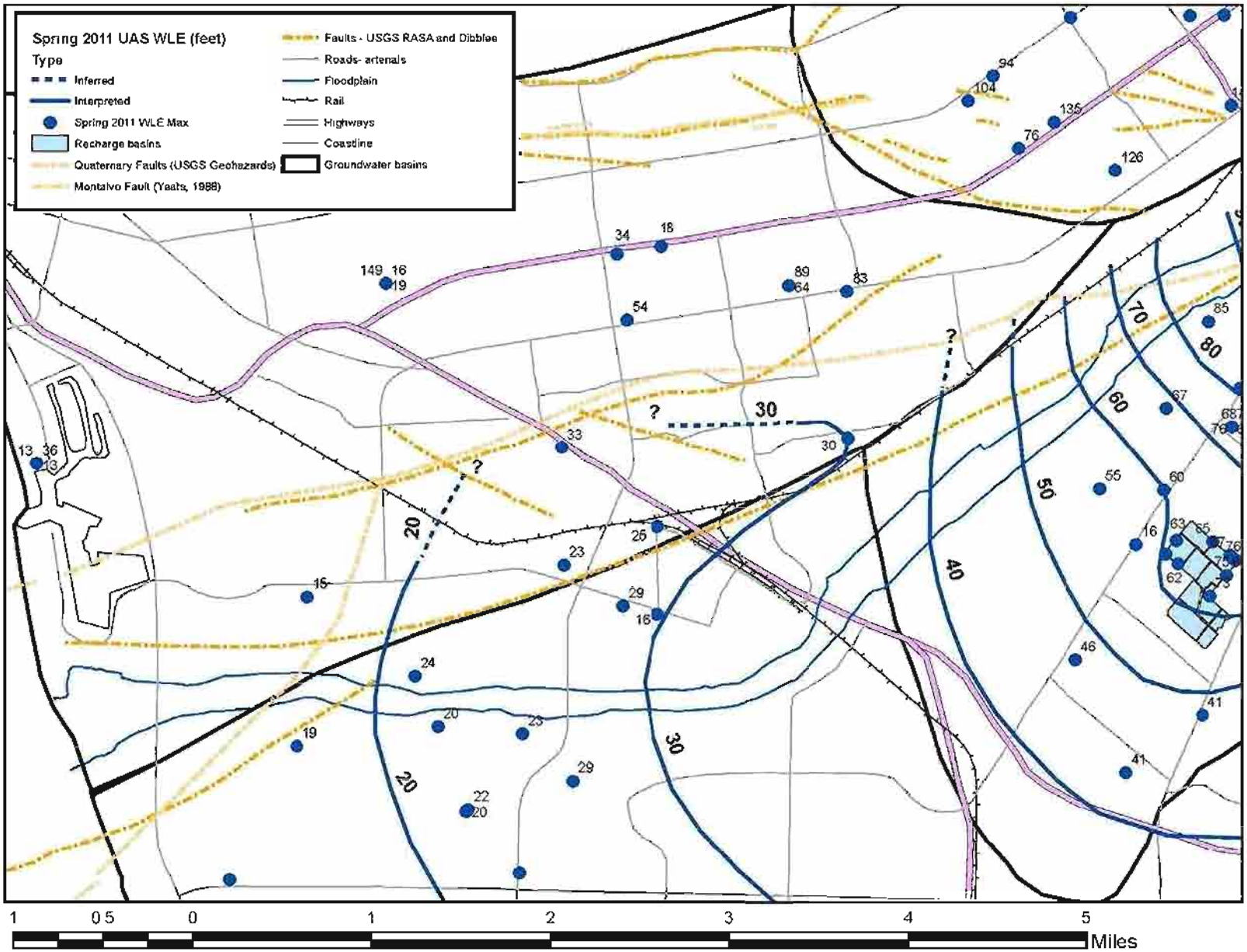


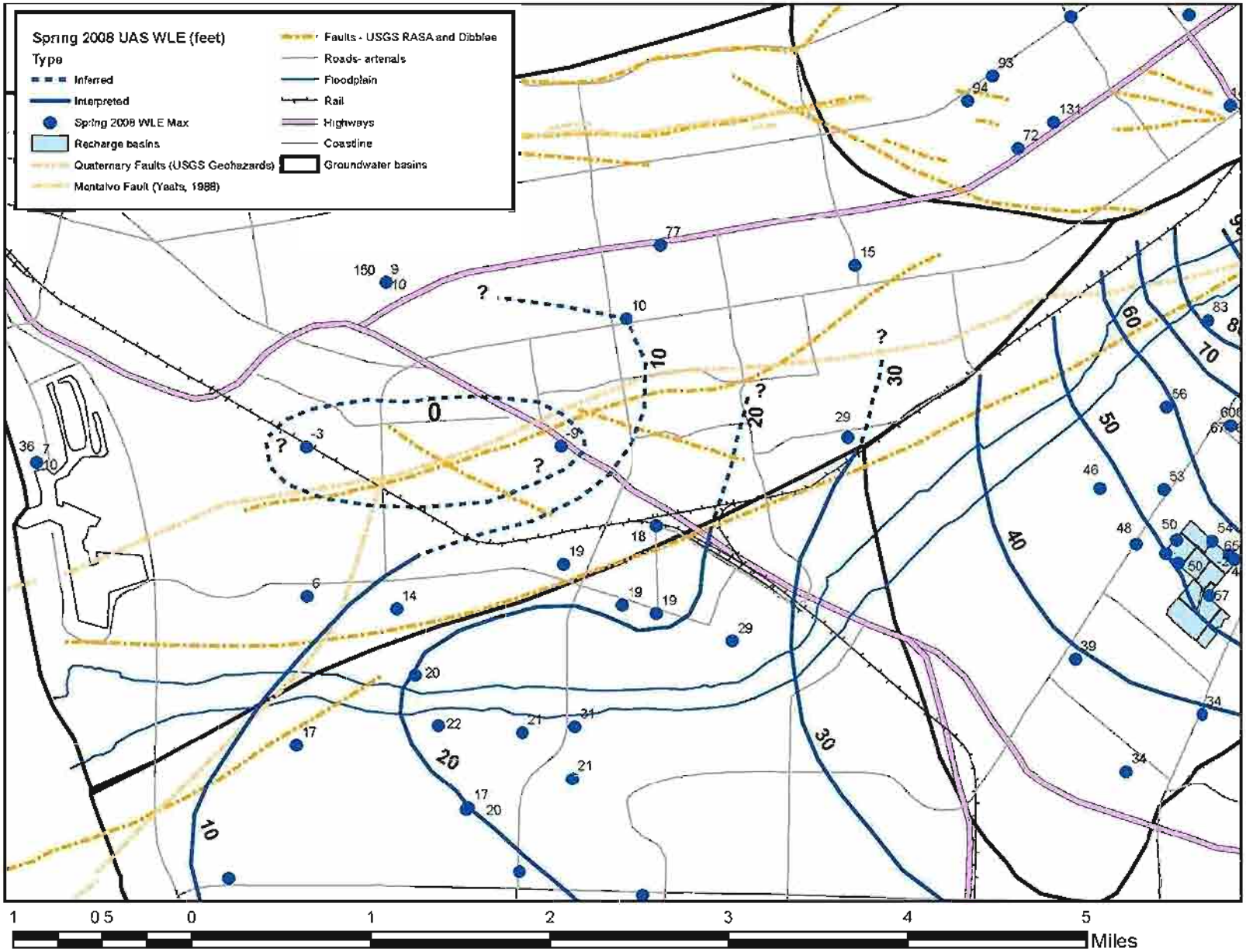
Figure 6-7. Well 02N23W14K01S water quality records.

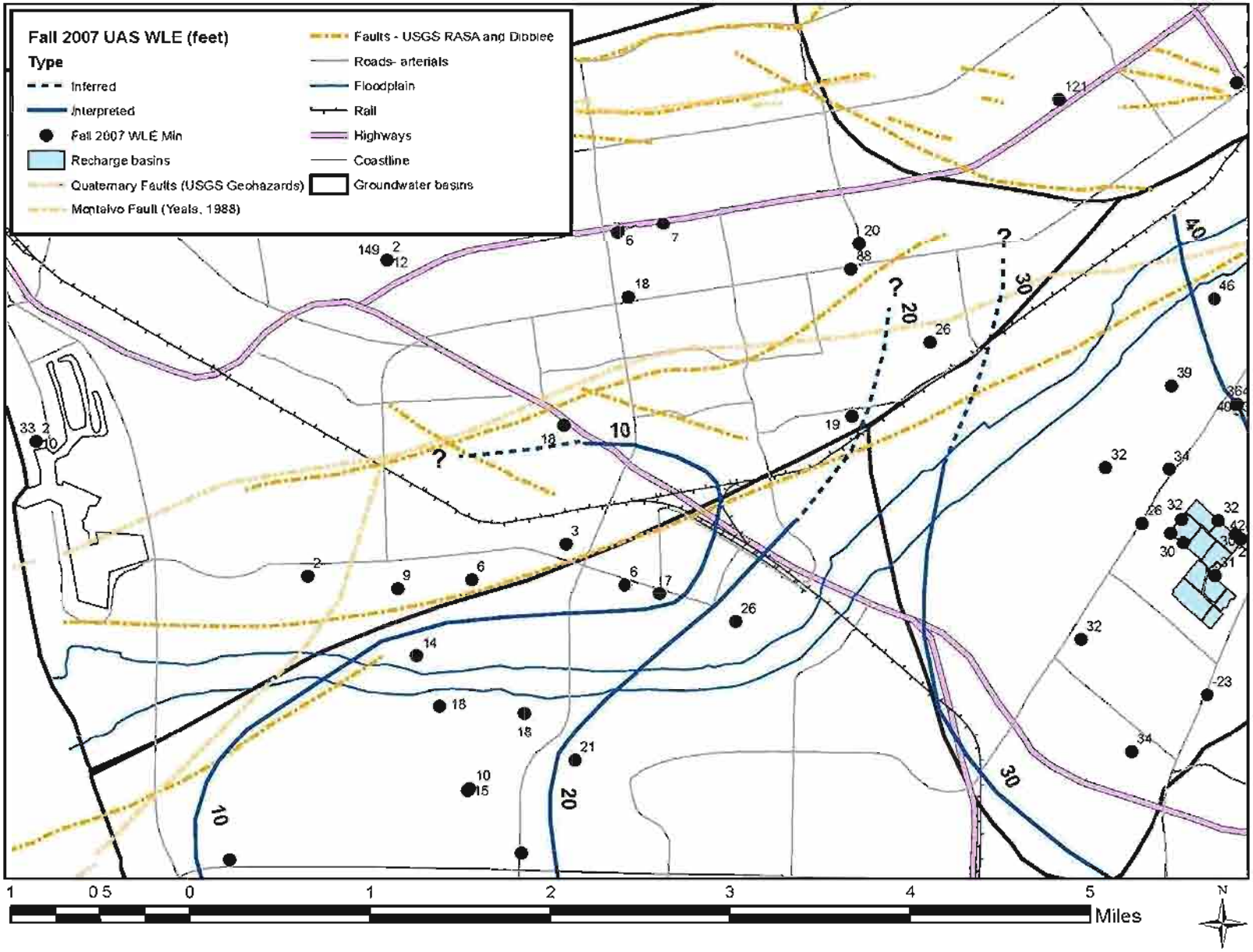
10 APPENDIX B - GROUNDWATER ELEVATION MAPS

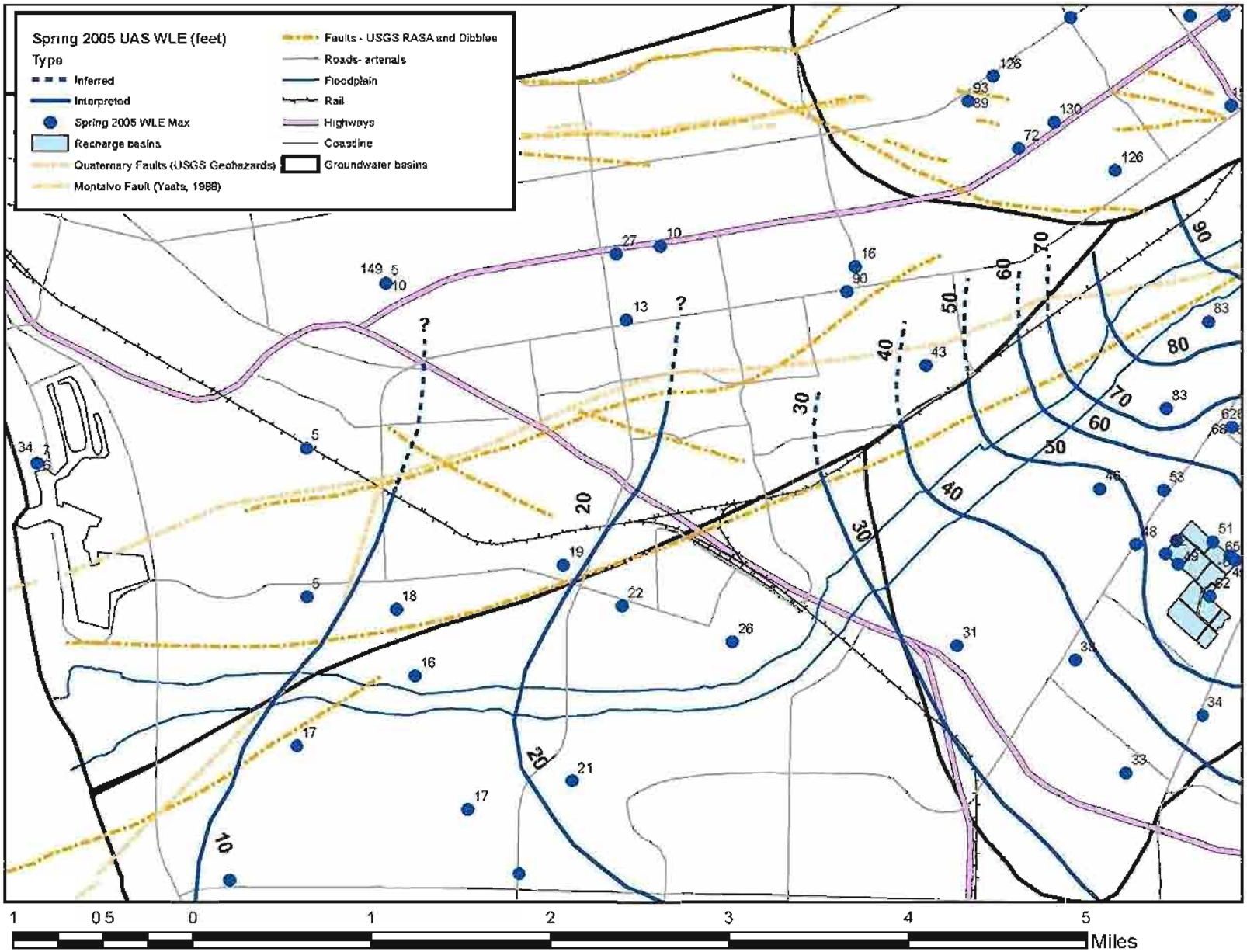
Appendix B contains representative groundwater elevation maps for 2001-2001. If sufficient data were available, both spring and fall groundwater elevation maps are included.

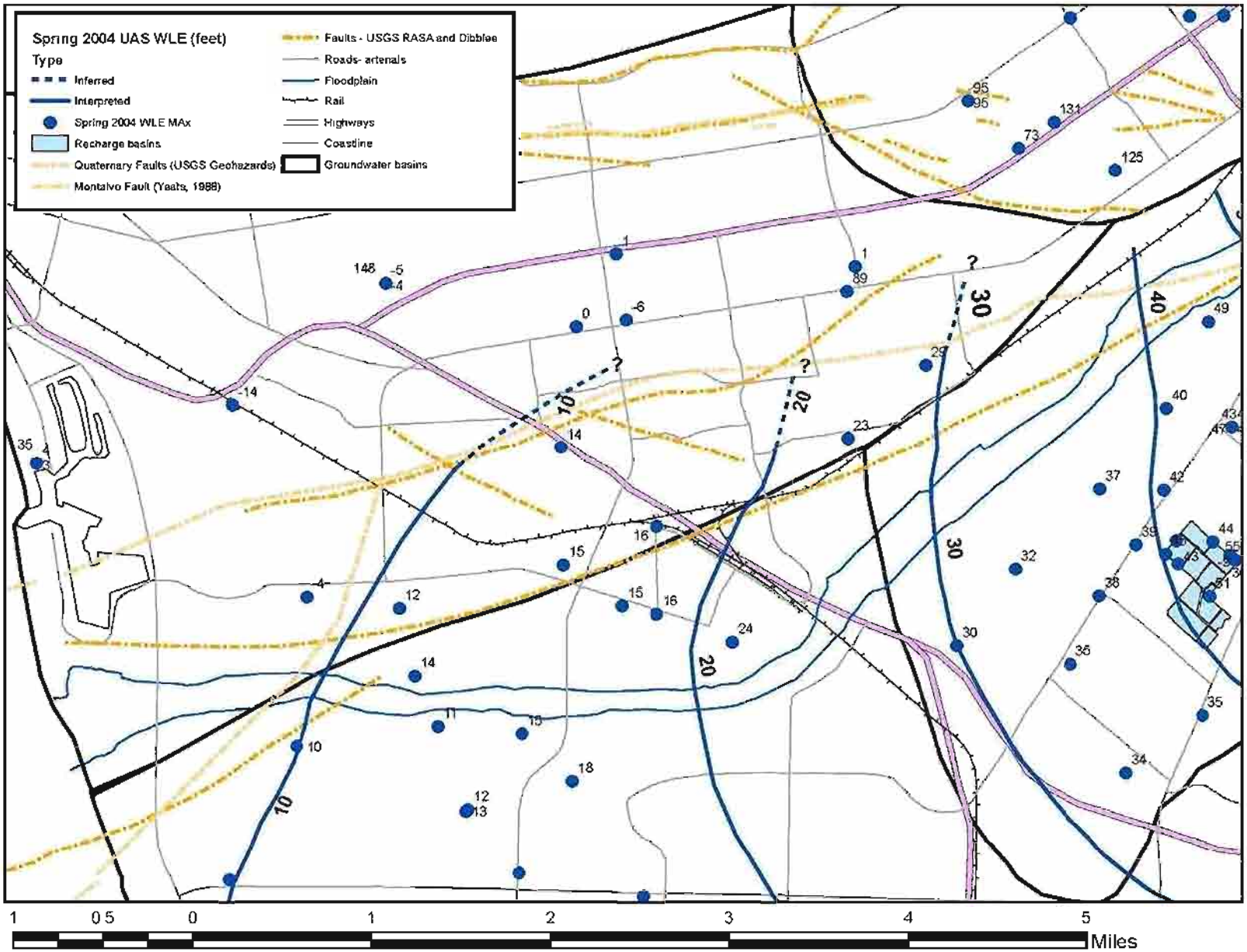

Fall 2011 UAS WLE (feet)
Type
Inferred
Interpreted
Fall 2011 WLE Min
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4
Miles
N

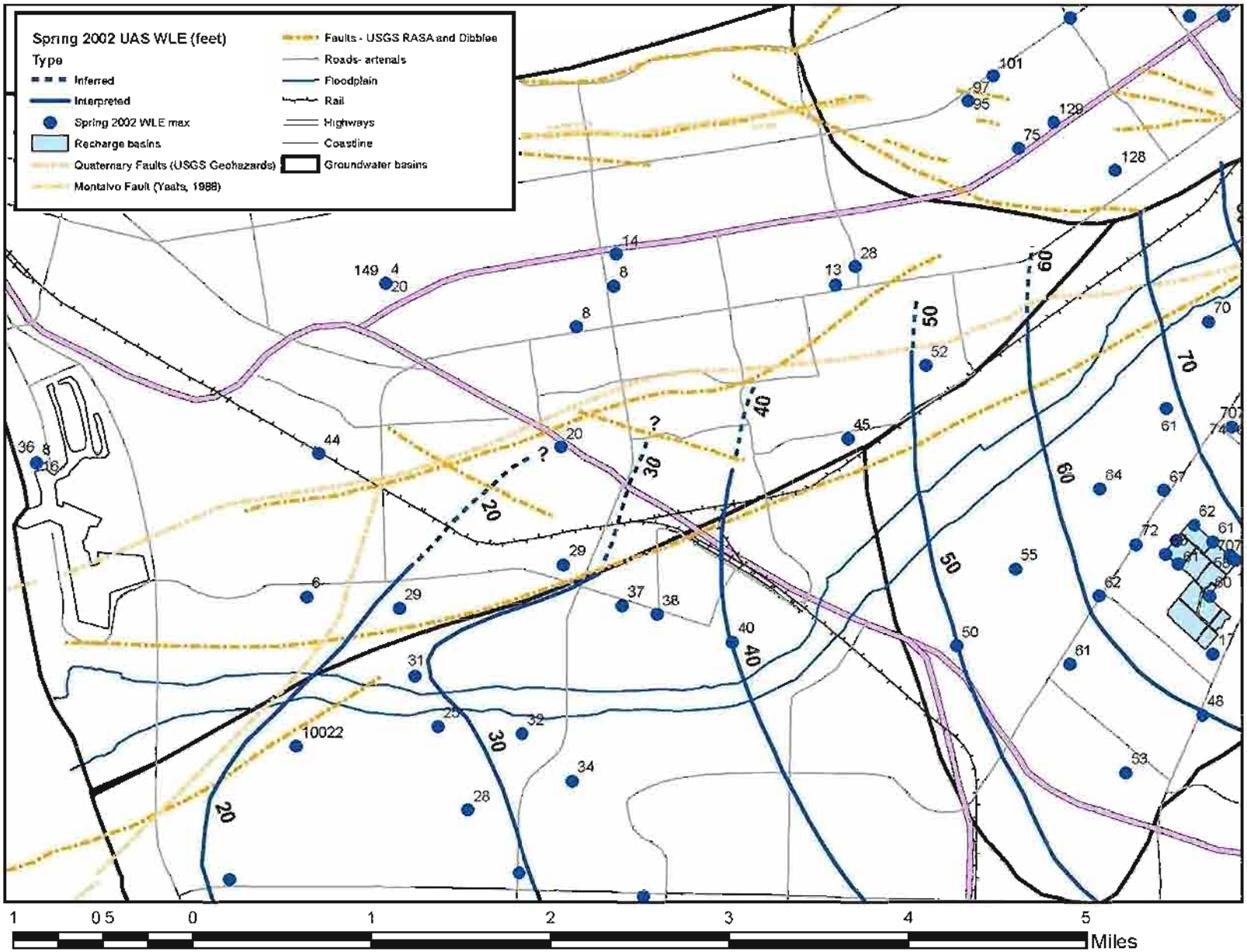

Spring 2011 UAS WLE (feet)
Type
Inferred
Interpreted
Spring 2011 WLE Max
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles


Spring 2008 UAS WLE (feet)
Type
Inferred
Interpreted
Spring 2008 WLE Max
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles


Fall 2007 UAS WLE (feet)
Type
Inferred
Interpreted
Fall 2007 WLE Min
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles
N


Spring 2005 UAS WLE (feet)
Type
Inferred
Interpreted
Spring 2005 WLE Max
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles


Spring 2004 UAS WLE (feet)
Type
Inferred
Interpreted
Spring 2004 WLE MAx
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- artenals
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles


Spring 2002 UAS WLE (feet)
Type
Inferred
Interpreted
Spring 2002 WLE max
Recharge basins
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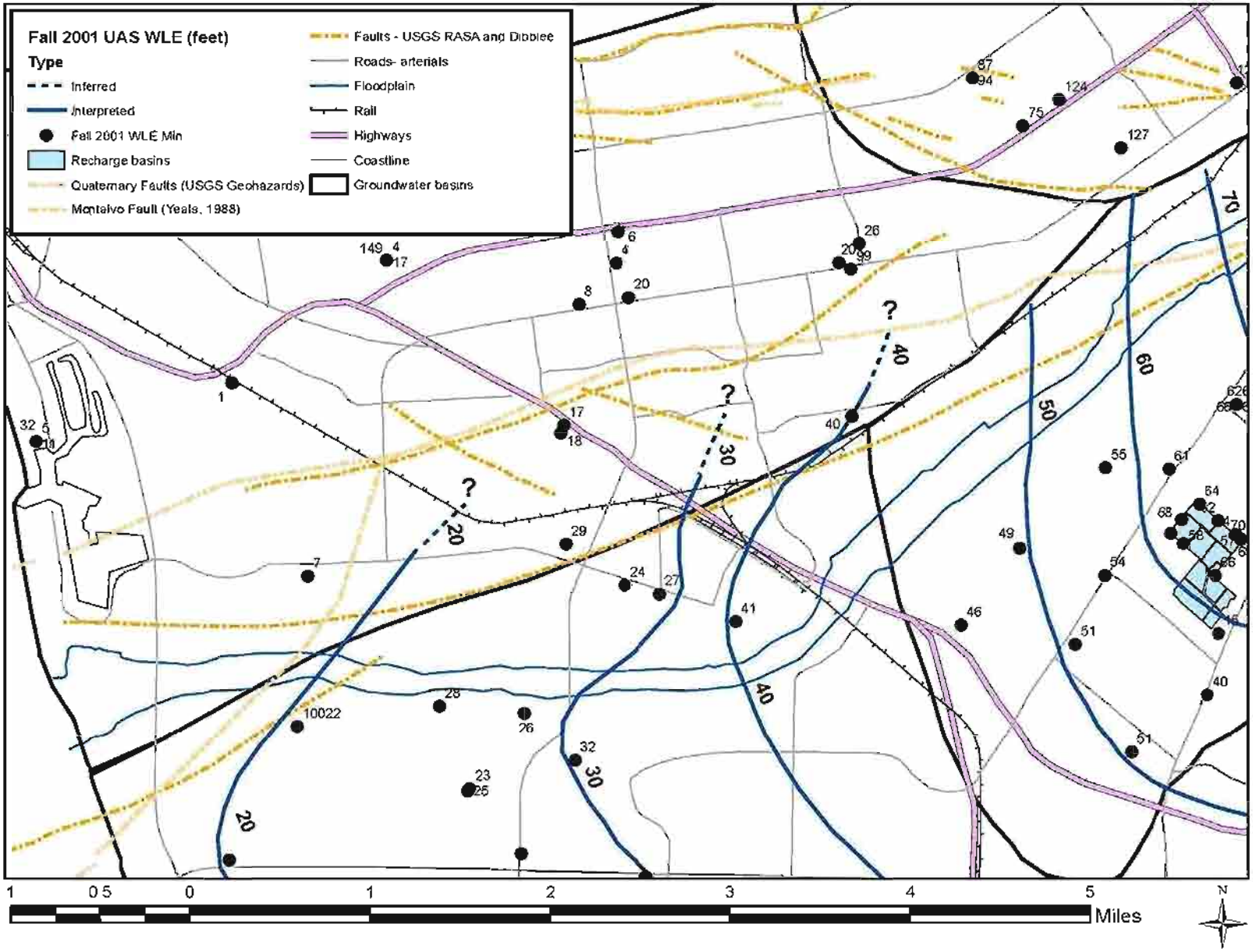
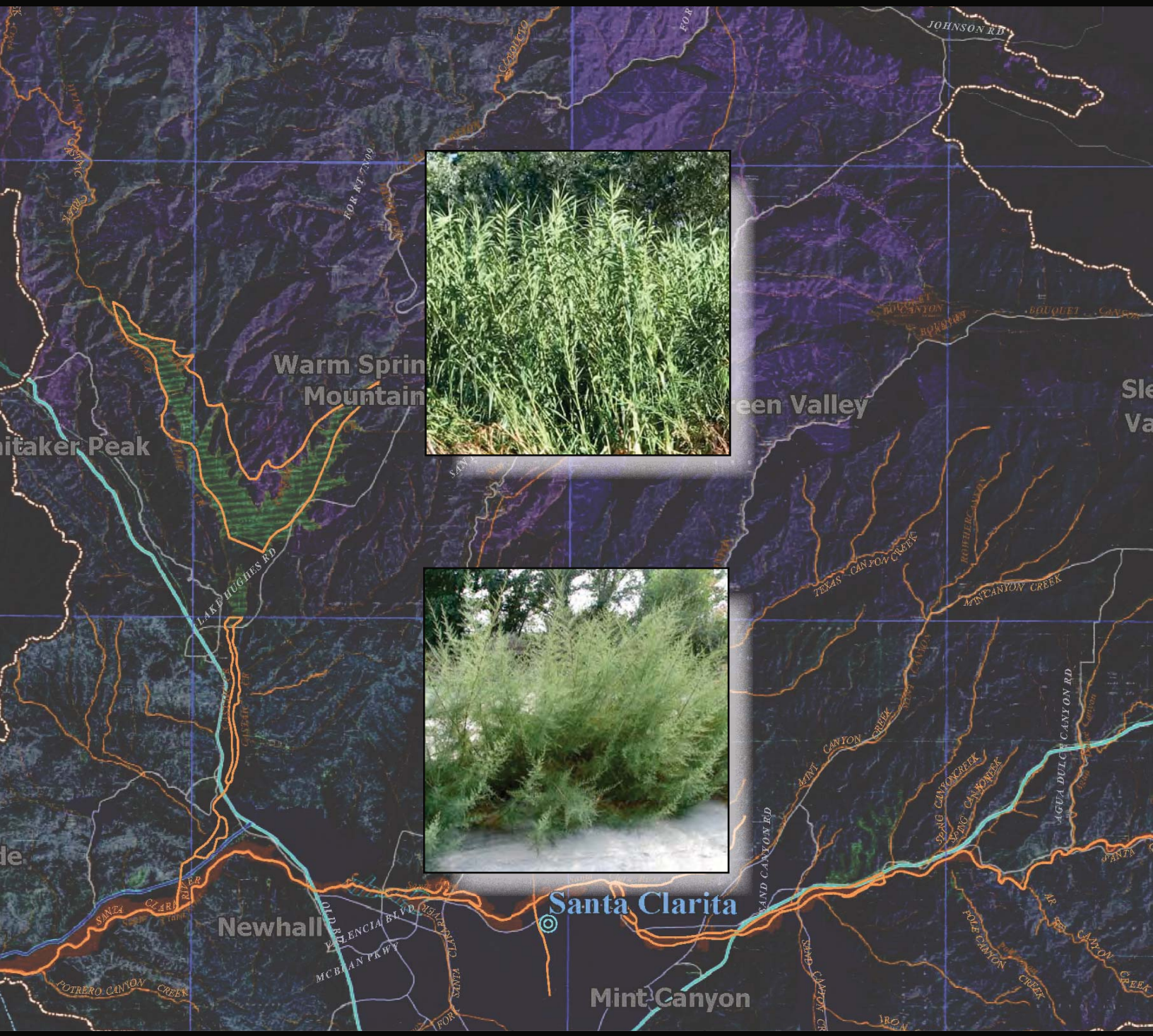
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles


Fall 2001 UAS WLE (feet)
Type
Inferred
Interpreted
Fall 2001 WLE Min
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles
N

Upper Santa Clara River Watershed
Arundo and Tamarisk Removal Program

Long-Term Implementation Plan



Ventura County Resource Conservation District

June 2006

Funding for this project has been provided in full through an Agreement with the State Water Resources Control Board (SWRCB) pursuant to the Costa-Machado Water Act of 2000 (Proposition 13) and any amendments hereto for the implementation of California's Nonpoint Source Pollution Control Program. The contents of this document do not necessarily reflect the views and policies of the SWRCB, nor does mention of trade names or commercial products constitute endorsement of recommendation of use.

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List of Acronyms

Acronym	Definition
°C	degrees Celsius
af	acre-feet
BMP	best management practices
Cal-IPC	California Invasive Plant Council
CDFA	California Department of Food and Agriculture
CDFG	California Department of Fish and Game
CA Parks/Rec	California Department of Parks and Recreation
CDPR	California Department of Pesticide Regulations
CESA	California Endangered Species Act
CLWA	Castaic Lake Water Agency
CNDDB	California Natural Diversity Database
CNPS	California Native Plant Society
CWA	Clean Water Act
DWR	California Department of Water Resources
FSCR	Friends of the Santa Clara River
FESA	Federal Endangered Species Act
I-5	Interstate 5
LADPW	Los Angeles County Department of Public Works
LBV	least Bell's vireo
MBTA	Migratory Bird Treaty Act
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
msl	mean sea level
NGO	Non-governmental organization
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
QAPP	Quality Assurance Project Plan
RGP	Regional General Permit
RWQCB	Regional Water Quality Control Board
SARMB	Santa Ana River Mitigation Bank
SCARP	Santa Clara River Arundo and Tamarisk Removal Program
SCREMP	Santa Clara River Enhancement Management Plan
SMSLRWMA	Santa Margarita and San Luis Rey Watershed Weed Management Area
SWFC	Southwestern willow fly-catcher
TADN	Team Arundo del Norte
TDS	total dissolved solids
TMDL	Total Maximum Daily Load
TNC	The Nature Conservancy
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UWCD	United Water Conservation District
VCRCD	Ventura County Resource Conservation District
VCWPD	Ventura County Watershed Protection District

1.0 Introduction

The Santa Clara River, its tributaries and the associated riparian or streamside habitats comprise one of the largest natural river systems remaining in Southern California. From its headwaters in the San Gabriel Mountains southeast of the town of Acton, the Santa Clara River flows for 84 miles through Los Angeles and Ventura Counties terminating at the Pacific Ocean. The 45-mile-long portion of the Santa Clara River and its associated tributaries within Los Angeles County are referred to as the upper Santa Clara River. Along this 45-mile course, the Santa Clara River crosses national forest land, large areas of moderately developed private rural lands, the growing City of Santa Clarita, and then large tracts of rural farmland extending west to the county line. The Santa Clara River and this wide range of adjacent land uses comprise the upper Santa Clara River watershed, which consists of approximately 680 square miles (409,703 acres). This area is the focus of this plan (Fig. 1).

The Santa Clara River system and its associated riparian habitats provide major benefits to the surrounding communities including groundwater recharge, urban and agricultural water supplies, flood conveyance, visual relief, and recreational opportunities. In addition, the types of habitat found in the Santa Clara River's riparian areas are some of the most valuable wildlife habitat in the state, in terms of both species diversity and abundance, and provide habitat for some of the state's most threatened and endangered wildlife. This is especially important since as much as 90 percent of California's streamside riparian plant communities have been eliminated by urban and agricultural development within the last 150 years.

Many threats to the values provided by the Santa Clara River and its tributaries exist, including encroaching development, increased urban runoff, and the spread of invasive, non-native plant species. According to the National Invasive Species Council, an "invasive species" is one that is a) non-native (or alien) to the ecosystem under consideration and b) whose introduction causes or is likely to cause economic or environmental harm or harm to human health.

In particular, the widespread establishment of two invasive plant species, arundo or giant reed (*Arundo donax*) and tamarisk or salt cedar (*Tamarix* spp.), severely threaten many of the benefits described above. Arundo and tamarisk have spread throughout the Santa Clara River and most of its tributaries such that their presence has become an important issue for the surrounding communities. Major stands of arundo dominate large sections of the Santa Clara River in northeast Los Angeles County and are even more prevalent throughout its reaches in Ventura County. Although less prevalent than arundo, tamarisk is also a major problem in some portions of the central and upper watershed.

1.1 Project Goals and Scope

The Upper Santa Clara River Watershed Arundo/Tamarisk Removal Plan (SCARP) provides guidance to stakeholders for implementing procedures to remove invasive, non native plants. The primary objective of the plan is to guide and facilitate the implementation of arundo and/or tamarisk removal projects within the upper Santa Clara River watershed of Los Angeles County. The SCARP is a living document and will be updated periodically as new technologies become available, regulations change, or new resources/issues are identified. The project focus is on approximately 16,300 acres of land within the 500 year floodplain of the Santa Clara River and its primary, secondary, and tertiary tributaries. These floodplain lands, particularly within the banks and channel of the Santa Clara River and tributaries, are where arundo and tamarisk infestations are primarily contained and where the bulk of removal activities would occur. However, additional activities such as access, equipment staging and storage, transport, and disposal may occur outside of the 500-year floodplain.

The SCARP has been prepared to provide local landowners, municipalities, environmental groups, and other stakeholders with a broad menu of available techniques for removal of arundo and tamarisk and guidance in obtaining proper permits and approval for removal. The SCARP also provides best management practices (BMP) needed to minimize impacts during removal projects. The following factors have been researched and considered in the development of this SCARP:

- Potential eradication methods
- Degree of infestation
- Existing habitats
- Presence of threatened and/or endangered species
- Access
- Land use
- Current work being conducted or planned
- Pre-existing environmental agency restrictions and permits
- Funding mechanisms in place and strategies for future funding

Taken together, these factors provide a framework for a long term eradication program and associated monitoring to facilitate removal of arundo and tamarisk from the upper Santa Clara River watershed and the restoration and maintenance of natural, economic and community values provided by these riparian corridors.

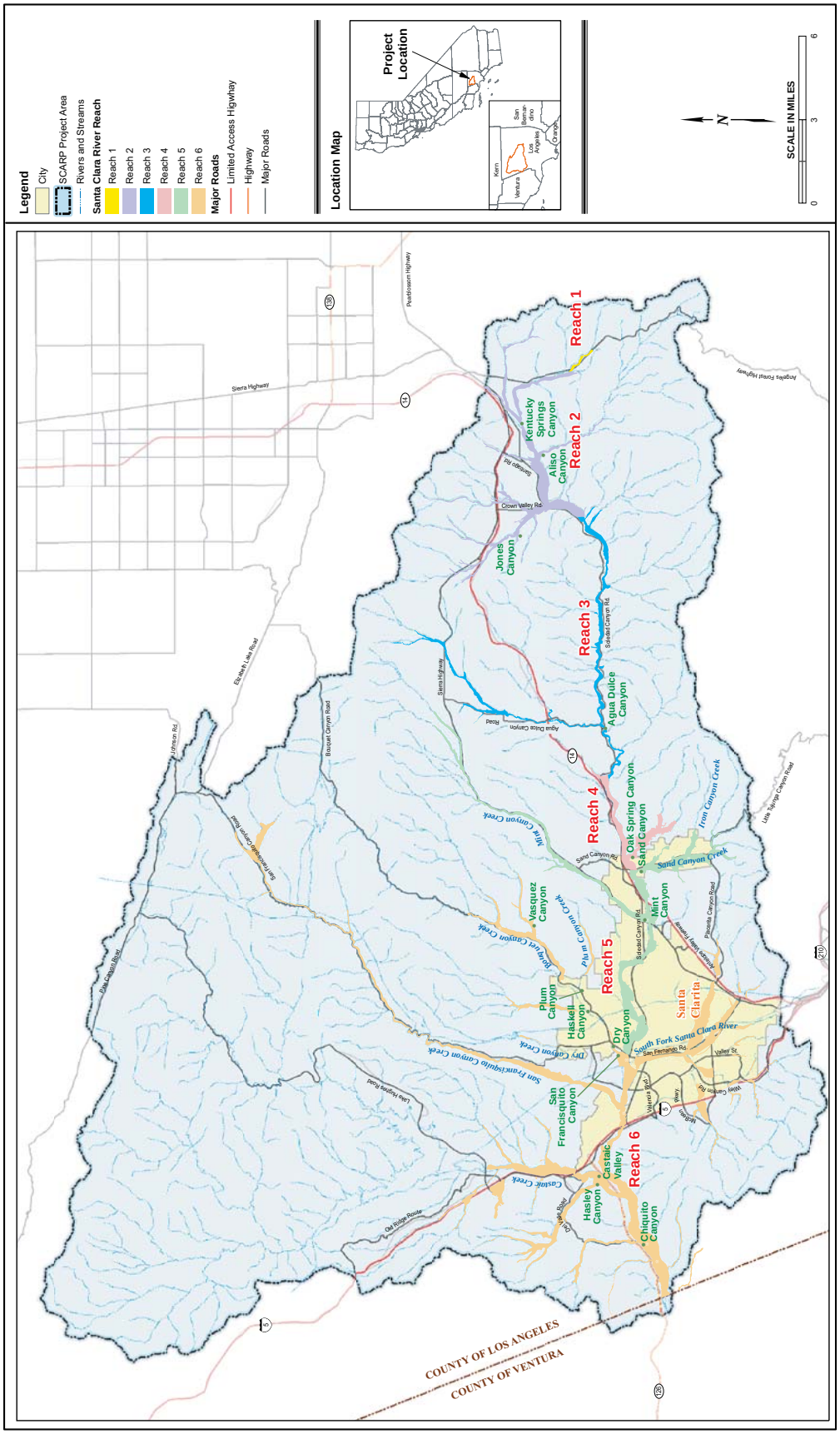
1.2 Project Partnerships

The lead agency directing this effort is the Ventura County Resource Conservation District (VCRCD). The VCRCD is one of 104 resource conservation districts in California and is a special district of the state, which receives funding primarily through grants. The VCRCD manages a diversity of programs including soil and water conservation projects, wildlife habitat enhancement and restoration, control of invasive plants species, and environmental education. The VCRCD has developed a Memorandum of Understanding (MOU) to show support for the SCARP project. The agencies and organizations, which have completed MOUs, are listed below and copies of these memoranda are included in Appendix 1:

- Antelope Valley Resource Conservation District (AVRCD)
- U.S. Forest Service (USFS)
- U.S. Fish and Wildlife Service (USFWS)
- Los Angeles County Department of Public Works (LADPW)
- Los Angeles Agricultural Commissioner's Office
- Los Angeles County Weed Management Area (LAWMA)
- City of Santa Clarita
- Friends of the Santa Clara River (FSCR)
- UC Cooperative Extension

A SCARP Working Group was also created to collaborate with the various organizations and agencies within the upper Santa Clara River watershed. There are many other local agencies and organizations assisting in various ways with the SCARP development such as the U.S. Army Corps of Engineers (USACE), the California Department of Fish and Game (CDFG), the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), the Los Angeles Regional Water Quality Control Board (RWQCB), the Ventura County Arundo Task Force, and the Ventura County Watershed Protection District (VCWPD).

Figure 1: SCARP Project Location and Associated River Reaches



Upper Santa Clara River Sub-Watershed – Santa Clara River Reaches

SCARP

2.0 Invasive Plant Species in the Santa Clara River

The primary focus of this program is the eradication of arundo and tamarisk from the upper Santa Clara River watershed. These species and the issues involving them are described in detail in this section. However, the SCARP recognizes that arundo and tamarisk are not the only non-native invasive plant species present in the upper Santa Clara River watershed. Other species that have been identified within the project area are listed at the end of this chapter. While the removal methods described in Chapter 10 are primarily listed for their use in eradicating arundo and tamarisk, they may also be used to remove other non-native invasive species that are encountered during an individual eradication project.

2.1 Background on Arundo

Arundo is native to the Mediterranean region. It was introduced to the western United States by Spanish settlers in the early 1800s and became abundant in the Los Angeles River by the 1820s. It was historically used as a windbreak, soil stabilizer, fodder, and for making reeds for woodwind instruments. Material from this plant was also commonly woven into mats and used as building material. It is no longer widely used or harvested for these traditional products, but is still used in landscaping.

Arundo is a tall, perennial grass that can reach up to 30 feet in height. It is light to dark green in color and has long, broad blades, with large plume-like flowers. Arundo is one of the fastest growing plants in the world and grows quickly in response to elevated nitrogen levels. This plant is tolerant of both drought and flooding, and can survive extended periods of salinity exposure. Arundo reproduces vegetatively from rhizomes (underground stems) and stem segments. Stem segments usually need two nodes or points for both roots and shoots to grow, but shoots have been observed on stem segments with a single node. Once introduced, arundo has the capability to spread rapidly, forming extensive rhizome systems that out-compete native riparian vegetation and require human intervention to remove. A single clump typically has hundreds of stems that grow very closely together and very rapidly, up to several inches per day during the spring and summer months. Arundo does not usually spread from seed.

Arundo thrives in warm, tropical environments and is most often invasive in coastal riparian areas, where it forms dense monocultures. The invasiveness of arundo substantially affects water quality, water conservation, native biological resources, flooding, erosion hazards, and wildfire risks. Arundo uses at least twice the amount of water as native riparian plants, and can use as much as 17.3 liters/m^2 per day, which is nearly 20 times the amount used by native vegetation (Hendrickson and McGaugh 2005). Arundo is extremely flammable throughout most of the year and is highly adapted to fire. The height of arundo growth spreads fires to tree canopies and the dense growth in the river channels spread fires up and down the river system. The rhizomes also respond quickly after fires, sending up new shoots, and quickly outgrow native species that may have otherwise taken root or sprouted in a burned site (Bell 1997).

2.2 Background on Tamarisk

Similar to arundo, tamarisk is a native of south Eurasia and may have been introduced by Spanish settlers. It was present in California by the early 1900s. Tamarisk was historically, and is currently, used for windbreaks, firewood, shade, and in landscaping. There are currently five known species of tamarisk in California including *Tamarix ramosissima*, *T. parviflora*, *T. gallica*, *T. aphylla*, and *T. chinensis*. Tamarisk is found in rivers, streams, wetlands, desert alkali sinks, playas, and springs throughout Southern and Central California and the western United States.

Although currently less of a problem than arundo in this watershed, tamarisk may be spreading and has potential to cause substantial long-term effects on the water quality, water conservation, native biological resources, flood control, and fire hazards. Tamarisk is a hardy, perennial shrub or small to medium-sized tree, which under favorable circumstances can reach 30 to 40 feet in height. Tamarisk foliage is light to dark green, with small, alternate scale-like leaves. The bark varies from smooth to rough and is reddish-brown. The plants are able to flower after one year of growth.

Tamarisk spreads by seed dispersal and vegetative reproduction. Full-grown mature trees can produce

500,000 seeds per year. These seeds remain viable up to five weeks after being produced and some may survive to the next spring (DiTomaso 2003). These seeds are extremely small with a terminal tuft of exposed fibers that allows them to travel greater distances via wind or water. Unlike arundo, seed dispersal is tamarisk's primary form of reproduction and spreading. However, under favorable moist conditions, tamarisk can also become easily established from stem and root segments.

Tamarisk is an aggressive invasive plant that has a long taproot capable of extending down to the water table. Because of this long taproot, tamarisk is capable of obtaining water in inhospitable and fluctuating groundwater environments, which allows it to out-compete native vegetation. In particular, tamarisk displaces native woody species, such as cottonwood, willow, and mesquite, especially in disturbed areas. Tamarisk consumes at least twice the amount of water that native vegetation uses, or about 3.3 liters/m^2 per day (Hendrickson and McGaugh 2005). Tamarisk further impacts the environment by its ability to concentrate soil salts. Tamarisk leaves collect salt brought up from the soil by the roots. As leaf litter accumulates under the plant, the surface soil can become highly saline, thereby impeding future colonization by many native understory plant species (Carpenter 1998). In addition, dense stands of tamarisk can be highly flammable and tamarisk is likely to persist following fire and expand its dominance with repeated burning of low-elevation riparian plant communities (Busch 1995).

2.3 Long-term Effects of Arundo and Tamarisk Invasion

Both arundo and tamarisk are officially recognized as undesirable invasive plants. Both plants are listed as 'A-1' invaders (the most invasive and widespread wildland pest plants) by the California Invasive Plant Council (Cal-IPC) [formerly known as California Exotic Pest Plant Council] and as noxious weeds by the California Department of Food and Agriculture (CDFA). While the degree and specifics of problems associated with these species vary, general negative effects associated with the establishment of arundo and tamarisk within the watershed.

2.3.1 Water Quality and Supply

Both arundo and tamarisk consume large amounts of water, which negatively affects both instream and groundwater availability. Reduced water availability also adversely affects water-dependent plants and wildlife, and reduces the water available for beneficial urban and agricultural uses. Although native riparian plants have similar transpiration rates per unit of surface area to arundo and tamarisk, arundo and tamarisk have approximately two or more times greater leaf surface area. Therefore, they transpire more water than native plants (Kelly 2003). Water consumption by these species is so high that dense infestations can desiccate riparian areas (seeps, springs, rivers) in arid habitats (Egan and Walker 2000; Dudley 2000). Major arundo infestations can cause an overall increase in water temperature by reducing shade in riparian areas. Increased water temperature can ultimately lead to a reduction of dissolved oxygen, making the water unsuitable for aquatic organisms (Bell 1997). In addition, increased light exposure and temperature may encourage algal blooms, and consequently increase pH levels and severely reduce available habitat for aquatic organisms (Adamus et al. 1997). Increased pH also facilitates the conversion of usable ammonia to a toxic byproduct, which degrades water quality. All of these changes can adversely affect wildlife, including rare and sensitive species.

2.3.2 Flooding and Erosion

Both arundo and tamarisk are known to increase flood hazards and the potential for erosion of adjacent lands, particularly for farmland along the Santa Clara River. Both plants can alter stream geomorphology by trapping and stabilizing sediment, which narrows stream channels, widens floodplains, and causes increased flooding (Carpenter 1998; Lovich 2000; Zouhar 2003). Large stands of arundo and tamarisk may also obstruct flows and shunt floodwaters into areas that historically have not experienced water flow. This can exacerbate bank erosion problems and lead to an unnatural increase in the loss of adjacent public and private property that is often valuable farmland. Arundo provides less protection for steam banks from erosion, because its dense but shallow root masses are more easily undercut than

deep-rooted native riparian vegetation. In addition to increasing flood magnitudes, arundo and tamarisk debris may accumulate downstream of the infestations, trapping sediments, and impeding natural water flow. Arundo debris can create new establishments downstream and on the beach. In many cases, costly clean up efforts or repairs are required.

2.3.3 Fire Hazards

Both arundo and tamarisk contribute to increased fire hazards. Under natural conditions, riparian areas act as firebreaks, but as they are overcome by invasive species, they not only enable wildfires to spread more rapidly, but they can also become sites where fires may originate. Arundo, in particular, is highly flammable and burns more intensely than native riparian vegetation even when green (Bell 1997; Dudley 2000). Because arundo is able to grow to substantial heights, it can act as a ladder fuel, effectively carrying, fire into tree canopies, thereby causing "crown fires" that increase tree mortality. Further, fire disturbance encourages regrowth of arundo. Burned areas also favor tamarisk regrowth, generating a positive feedback loop which is ultimately destructive to native habitat and dangerous to human developments (Bell 1997). Tamarisk leaf litter is also highly flammable, and because both plants are more flammable than native riparian vegetation, fires may occur more frequently and contribute to the eventual exclusion of native plant species (Bell 1997; Carpenter 1998; Lovich 2000).

2.3.4 Native Habitats and Wildlife

Arundo and tamarisk threaten native riparian habitats and the wildlife that depends upon these habitats by excluding native plants from water resources, growing space, and sunlight. Arundo often forms dense monocultures that exclude native vegetation by monopolizing water resources, shading, and altering flood regimes critical to the establishment of native riparian vegetation (Bell 1997; Dudley 2000). The salt-laden leaf litter of tamarisk also precludes such native understory from establishing. Both plants do not offer the same amount of shade as native vegetation (Carpenter 1998). Both arundo and tamarisk reduce habitat quality and food supply for native wildlife, including insects and bird species (Bell 1997; Dudley 2000; Herrera 2003). Insects and other grazers are not able to use arundo as a food source due to the noxious chemicals it contains and its defensive cellular structure (Bell 1997). This is particularly important for federal and state listed species, such as least Bell's vireo, southwestern willow flycatcher, and yellow-billed cuckoo, which utilizes insects as a food source. Documented decreases in wildlife usage of riparian areas have occurred due to massive stands of arundo (Dudley 2000).

2.4 Other Invasive Species

In addition to arundo and tamarisk, perennial pepperweed is a third significant threat to the watershed. Once established, it is very difficult to remove, and the monocultures it creates effectively displace native flora and fauna. Similar to tamarisk, perennial pepperweed also has the ability to concentrate salts near the ground surface (Renz 2000). The following list contains additional noxious and invasive plant species, which may be treated when encountered. The Cal IPC and CDFA also have lists of noxious and invasive plant species. The removal project manager, in coordination with the resource agencies, will make a determination regarding the level of effort that should be exerted in removing each species. For example, mustard may only require treatment if it occurs in stands greater than 0.25 acre at greater than 50-percent cover. Table 1 below lists additional invasive plant species.

Table 1: Invasive Plant Species

Scientific Name	Common Name
Ageratina adenophora	eupatory
Ailanthus altissima	tree of heaven
Aptenia spp.	iceplant
Atriplex semibaccata	Australian saltbush
Avena spp.	non-native grasses
Bassia hyssopifolia	five hook bassia
Brassica spp.	mustard species
Bromus spp.	non-native grasses
Cardaria chalepensis or *C. draba*	hoary cress, white top
Carduus pycnocephalus	Italian thistle
Carpobrotus spp.	iceplant
Centaurea melitensis	tocalote
Centaurea solstitialis	yellow starthistle
Cirsium arvense	Canada thistle
Cirsium vulgare	bull thistle
Conium maculatum	poison hemlock
Cortaderia jubata or *C. selloana*	pampas grass
Cynara cardunculus	artichoke thistle
Cynodon spp.	non-native grasses
Cytisus scoparius	scotch broom
Erodium cicutarium	red stem filaree
Eucalyptus spp.	eucalyptus
Foeniculum vulgare	fennel
Genista monosperma	bridal veil broom
Hedera helix	English ivy
Lepidium latifolium	pepper weed
Linaria dalmatica	dalmation toadflax
Mesembryanthemum spp.	iceplant
Nerium oleander	oleander
Nicotiana glauca	tree tobacco
Phoenix canariensis	canary island palm
Ricinus communis	castor bean
Robinia pseudoacacia	black locust
Salsola spp.	Russian thistle
Schinus spp.	pepper trees
Silybum marianum	milk thistle
Washingtonia spp.	fan palm

3.0 Description of Project Area Reaches

This section provides specific details on the physical and environmental characteristics for each of the upper Santa Clara River's six designated reaches and discussion of future removal program issues and recommendations. The same general analysis is also provided for each of the upper Santa Clara River's ten major tributary systems. In some reaches, removal work may have been conducted prior to the development of the SCARP. The goal of this background information and analysis is to facilitate an understanding among and between future removal project applicants and concerned state and federal resource agencies about the issues surrounding arundo and tamarisk removal proposals. An additional goal is to set the stage for resource agencies such as CDFG, USFWS, and USACE to issue programmatic permits, which will facilitate future removal projects while still protecting critical resources. Reach discussions are generally organized from east to west; with Reach 1 beginning upstream at the eastern project boundary, and Reach 6 ending downstream at the western project boundary.

The upper Santa Clara River's ten main tributaries are grouped based on their hydrological connections to one another and their point of intersection with the mainstem. Eight of these tributaries are located on the north side of the watershed and extend into USFS land. Two tributaries are located on the south side of the watershed. Tables 2 and 2a list the reaches and tributaries within the upper Santa Clara River watershed. The location of the project area is shown in Figure 1. Mainstem and tributary surveys performed by AMEC are described in the text, however detailed tributary surveys conducted by Condor Environmental are included as a separate document in the Appendices. Additional information for each reach and its respective tributaries such as summary tables for reach characteristics, channel cover, and sensitive species can be found in Appendix 6.

Table 2: Reach Descriptions

Reach	Location (east to west)	Length of Reach (miles)	Arundo Coverage (acres)	Tamarisk Coverage (acres)
Reach 1	Eastern Project Boundary to the Angeles Forest Highway	3.6	0	0
Reach 2	Angeles Forest Highway to Acton	8.0	0	2.5
Reach 3	Acton to Spring Canyon	11.4	111	30
Reach 4	Spring Canyon to Sand Canyon	3.9	70.7	21.3
Reach 5	Sand Canyon to Bouquet Canyon	7.9	98.7	202.5
Reach 6	Bouquet Canyon to the Los Angeles County Line	11.0	464.3	190.3

Table 2a: Tributary Descriptions

Reach	Tributary Name	Length of Reach (miles)	Arundo Coverage Greater than 50% (acres)	Tamarisk Coverage Greater than 50% (acres)
Reach 1	No tributaries	n/a	0	0
Reach 2	Jones Canyon Tributaries	9.0	0	0
	Soledad	6.87	0	0
	Aliso Canyon	3.02	0	0
	Escondido Canyon	6.41	0	0
	Santiago Road	n/a	0	0
Reach 3	Aqua Dulce Canyon Tributary	4.7	0	0.15
Reach 4	Oak Spring	5.13	0	0
Reach 5	Sand Canyon Creek	8.5	0	0
	Mint Canyon Creek	13.6	3	0
Reach 6	Bouquet Canyon Creek	25.0	0	0
	South Fork Tributaries	7.5	0	0
	San Francisquito Canyon Creek	21.7	5	0
	Castaic Creek	23.5	3	2
	Hasley Canyon	5.4	0	0
	Chiquito Canyon Tributary	4.9	0	0
	Potrero	3.61	0	0
	Salt	7.24	0	0
	San Martinez Grande	3.22	0	0

3.1 Reach 1: Eastern Project Boundary to Angeles Forest Highway

Characteristics

Extending 3.6 miles, Reach 1 comprises the headwaters of the Santa Clara River which are located in Soledad and Kentucky Springs Canyons; and the river flows through Soledad Canyon for many of the following reaches. Kentucky Springs Canyon is fed by several small streams originating in the San Gabriel Mountains. Reach 1 lies entirely within the Angeles National Forest, although there are several private in-holdings. Reach 1 is an ephemeral stream, where surface water is present only after major storm events. The stream channel within this reach is narrow and steep due to surrounding topography. The 500-year floodplain of Reach 1 ranges between 250 and 500 feet in width and has primarily natural streambanks.

The vegetation in Reach 1 is dominated by big sagebrush and chamise. The remainder of the floodplain is dominated by juniper and walnut woodlands. Sensitive species including the coast horned lizard (state candidate for listing) and the short-joint beavertail cactus (state species of concern) have been reported in Reach 1 (CDFG 2004). This reach's high quality habitat may support other sensitive species; however, this area has only been partially surveyed.

Target Species

No known infestations of arundo, tamarisk, or other invasive plant species have been observed in Reach 1 and therefore no eradication projects are currently anticipated. Although this reach is not threatened or highly suitable for arundo or tamarisk, this reach should be monitored for development of arundo and tamarisk colonies, as presence of these species can lead to infestations downstream.

3.2 Reach 2: Angeles Forest Highway to Acton

Characteristics

Reach 2 begins where Angeles Forest Highway crosses the Santa Clara River at its intersection with BP & L Road and extends eight miles towards the town of Acton. Tributaries draining into the reach include Jones, Acton, and Aliso Canyons. Reach 2 contains substantial acreage of low-level development associated with the town of Acton. Low-density development is present throughout the reach, although it is primarily concentrated around the town of Acton and toward the western end of the reach. This development includes residential housing, ranches, campgrounds, recreation fields, and recreational vehicle parks. The channel within Reach 2 is an open, often shallow, low-gradient wash. The 500-year floodplain is relatively wide near the reach's western boundary, varying between 350 feet in width near its eastern extent and 2,250 feet near Acton.

Vegetation in this reach gradually shifts from dense brush to sparse scrub, with pinyon-juniper woodland in the east transitioning into high desert scrub in the west. Sensitive species in Reach 2 include the coast horned lizard and Mason's neststraw (CNPS List 1B), both known to occur within the 500-year floodplain of the reach (CDFG 2004). As with Reach 1, the lack of reported sensitive species may be due the lack of area surveys.

Target Species

No arundo infestation has been reported within the 500-year floodplain of Reach 2. However, tamarisk occurs in a few small stands at low densities within one mile of the western boundary of the reach.

3.2.1 Acton, Jones, and Kashmere Canyon Tributaries

Characteristics

The Jones Canyon tributaries are located north of the mainstem and connect with the Santa Clara River in Acton. These tributaries include Acton, Jones, and Kashmere Canyons. These canyons consist primarily of private land and scattered rural residences are located in the upper sections of these canyons. These tributaries tend to be arid washes with little or no surface flow of water except under high rain conditions. All three are dominated by desert vegetation and scrub. Sightings of coast horned

lizard have been recorded in these tributaries.

Target Species

Neither tamarisk nor arundo have been recorded in these tributaries. However, the tributaries are susceptible to infestation from ornamental landscaping by proximate private landowners. Therefore, residents in the area should be educated about arundo and tamarisk and the area should be monitored for possible future infestations.

3.2.2 Aliso Canyon Tributary

Characteristics

Aliso Canyon is located south of the mainstem in Reach 2. Aliso Canyon is also an arid wash, except in high rain conditions. Scattered rural residences and areas of agricultural production exist along portions of the canyon. Similar to the Jones Canyon tributaries, Aliso Canyon is characterized by desert vegetation and scrub and coast horned lizards have been sighted.

Target Species

Neither tamarisk nor arundo have been recorded in these tributaries. However, they are also susceptible to infestation from ornamental landscaping by proximate private landowners. Therefore, residents in the area should be educated about arundo and tamarisk and the area should be monitored for possible future infestations.

3.3 Reach 3: Acton to Spring Canyon

Characteristics

Reach 3 is the longest reach in the project area and extends for 11.4 miles from Acton to Spring Canyon. The only major tributary draining into Reach 3 is Agua Dulce Canyon, entering the mainstem from the north about two miles east of Spring Canyon. Development within the floodplain totals approximately 141 acres, including rural-residential housing, recreational vehicle parks, and campgrounds. Reach 3 traverses deep, narrow Soledad Canyon for nearly its entire length. The river channel is correspondingly narrow, with the 500-year floodplain generally limited to 200 and 500 feet in width. The stream channel is broad and often dry at its eastern border, transitioning into a steep narrow canyon for virtually its entire 11-mile extent. The majority of Reach 3 is bounded by natural banks that rise sharply from the channel, with minor areas of concrete hard bank protection.

This reach provides large areas of relatively high quality native riparian habitat Cottonwood woodland dominates this reach, occupying 329 acres of the floodplain, with 119 acres of open unvegetated channel breaking up these expanses of woodlands. These woodlands and associated habitats, such as the mixed willow and big sage, provide several uninterrupted one to two mile stretches of high value native habitat, particularly in the central portions of this reach. This area supports known resident populations of the federal and state endangered arroyo toad, unarmored threespine stickleback, and slender-horned spineflower. Potential suitable breeding habitat for the federal and state endangered least Bells' vireo and southwestern willow flycatcher also exist.

Target Species

There are only a few minor stands of arundo or tamarisk in the eastern five miles of Reach 3. Dense arundo stands occupy a total of 111 acres along this reach. With dense stands occurring approximately one mile both upstream and downstream of the confluence with Agua Dulce Creek. Tamarisk infestation occurs at low-to-moderate densities with approximately 30 acres of the reach's total area. Tamarisk is located in the same general areas of dense arundo stands, including upstream from Indian Springs Road, one mile upstream and downstream of the Agua Dulce tributary intersection, and near Capra Road.

3.3.1 Agua Dulce Canyon

Characteristics

Agua Dulce Canyon is a narrow canyon on the north side of the mainstem with headwaters near Vasquez Rocks County Park. It passes through steep rock walls and intersects with the mainstem in Reach 3 approximately four miles downstream from the headwaters. Near the headwaters, the stream channel is wash-like and has only seasonal surface flow. This section of the

canyon is used for rural residences and small ranches. As the canyon approaches the mainstem, it narrows and becomes steeper, especially downstream near the canyon's intersection with the mainstem. The only development in the base of the canyon is Agua Dulce Road.

The vegetation in Agua Dulce Canyon is dominated by mixed riparian vegetation and some desert species. There is no single dominant plant assemblage within Agua Dulce Canyon. Small cottonwood stands occur throughout the creek, as well as other riparian tree species. Sparse mule fat and other riparian scrub species occur within the creek, as well as scattered desert species such as juniper. Sensitive wildlife species that may be present in the canyon include the arroyo toad, coast horned lizard, and unarmored threespine stickleback.

Target Species

Arundo occurs in scattered, but dense stands along the streambed and on the banks of Agua Dulce Canyon. Due to the narrow nature of this tributary, many of the stands are smaller in size (approximately 5 meters in diameter), except for elbows in the tributary where some larger stands exist. Tamarisk occurs primarily in one stand mid-way to the headwaters off Agua Dulce Road, but additional stands may exist. Surrounding ranches provide sources of arundo and tamarisk.

3.4 Reach 4: Spring Canyon to Sand Canyon

Characteristics

Reach 4 extends 3.9 miles from Spring Canyon to Sand Canyon through the eastern extent of the City of Santa Clarita. The communities of Pine Tree and Canyon Country lie north of the Santa Clara River in this reach, while the communities of Lang and Sulfur Springs extend south from the Santa Clara River. Reach 4 is composed mainly of residential and mining development (91 acres) among sparsely scattered great basin and riparian vegetation. The 500-year floodplain through Reach 4 varies in width from 1,500 feet at its eastern border to 350 feet near Shadow Pines Boulevard and widening to 1,800 feet near Sand Canyon Road. Sand mining in the area near Spring Canyon has lowered the channel approximately 40 feet from its historic elevation.

Reach 4 is dominated by open channel, particularly in its central sections. Great basin and coastal scrub communities total 131 acres of the floodplain along this reach. At the reach's east end, stands of cottonwood woodland are intermixed with the scrub habitats. Sensitive species reported from Reach 4 are limited to coast horned lizard (state species of concern) from the northern margin of the east end of the reach. The two-striped garter snake (state species of concern) has been observed to the south and may occur when water is present in the floodplain area (CDFG 2004). The endangered slender-horned spineflower may also grow along the stream bank in the upstream portions of Reach 4, but its presence has not been confirmed (AMEC 2004).

Target Species

Arundo infestations range from low-to-high density throughout the 500-year floodplain, occupying approximately 71 acres. There are two extensive arundo stands located at the reach's east end, near the private River's End Campground (located in Reach 3). A one-mile section starts at the vicinity of Lang Station Road. Tamarisk is present on 21 acres of the floodplain in generally medium-to-low densities. With the exception of a small patch at the western end of Reach 4, tamarisk concentration within the 500-year floodplain is limited to the area between Lang Station Road and Poppy Meadows Street.

3.4.1 Oak Spring Tributary

Characteristics

Oak Spring Canyon feeds into the western extent of Reach 4. The golf course at the mouth of Oak Spring Canyon has contoured the channel throughout the golf course. Sensitive species reported in these tributaries include the two-striped garter snake.

Target Species

Neither tamarisk nor arundo have been recorded in these tributaries. However, they are also susceptible to infestation from ornamental landscaping by proximate private landowners. Therefore, residents in the area should be educated about arundo and tamarisk and the area should be monitored for possible future infesta-

tions.

3.5 Reach 5: Sand Canyon to Bouquet Canyon

Characteristics

Reach 5 extends 7.9 miles from Sand Canyon Road downstream to Bouquet Canyon Road. The majority of this reach falls within the City of Santa Clarita. Major tributaries to Reach 5 include those from Sand Canyon joining the mainstem from the south at the junction between Reaches 4 and 5, and Mint Canyon flowing into the Santa Clara River from the north approximately two miles downstream from this junction. Approximately 360 acres of the 500-year floodplain is developed along Reach 5, which is mostly within the City of Santa Clarita. The 500-year floodplain in Reach 5 varies in width from 500 feet by the Sierra Highway bridge to nearly 2,500 feet in the developed area off Oak Avenue.

Open channel dominates this reach, occupying 404 acres of the floodplain, with great basin plant communities concentrated along the east and west ends of the reach. The channel is heavily braided. Native vegetation communities are dominated by scalebroom and big sagebrush. Although there are scattered groves of cottonwoods and willows along the channel margins in the western portion of this reach, the riparian vegetation consists primarily of mule fat. This reach has limited native vegetation and only sparse data on sensitive species are available. However, the western spadefoot toad (state species of concern), arroyo chub (state species of concern), and the endangered unarmored threespine stickleback, federal threatened California red-legged frog have reported observations in Reach 5. Others that may be present are the coast horned lizard (state species of concern) and western whiptail (state candidate). Similarly, sensitive plant species have not been observed, but the floodplain in Reach 5 has the potential to support the endangered slender-horned spineflower and federally threatened spreading navarretia.

Target Species

Arundo and tamarisk occupy 302 acres together in low-to-moderate densities throughout this reach. Arundo is established on approximately 203 acres. Large stands of low-density arundo extend downstream for approximately 3.5 miles from the eastern boundary of Reach 4. Within the mainstem, one source of arundo is one mile west of the conservation camp near the stream channel. The Angeles National Forest cleared one-mile of the channel in 1995 downstream of the conservation camp. A large, high-density stand of arundo is also located downstream from where the Los Angeles aqueduct crosses the river. Additional large areas of low- and medium-density infestations are heavily intermixed with high-quality habitat at the western boundary. Tamarisk occupies approximately 99 acres. Dense stands occur one mile east of Bouquet Canyon Road, and are scattered throughout the eastern portion of the reach. Other invasive plant species identified in Reach 5 included tree tobacco, black locust, and pepper tree.

3.5.1 Sand Canyon Tributaries

Characteristics

The Sand Canyon tributaries are located on the south side of the mainstem and include Sand Canyon and Iron Canyon. Sand Canyon joins the mainstem at the intersection between Reaches 4 and 5. Iron Canyon joins Sand Canyon approximately two miles upstream from the mainstem. Channels of Sand Canyon tributaries tend to be narrow with seasonal surface water flows. Rural residences surround the majority of the Sand Canyon tributaries, many of which are sited in the 500-year floodplain. The headwaters of these tributaries are generally surrounded by protected open space. The Sand Canyon tributaries support scattered mule fat within the channel and live oaks near the stream banks. This stream channel supports only seasonal surface flow. Sensitive species reported in these tributaries include the western spadefoot toad reported in Sand Canyon.

Target Species

Arundo and tamarisk have not yet been identified in any of these tributaries; however, introductions may occur due to landscaping of rural residences.

3.5.2 Mint Canyon Tributaries

Characteristics

The Mint Canyon tributaries are located on the north

side of the Santa Clara River and join the mainstem about two miles downstream from the Reach 4 boundary. These tributaries include Mint and Rowher Canyons. The 500-year floodplain in Mint Canyon varies between 300 and 1,000 feet wide at its mouth. The streambed is narrow and channelized for 3.5 miles upstream from the mainstem. Surface water is seasonal within Mint Canyon.

Scattered mule fat and great basin scrub communities dominate the stream channel. In some areas, robust cottonwood-willow groves are also present. Southern sycamore-alder riparian forest is also found in a minor tributary near the headwaters of Mint Canyon. Slender-horned spineflower and slender mariposa lily have been reported within Mint Canyon. These occurrences were in the 3.5-mile stretch extending downstream from the intersection of Sand Canyon Road to the mainstem, and species may have since been extirpated by recent development.

Target Species

Tamarisk is present in moderate levels and arundo is present at low to moderate levels within and adjacent to the stream channel throughout Mint Canyon. Much of these infestations are associated with residences using arundo and tamarisk as landscaping plants, which now grow wild in stands. Pepper trees are also present within the stream corridor and are beginning to establish within Mint Canyon.

3.6 Reach 6: Bouquet Canyon to Ventura County Line

Characteristics

Reach 6 begins in Santa Clarita where Bouquet Canyon drains into the mainstem and stretches west 11 miles to the Ventura County line. Six main tributaries drain into Reach 6: Bouquet Canyon, South Fork, San Francisquito Canyon, Castaic Creek, Hasley Canyon, and Chiquito Canyon. Interstate 5 (I-5) divides Reach 6 into two characteristically distinct sections at the western border of Santa Clarita. The land surrounding this reach east of I-5 within Santa Clarita is heavily developed with residential, commercial, and industrial land uses. A public recreational path borders Reach 6 for its entire length between Bouquet Canyon Road and the South River Village Apartment Complex. The width of the 500-year floodplain on this part of the reach ranges between 700 to 1,000 feet. West of I-5, with the exception of the Six Flags Magic Mountain Theme Park (located adjacent to the Santa Clara River just west of I-5), the Santa Clara River is bordered by agricultural and other undeveloped open land. The majority of the land here is under the ownership of the Lennar-LNR. From I-5 to the Ventura County line, Reach 6 traverses a broad open valley, with a 500-year floodplain of ranging between 1,800 and 3,000 feet in width.

Water flow within Reach 6 is braided and subsidized year-round by effluent from two wastewater treatment plants: the Saugus Wastewater Treatment Plant and the Valencia Water Reclamation Plant. Over 600 acres of Reach 6 is currently open un-vegetated channel. The perennial water flows, cottonwood woodlands, and associated habitats such as mixed willow, mule fat, and big sage provide high quality habitat for several sensitive species. In particular, this reach includes the only known occurrences along the mainstem of the Santa Clara River for breeding of endangered least Bells' vireo. Further, these riparian habitats provide extensive suitable breeding habitat for the endangered southwestern willow flycatcher. This reach also supports known populations of the endangered arroyo toad and unarmored threespine stickleback. Declining sensitive aquatic species such as the western pond turtle (state species of concern) and the two-striped garter snake (state species of concern) are also present.

Target Species

The environmentally sensitive habitats along Reach 6 are also the section of the upper Santa Clara River watershed most heavily infested with arundo. Tamarisk is present to a lesser extent. Large areas of arundo and tamarisk occur at a low density infestation range of about 355 acres. An additional 176 acres of arundo occurs at densities of high density infestation range.

3.6.1 Bouquet Canyon Tributaries

Characteristics

The Bouquet Canyon tributaries are located on the north side of the mainstem and include Bouquet

Canyon, Dry Canyon, Haskell Canyon, Texas Canyon, Vasquez Canyon, and Plum Canyon. Land use surrounding Bouquet Canyon transitions from a highly urbanized area near the confluence to residential and rural residential upstream, before Bouquet Canyon enters Angeles National Forest. Land currently developed is used for campgrounds or rural residences. The length of the tributary that flows from the intersection of Plum Canyon and Bouquet Canyon through Santa Clarita to the mainstem is channelized. Above Plum Canyon, Bouquet Creek is often confined to a narrow natural channel. Scattered groves of cottonwood, oaks, and willows intermixed with mule fat are located throughout this section of the reach. Upstream, past the USFS boundary, cottonwood woodland transitions to dense live oak woodland. Portions of several of Bouquet Canyon's tributaries, notably the lower portions of Plum, Haskell, Vasquez, and Texas Canyons, contain 500-year floodplains that fall within the project boundary. These canyons vary from broad floodplain supporting scrub habitats with scattered cottonwoods to areas with higher quality riparian habitats. Some areas have been subject to extensive development and the streams are largely channelized.

Target Species

Bouquet Canyon exhibits heavy arundo infestation throughout the lower reaches of the canyon, and lacks public access to the tributary in some of the most heavily infested areas. Once beyond the channelized portion of the tributary, Bouquet Canyon is heavily infested with arundo. Arundo is also present north of the Angeles National Forest boundary. These infestations are smaller and are closely associated with private properties. No tamarisk was observed within Bouquet Canyon. Scattered stands of eucalyptus, pine trees, and pampas grass are located throughout Bouquet Canyon.

3.6.2 South Fork Tributaries

Characteristics

The South Fork of the Santa Clara River is a system of major tributaries, passing through the City of Santa Clarita. Tributaries include South Fork, Pico Canyon, Newhall Creek, and Placerita Creek. These tributaries are mostly contained within the limits of urban development. With the exception of Placerita Creek, the streams are channelized throughout much of South Fork system. The waterways therefore tend to be fairly degraded, with little or no vegetation growing within most of the channels. However, the four mile section of the South Fork tributary just prior to where it enters the mainstem is wider and contains more native vegetation, including scattered great basin scrub and mule fat. The channel has seasonal flow, which may be supplemented by urban runoff.

Target Species

Arundo is present in Placerita Creek, near its intersection with South Fork. Due to the channelization of the remaining waterways, there is little potential for invasive species to establish.

3.6.3 San Francisquito Canyon

Characteristics

San Francisquito Canyon is a large tributary of the Santa Clara River, stretching nearly 22 miles from headwaters on the northeastern boundary of the watershed to the mainstem. It enters the mainstem from the north in Santa Clarita near McBean Parkway. Much of the northern portion of the canyon is located within Angeles National Forest. As with Bouquet Canyon, land use surrounding San Francisquito Creek transitions from highly urban at the confluence to rural residential in the middle reaches and protected open space in the upstream half of the canyon. The 500-year floodplain of the San Francisquito Canyon ranges between 700 and 1,200 feet in the lower portion of the canyon. Most of San Francisquito Canyon has a wide, shallow stream channel with low velocity water flow, although some upstream sections are narrow and undeveloped, particularly near the headwaters in Angeles National Forest. San Francisquito Canyon provides large areas of relatively high value natural habitat, including sage scrub, cottonwood forest, mixed willow forest, sycamore and alder forest, coast live oak woodland.

Target Species

Arundo occurs at moderate to high densities throughout San Francisquito Canyon and presents a

threat to both resources in this tributary and the Santa Clara River's mainstem. Moderate density arundo infestations exist at and downstream of the Los Angeles County Fire Station. Small infestations were observed as high in the watershed as Bee Canyon. No infestations were observed beyond Bee Canyon. No tamarisk was identified within San Francisquito Canyon.

San Francisquito Canyon has had continuing efforts for arundo removal since 1995, which were initiated by the Angeles National Forest Service. The program was expanded in 1999 to include the LADWP property. During 2000 and 2001, the lowest 2.5 miles of San Francisquito were treated for mitigation as a result of a bridge construction and bank stabilization project. Other areas on San Francisquito have been treated by commercial property companies as mitigation for development impacts.

3.6.4 Castaic Creek Tributaries

Characteristics

The Castaic Creek tributaries are located on the northern side of the mainstem. Castaic Creek tends to be low velocity. Water flow may be subsurface throughout much of the year. The streambed is wide at the mouth of the creek, and is constrained by a barrier fence and agricultural lands on either side. Most of the adjacent land in this area is agricultural with a small amount of recreational open space. Water availability in the downstream section of the Castaic Creek is regulated by dam releases from Castaic Lake. Castaic Lake creates an artificial disjunct in the streambed geomorphology, which is broad with low velocity flow downstream and narrow and deeply incised upstream. Most of the land upstream of Castaic Lake is protected USFS land and is outside of the project area.

Target Species

Tamarisk and arundo are present in the area of Castaic Creek near where Commerce Center Drive meets Highway 126 and upstream of Castaic Lake on USFS property.

3.6.5 Hasley Canyon Tributary

Characteristics

Hasley Canyon is a small tributary that drains north from Castaic Creek. In general, the channel tends to have little vegetation, but contains some intermittent coastal scrub and live oaks. The channel has been contoured and directed by residents within much of the canyon. A large construction effort has widened the stream channel near the intersection of Hasley Canyon Road and Commerce Center Drive. Rural residential land surrounds most of Hasley Canyon, although the mouth of the tributary does pass through an unincorporated urbanized area.

Target Species

No arundo or tamarisk was identified within Hasley Canyon. The majority of other invasive species in the canyon persist as an artifact of private landscaping. Eucalyptus and pepper trees have sprouted outside private yard areas and are colonizing the canyon in areas. Sensitive species, which have been reported in Hasley Canyon, include the San Fernando Valley spineflower, the Los Angeles sunflower, and the Santa Ana sucker.

3.6.6 Chiquito Canyon Tributaries

Characteristics

The Chiquito Canyon tributaries consist of Chiquito Canyon and San Martinez Grande Canyon. In general, these tributaries are heavily affected by surrounding rural residences, with many landscaping plants encroaching on the stream channel. The stream channels tend to be narrow, and are sometimes paved-over at road crossings and other areas to avoid erosion. In general, there is little water, except for that introduced via runoff and over watering. However, higher amounts of water are present after heavy rain events. Rural residential areas and open space surround the Chiquito Canyon tributaries.

Great basin sagebrush and limited cottonwoods are present within the stream channel although in most areas the stream channel has no vegetation. Disturbed oak savanna, which appears to have been grazed historically, is present along downstream portions of the tributaries. The headwaters are dominated by high-quality coastal sage scrub. The San Fernando Valley spineflower is the only sensitive species known to be present in these

tributaries.

Target Species

There is little to no arundo within the Chiquito Canyon tributaries. Tamarisk is present at moderate densities within the Chiquito Canyon tributaries as individual plants have escaped residential cultivation and have become established along the stream bank. San Martinez Grande Canyon tends to have more tamarisk than Chiquito Canyon. Landscaping plants and non-native grass are the primary invasive species within the Chiquito Canyon tributaries. Liquid amber trees and pepper trees are also present within and along the stream channel.

4.0 Biological Resources

The upper Santa Clara River drains an area that extends from the mountainous areas along the western edge of the Mojave Desert in the east and north of the watershed, west to the inland extent of areas that are typically dominated by coastal habitat associations. The habitats present along the Santa Clara River itself and in the surrounding areas reflect the Santa Clara River's transit of habitats ranging from high desert and montane associations in the inland areas to coastal valley associations near the project area's western boundary. A similar transition from high desert or montane also occurs along many of the Santa Clara River's larger tributaries. Mapping has been completed for the mainstem and tributaries of the upper Santa Clara River watershed (Appendices 6 and 7). A plant and wildlife species list was compiled during these surveys and is included in Appendix 5.

Special status plant and wildlife species are recognized by the California Native Plant Society, CDFG, or USFWS because these species have limited populations. It is important to recognize these species and avoid impacts to them because of various regulatory restrictions as discussed in Chapter 9.

4.1 Special Status Plant Species

A total of 19 special status plant species with the potential to occur within the project area were identified (Table 3). The potential for these species to occur in the study area is based on a review of historical sensitive plant species locations identified in the CNDDB (CDFG 2002).

4.2 Special Status Wildlife Species

A total of 21 special status wildlife species with the potential to occur within the project area were identified (Table 4). The potential for these species to occur in the study area is also based on a review of historical wildlife species locations identified in the CNDDB), and a review of pertinent literature. Of these 21 species, eight are federally listed under the Federal Endangered

Table 3: Special Status Plant Species

Scientific Name	Common Name	Status[1]	Habitat	Potential to Occur in Each Reach/Tributary	Potential to Occur (High, Medium, Low, and Why)
Allium howellii var. *clokeyi*	Mt. Pinos onion	List 1B	Pinyon and juniper woodlands and Great Basin scrub; 4,265-6,000 feet above msl.	Potential to occur in Reaches 1 and 2 and all tributaries. Known to occur in Castaic Creek tributaries.	Low: The project area elevation is 4,265 feet at its highest point. This plant does not grow in the riparian flood channel where weed removal will occur.
Arenaria macradenia var. *kuschei*	Kusche's sandwort	List 1B	Granitic openings in chaparral; 4,000- 5,700 feet above msl.	Potential to occur in Reaches 1, 2, and 3 and all tributaries.	Low: The elevation for this plant is close to the highest elevation for the project (4,265 feet). This plant does not grow in the riparian flood channel where weed removal will occur.
Berberis nevinii	Nevin's barberry	SE, FE, List 1B	Chaparral, cismontane woodland, coastal scrub, riparian scrub/sandy or gravelly soils; 1,000-2,700 feet above msl.	Potential to occur in Reaches 2 though 6 and all tributaries. Known to occur in San Francisquito Canyon.	High: This plant grows in habitats (e.g., riparian scrubs) that could be impacted during weed removal and in habitats where access roads may need to be built.
Calochortus clavatus var. *gracilis*	Slender mariposa lily	List 1B	Chaparral and coastal sage scrub; 1,100-3,200 feet above msl.	Potential to occur in Reaches 3 though 6 and all tributaries. Known to occur in Mint Canyon Tributaries and in San Francisquito Canyon.	Low: This plant does not grow in the riparian flood channel where weed removal will occur.
Calochortus plummerae	Plummer's mariposa lily	List 1B	Chaparral, cismontane woodland, coastal scrub, lower montane coniferous forest, valley and foothill grassland in rocky habitats; 330-5,600 feet above msl.	Potential to occur in all reaches and tributaries. Known to occur in Agua Dulce Canyon and in the South Fork Tributaries.	Low: This plant does not grow in the riparian flood channel where weed removal will occur.
Castilleja gleasonii	Mt. Gleason Indian paintbrush	SR, List 1B	Lower montane coniferous forests and pinyon and juniper woodlands; 3,800-7,100 feet above msl.	Potential to occur in Reaches 1, 2, and 3 and all tributaries.	Low: The elevation for this plant is close to the highest elevation for the project (4,265 feet). This plant does not grow in the riparian flood channel where weed removal will occur.
Centromadia parryi var. *australis*	Southern tarplant	List 1B	The margins of marshes and swamps, valley and foothill grasslands, and vernal pools; 0-1,400 feet above msl.	Potential to occur in Reaches 5 and 6 and all tributaries.	High: This plant grows in habitats (e.g., margins of marshes and swamps) that could be impacted during weed removal and where access roads may need to be built.
Chorizanthe parryi var. *fernandina*	San Fernando Valley spineflower	SC, FC, List 1B	Sandy soils in coastal scrub; 500-4,000 feet above msl.	Potential to occur in Reaches 3 though 6 and all tributaries. Known to occur in Reach 6 and in Castaic Creek and Chiquito Canyon Tributaries	Medium: This plant grows in coastal sage and alluvial scrub habitats.

Scientific Name	Common Name	Status[1]	Habitat	Potential to Occur in Each Reach/Tributary	Potential to Occur (High, Medium, Low, and Why)
Dodecahema leptoceras	Slender-horned spineflower	SE, FE, List 1B	Sandy soils in chaparral, cismontane woodland, and coastal scrub (alluvial fans); 650-2,500 feet above msl.	Potential to occur in Reaches 2 though 6 and all tributaries. Known to occur in Reaches 3 and 5 and in Mint Canyon, South Fork, and Halsey Canyon Tributaries.	High: This plant grows in habitats (e.g., alluvial fans) that could be impacted during weed removal and in habitats where access roads may need to be built.
Erodium macrophyllum	Round-leaved filaree	List 2	Clay soils in cismontane woodland, valley and foothill grassland; 50-4,000 feet above msl.	Potential to occur in all reaches and tributaries.	Low: This plant does not grow in the riparian flood channel where weed removal will occur.
Galium grande	San Gabriel bedstraw	List 1B	Broadleaved upland forest, chaparral, cismontane woodland, lower montane coniferous forest; 1,400-5,000 feet above msl.	Potential to occur in all reaches and tributaries. Known to occur in Castaic Creek Tributaries.	Low: This plant does not grow in the riparian flood channel where weed removal will occur.
Helianthus nuttallii ssp. *parishii*	Los Angeles sunflower	List 1A	Coastal salt and freshwater marshes and swamps; 30-1,600 feet above msl.	Potential to occur in Reaches 3 through 6 and all tributaries. Known to occur in Reach 6.	High: This plant grows in habitats (e.g., marshes and swamps) that could be impacted during weed removal.
Lilium parryi	Lemon lily	List 1B	Mesic areas in lower montane coniferous forest, meadows and seeps, riparian scrub, upper montane coniferous forest; 4,300-8,600 feet above msl.	Potential to occur in Reaches 1 and 2 and all tributaries.	Low: The project area elevation is 4,265 feet at its highest point. This plant does not grow in the riparian flood channel where weed removal will occur.
Malacothamnus davidsonii	Davidson's bush mallow	List 1B	Chaparral, cismontane woodland, coastal scrub, riparian woodland; 600-2,800 feet above msl.	Potential to occur in Reaches 2 though 6 and all tributaries.	High: This plant grows in habitats (e.g., riparian woodland) that could be impacted during weed removal and in habitats where access roads may need to be built.
Navarretia fossalis	Spreading navarretia	FT, List 1B	Chenopod scrub, marshes and swamps (assorted shallow freshwater), playas, vernal pools; 100-4,300 feet above msl.	Potential to occur in all reaches. Known historically in Reach 5 and the Plum Canyon Tributary.	High: This plant grows in habitats (e.g., marshes and swamps) that could be impacted during weed removal and in habitats where access roads may need to be built.
Opuntia basilaris var. *brachyclada*	Short-joint beavertail	List 1B	Chaparral, Joshua tree woodland, Mojavean desert scrub, pinyon and juniper woodlands; 1,400-5,900 feet above msl.	Potential to occur in all reaches and tributaries. Known to occur in Reach 1 and in Bouquet Canyon and South Fork Tributaries.	Low: This plant does not grow in the riparian flood channel where weed removal will occur.

Scientific Name	Common Name	Status[1]	Habitat	Potential to Occur in Each Reach/Tributary	Potential to Occur (High, Medium, Low, and Why)
Orcuttia californica	California Orcutt grass	List 1B	Vernal pools; 50-2,200 feet above msl.	Potential to occur in Reaches 3 though 6 and all tributaries. Known to occur in Bouquet Canyon and in South Fork Tributaries.	Low: This plant does not grow in the riparian flood channel where weed removal will occur.
Senecio aphanactis	Rayless ragwort	List 2	Alkaline areas in chaparral, cismontane woodland, coastal scrub; 50-2,600 feet above msl.	Potential to occur in Reaches 2 though 6 and all tributaries. Known to occur in the South Fork Tributaries.	Low: This plant does not grow in the riparian flood channel where weed removal will occur.
Stylocline masonii	Mason's neststraw	List 1B	Sandy soils in chenopod scrub, pinyon, and juniper woodlands; 330-4,000 feet above msl.	Potential to occur in all reaches and tributaries. Known to occur in Reach 2.	Low: This plant does not grow in the riparian flood channel where weed removal will occur.

[1]FC: federal candidate
FE: federally listed as endangered
FT: federally listed as threatened
SC: state candidate
SR: state listed as rare
ST: state listed as threatened
CNPS List 1A: plant species are presumed extinct in California
CNPS List 1B: plant species are rare, threatened, or endangered in California and elsewhere
CNPS List 2: plants species are rare, threatened, or endangered in California, but more common elsewhere

Table 4: Special Status Wildlife Species

Scientific Name	Common Name	Status	Habitat	Potential to Occur in Each Reach/Tributary	Potential to Occur (High, Medium, Low) and Why
Mammals					
Neotoma lepida intermedia	San Diego desert woodrat	SC, SSC	Pinyon-Juniper in association with rocky outcrops, including burrows of ground squirrels and woodrats.	Upstream and middle reaches of project area.	Medium potential to occur since it is not a riparian species. Uplands surrounding riparian zone have greater potential for this species.
Perognathus alticola inexpectatus	Tehachapi pocket mouse	SSC	Prefers open, sandy upland habitats, with friable soils.	Potentially found in adjacent upland habitats in all reaches and tributaries.	Low potential since this species is primarily associated with upland habitats.
Taxidea taxus	American badger	SSC	Prefers open, sandy upland habitats.	Potentially found in adjacent upland habitats in all reaches and tributaries.	Medium potential to occur, but seldom seen due to its fossorial ecology. Not usually associated with riparian habitats, but found in adjacent upland habitats.
Birds					
Accipiter cooperii	Cooper's Hawk	SSC	Found in a variety of habitats, including riparian and uplands, as well as urban areas.	Found in all reaches and tributaries.	High potential to occur, for breeding, roosting, and foraging.
Athene cunicularia	Burrowing owl	SC, SSC	Typically found in open scrub habitats in uplands.	Potentially found in high-quality upland habitats in all reaches and tributaries.	Low potential, since this species does not typically inhabit riparian zones.
Coccyzus americanus occidentalis	Western yellow-billed cuckoo	SE	Prefers dense riparian habitats, including willow-cottonwood.	Potentially found in all reaches, although the species is very rare.	Low potential given the scarcity of this species, but it could be found in any reach with an overstory of riparian hardwoods.
Dendroica petechia brewsteri	Yellow warbler	SSC	Prefers willow riparian and associated habitats.	Potentially found throughout all reaches and tributaries.	Medium potential since this species will occur disjunctly throughout appropriate habitats.
Empidonax traillii extimus	Southwestern willow flycatcher	FE, SE	Riparian scrub, willow and mule fat, including arundo stands.	Known in Reaches 3 and 6.	High potential to occur in downstream reaches, below Soledad Canyon where high quality riparian habitat is prevalent.
Pilioptila californica californica	Coastal California gnatcatcher	FT, SSC	Coastal sage scrub	Known in Plum and Placerita Canyons.	Low potential, since this species does not typically inhabit riparian zones.

Scientific Name	Common Name	Status	Habitat	Potential to Occur in Each Reach/Tributary	Potential to Occur (High, Medium, Low) and Why
Gymnogyps californianus	California condor	FE, SE	Montane and cliff habitats, primarily limited to Sespe Wilderness area and adjacent lands.	Potentially found in all reaches, although the species is very rare.	Low potential to occur since no breeding sites are located within the project area, although this species has large home ranges and could potentially forage within the project area.
Icteria virens	Yellow-breasted chat	SSC	Riparian scrub, willow and mule fat, including arundo stands.	Likely to be found in all reaches with willow riparian habitat	High potential to occur in downstream reaches, below Soledad Canyon where high quality riparian habitat is present.
Toxostoma lecontei	Le Conte's thrasher	SSC	Open desert scrub, primarily found in habitats dominated by common saltbush.	Potentially found in Real 1 and 2.	Medium potential to occur in scrub habitats areas.
Vireo bellii pusillus	Least Bell's vireo	FE, SE	Riparian scrub, willow and mule fat, including arundo stands.	Most likely to be encountered in the downstream reaches, but possibly occurs throughout the Santa Clara River.	High potential to occur in downstream reaches, below Soledad Canyon.
Reptiles					
Aspidoscelis tigris stejnegeri	Coastal western whiptail lizard	SC	Chaparral, riparian scrub.	Can be found in open riparian scrub, but chiefly associated with upland habitats.	High potential to occur in appropriate habitats throughout The Santa Clara River.
Phrynosoma coronatum blainvillei	Coast horned lizard	SC, SSC	Chamise chaparral.	This species is unlikely to occur in riparian habitats in the project area, but can be found in uplands.	High potential to occur in appropriate habitats throughout the Santa Clara River.
Thamnophis hammondii	Two-striped garter snake	SC, SSC	Riparian habitat.	May be found throughout project area.	High potential to occur throughout project area. Forages widely, and usually active during the day on highly vegetated stream banks.
Amphibians					
Bufo californicus	Arroyo toad	FE, SE	Sandy alluvial stream courses and adjacent uplands.	Possible throughout project area. Known in Reaches 3 and 6 and Castaic and San Francisquito Creeks.	Medium potential to occur since the species will be locally abundant in the few areas it is found, and thorough surveys of the entire project area are lacking.
Rana muscosa	Mountain yellow-legged frog	FE	Montane streams at higher elevations.	None	Species does not occur in the project area.

Scientific Name	Common Name	Status	Habitat	Potential to Occur in Each Reach/Tributary	Potential to Occur (High, Medium, Low) and Why
Scaphiopus hammondii	Western spadefoot toad	SC, SSC	Upland and riparian habitat. Breeds in ephemeral pools.	Potential to occur throughout the project area.	High potential to occur, where intact native upland habitat contacts riparian areas.
Rana aurora draytonii	California red-legged frog	FT, SSC	Prefers permanent water with vegetated edges.	Known only from remnant population in San Francisquito Creek, but could occur elsewhere.	High potential in San Francisquito Creek where current population exists, low potential elsewhere.
Fishes					
Catostomus santaanae	Santa Ana sucker	FT	Swift flowing stretches of Santa Clara River.	Primarily in upstream reaches, but can be found elsewhere during high flows.	High potential to occur when water is present, but low detectability in the absence of trapping/netting surveys.
Gasterosteus aculeatus williamsoni	Unarmored threespine stickleback	FE, SE, DFG: Fully Protected	Typically in slow moving water with vegetated edges.	Possible throughout entire project area.	High potential to occur when water is present, but low detectability in the absence of trapping/netting surveys.
Gila orcutti	Arroyo chub	SC, SSC	Prefers slow water with sand or mud bottom.	Possible throughout project area.	High potential to occur when water is present, but low detectability in the absence of trapping/netting surveys.

FE: federally listed as endangered
FT: federally listed as threatened
SC: state candidate
SE: state listed as endangered
SSC: state species of special concern
ST: state listed as threatened
DFG Fully Protected: The Fish and Game Codes sections dealing with Fully Protected species state that these species "...may not be taken or possessed at any time and no provision of this code or any other law shall be construed to authorize the issuance of permits or licenses to take any fully protected" species, although take may be authorized for necessary scientific research. This language arguably makes the "Fully Protected" designation the strongest and most restrictive regarding the "take" of these species. In 2003, the code sections dealing with fully protected species were amended to allow the Department to authorize take resulting from recovery activities for state listed species. More information on Fully Protected species and the take provisions can be found in the Fish and Game Code (birds at §3511, mammals at §4700, reptiles and amphibians at §5050, and fish at §5515). Additional information on Fully Protected fish can be found in the California Code of Regulations, Title 14, Division 1, Subdivision 1, Chapter 2, Article 4, §5.93. The category of Protected Amphibians and Reptiles in Title 14 has been repeated. The Fish and Game Code is available online at: http://www.leginfo.ca.gov/cgibin/calawquery?codesection=fgc. Title 14 of the California Code of Regulations is available at http://ccr.oal.ca.gov

Species Act (FESA).

5.0 Project Planning

Coordinated removal projects can lead to control of an invasive plant species in the entire watershed. However, before implementing a removal project, it is important to consider the various project elements, which include:

- integrated weed management
- project prioritization
- working with landowners
- public outreach
- surveys and mapping
- methods
- regulatory requirements
- scheduling
- costs
- funding

5.1 Integrated Weed Management

Integrated Weed Management (IWM) is a comprehensive strategy for the control of weeds. It considers each of the various factors influencing a weed removal strategy, such as different removal methods, the timing of the project, the location of the project, and potential impacts to the environment. There are also other factors such as overall project goals, specific agency policies, and local politics. The federal Noxious Weed Act further narrows the concept of Integrated Weed Management. It defines IWM as "a system for the planning and implementation of a program, using an interdisciplinary approach, to select a method for containing or controlling undesirable plant species or groups of species using all available methods, including education, prevention, physical or mechanical methods, and general land management practices."

Integrated Weed Management is vital for the control and potential eradication of invasive plant species. Removal projects often achieve the most success when a variety of strategies are implemented. For example, it may be effective to implement herbivory as a control measure in one section of a removal project area, while other sections undergo eradication measures. Active surveying can assist with controlling outlier populations of invasive plants that have not established yet. Strategies to prevent the spread of invasive species are also part of IWM. This can be approached from a cultural aspect as educating the public about the threat invasive species pose to the environment may help to avoid the use of these species in residential landscaping.

With IWM practices in place, it is also important to minimize the project impacts. Individual projects will utilize Best Management Practices to reduce impacts to the environment, ensure public health and safety, and increase worker safety. These BMPs are listed in Chapter 14. BMPs can be adapted and modified for each individual project depending upon the removal techniques and sensitive habitat and species present.

The Best Available Technologies are used in addition to the BMPs to achieve successful management strategies. The Best Available Technologies will change over time, as research, technologies, and methods are updated. Geographic Information Systems (GIS) and Global Positioning System units (GPS) assist with surveying and mapping while new methods and equipment can increase removal efficiency. The SCARP is a living document and will be revised as necessary to incorporate the Best Available Technologies.

5.2 Prioritization

Individual projects can be conducted anywhere in the upper Santa Clara River watershed. However, since arundo and tamarisk tend to spread downstream, it is best to begin projects at the headwaters of the mainstem of the Santa Clara River and smaller tributary watersheds such as San Francisquito Canyon to ensure effective invasive plant removal. Ideally, the collective effect of the individual projects will eventually be to control invasive plant populations in the watershed.

There are other factors that influence the project site beyond its location in the watershed. These include landowner cooperation, budget, scheduling, regulatory requirements, and many others. Prioritization of projects beyond starting at the highest known establishment should be oriented toward: 1) early detection and control of outlier establishments, 2) control and restoration of limited infestations where sensitive resources are located, and 3) control and restoration of large infesta-

tions.

Early detection and control of outlier establishments

This strategy concentrates on areas where arundo or tamarisk have small, limited infestations and do not have any upstream source populations. This strategy may be more time and labor intensive due to potentially difficult logistical issues such as hard to reach locations and/or careful hand-removal techniques of arundo or tamarisk to avoid impacts to wildlife. However, this strategy prevents dense establishment of invasive plant species where there is moderate to good habitat.

Control and restoration of limited infestations where sensitive resources are located

This strategy concentrates on areas where arundo or tamarisk have limited infestations and where sensitive resources are located. This strategy may be more time and labor intensive due to careful implementation of hand-removal techniques of arundo or tamarisk to avoid impacts to wildlife. However, this strategy also prevents dense establishment of invasive plant species where there is moderate to good habitat.

Control and restoration of large infestations

This strategy concentrates on areas where arundo or tamarisk are dense monocultures in order to completely eradicate their presence and to restore habitat. It may be easier and/or more cost-efficient to use mechanical removal techniques or broadcast foliar spraying in areas with thick infestations. This strategy allows the restoration of large areas, which previously had no habitat value.

6.0 Surveying and Mapping

Project applicants should develop detailed maps for their specific project areas. Maps are integral to effective eradication of establishments of invasive plant colonies. They are important for documenting the current vegetation status, detecting and tracking pioneer colonies of invasive plant clusters, and monitoring the level of success after invasive plant removal.

Effective mapping is a result of organized and consistent data collection. In planning an invasive species removal project, applicants should follow an established protocol for their data collection efforts. Data collection can be accomplished using field forms, aerial maps, photo documentation, and/or GPS units. Utilization of established protocols for data collection also facilitates the sharing of weed information with other agencies that have a stake in controlling and eradicating invasive plant species.

There are numerous mapping techniques with different protocols and different nomenclature (naming) systems. Maps can be prepared manually via the annotation of aerial photographs, or via various GIS software packages in tandem with GPS hand-held units for data capture. Maps may simply reflect the extent of infestations, or may also contain additional attribute information that further characterizes the infestation. Resources for current mapping protocols include the CDFA weed mapping handbook and The Nature Conservancy's Weed Inventory and Mapping System (WIMS), which is currently being adapted by Cal-IPC for California's wildland weeds. CDFG promotes vegetation mapping according to A Manual of California Vegetation (Sawyer and Keeler-Wolf 1995).

AMEC Earth and Environmental performed mainstem vegetation surveys and a preliminary tributary overview in Winter 2004-2005, which are both discussed within the text of this document. Condor Environmental performed tributary vegetation surverys in Fall 2005. Detailed maps are provided as individual files in the Appendices.

The vegetation mapping surveys undertaken by the VCRCD for the Upper Santa Clara River identified 43 vegetation series located within the 500-year floodplain of the mainstem. Vegetation falling outside of the 500-year floodplain was not mapped. Most of the mapped vegetation series were delineated on maps created from aerial photographs following the vegetation series listed in A Manual of California Vegetation (Sawyer and Keeler-Wolf 1995). However, several of the vegetation series incorporated in the SCARP were not derived from the preceding document, but were rather based on the dominant and associated plant species present (e.g., Pepper Tree).

The VCRCD has a long-term interest in the removal of invasive species from the Upper Santa Clara River watershed. As such, the VCRCD recommends that applicants follow an established protocol of data collection so that consistency of data can be achieved, and for ease of future monitoring efforts. Project applicants are encouraged to use the existing VCRCD maps not only for refer-

ence, but also as models for their own map products.

7.0 Working With Landowners

The majority of the mainstem of the upper Santa Clara River as well as the lower middle reaches of the tributaries are privately owned. A cooperative working relationship with private landowners is critical in order to address the areas of heavy infestations. Several large landowners such as Lennar-LNR and various sand and gravel mining companies own substantial portions of the Santa Clara River. Hundreds of small- and mid-sized parcels are also located throughout the Santa Clara River's middle and upper reaches as well as the lower tributaries. These parcels include private campgrounds, mobile home parks, small ranches, and residential estates. The cooperation of both large and small landowners is essential for successful eradication. Landowners may not be aware of the impacts caused by invasive plants to public safety, property, and the environment. Education and outreach will increase knowledge of these impacts.

Landowners can work with Non-Governmental Organizations (NGOs), Resource Conservation Districts (RCDs), or other groups to perform removal work on their property. Agencies such as RCDs can assist with the regulatory process as well. Project applicants that do not own the property they wish to work on should request a cooperative landowner agreement prior to starting a project.

8.0 Public Outreach

Members of the public are often not aware of the negative impacts that invasive species bring to an ecosystem. The public typically assumes that the presence of any variety of greenery in the environment is beneficial and associates scenic value to it. Therefore, increasing public awareness of the impacts from these invasive species and support for their eradication is a critical component of project success. Public outreach activities should focus on a particular audience and have a specific goal, and individual projects should focus on outreach efforts prior to initiating removal. For example, local residents who live adjacent to removal sites should be notified of project activities, removal techniques, and potential impacts such as noise or visual changes before the commencement of the project.

Various organizations and municipalities are already engaged in outreach activities supporting the removal of invasive plants as well as the preventative measures that help reduce the spread of these plants. CAL-IPC is a non-profit organization that works with the California Department of Food and Agriculture's (CDFA) Weed Management Areas (WMA) and other local agencies to educate the public and municipalities on invasive plants and their eradication. Additionally, the Los Angeles Weed Management Area has created a Best Management Practices for Vegetation Removal as well as a children's booklet on invasive plants. There are numerous brochures from the various agencies on how to prevent the spread removal invasive plants. See Chapter 19.0 for resource information.

Where arundo is targeted for removal from private parcels, personal contact with parcel owners must be made to in order to gain access to removal sites. Landowners are often concerned about the impacts the removal activities will cause, and care should be taken to acknowledge and address their concerns. While one-on-one meetings may be time consuming, they are a beneficial investment towards a successful removal program. Typical landowner concerns include issues relating to privacy, liability, property damage, impacts to natural resources, erosion, and regulatory problems.

When removal projects are planned for sites that

are adjacent to developed areas, especially residential zones, it is important to notify or otherwise communicate with residents about the removal activities. Tolerance and support of residents for removal projects is enhanced via outreach and education efforts. This can be achieved via an informational postcard mailing, or by distributing brochures or handouts on a door-to-door basis.

The success of outreach efforts can be enhanced by incorporating the following points:

- Understand Your Audience: Do not assume individuals are versed in issues pertaining to invasive plant species. Present the information in a manner that is informative and engaging. Photographs and other visual cues are often very helpful in illustrating important points.
- Keep It Basic: Focus on primary issues. Over whelming your audience with information may not necessarily inspire them to join your cause. However, casting illumination on the most important issues will initiate a constructive increase in awareness of the problem.
- Be Context Aware: If members of the public initiate casual dialogue about a removal project with you, a casual response will be more appropriate than a technical monologue.
- Signage: Post signs where removal work is already underway. Incorporate photos that illustrate "before" and "after" scenarios to reinforce the benefits of the project.

For its own arundo removal efforts, the VCRCD has initiated several public outreach activities; selected examples are listed below:

- Prepared and distributed brochures containing information about arundo and tamarisk and the problems they cause, as well as the benefits of removal.
- Held public workshops such as those associated with the EIR/EA scoping in January 2005, as well as more recent workshops in Santa Clarita and Acton about the infestation problem in general.
- Created the SCARP Working Group to facilitate community and agency coordination on this issue.
- Contacted local schools to educate students about invasive plants and Weed Awareness Week.
- Sent out postcards to local residents around the Santa Clarita project site to inform them about the various aspects of the individual project.
- Held two public hearings inviting comments regarding the EIR/EA.
- Participated in the Santa Clara River Rally, a river clean-up event organized by the City of Santa Clarita.

Another important aspect of public outreach is the utilization of local resources. Various organizations and municipalities already support the removal of invasive plant species, and many have implemented preventative measures to reduce the spread of these species. The events they organize help raise public awareness about specific environmental hazards and the measures being taken to remove them. The VCRCD has participated in many such events in an effort to bring additional attention to the Upper Santa Clara River project . The various agencies and/or events that address invasive species are listed below:

- City of Santa Clarita sponsored events such the Santa Clara River Rally, Arbor Day, and Earth Day
- Los Angeles County sponsored events such as the County Fair and Earth Day
- Los Angeles County Weed Management Area Meeting
- Southern California Wetlands Recovery Project (SCWRP) Task Force Meetings
- Santa Clarita Organization Planning for the Environment (SCOPE)
- Friends of the Santa Clara River
- The Nature Conservancy
- Sierra Club
- California Native Plant Society
- Audubon Society
- Santa Clarita Well Owners Society
- Local Schools

9.0 REGULATORY SETTING

A primary goal of the SCARP is to facilitate the permitting of arundo and tamarisk removal projects by state and federal regulatory agencies, consistent with protection of sensitive resources. VCRCD is coordinating with regulatory agencies to develop a programmatic regulatory framework for future removal projects. As this process may take several years, individual permits may be necessary for removal projects. The following discussion provides an overview of the primary existing regulatory structure covering removal projects. Table 5 provides guidance for individual project applicants for regulatory compliance on their projects.

9.1 U.S. Army Corps of Engineers

Under Section 404 of the Clean Water Act (CWA), a permit is required by USACE for any activity that results in discharge of dredged or fill material into "waters of the United States (U.S.)" and associated wetlands. Waters of the U.S. refers to water in drainages that occurs below the plane of the ordinary high water mark. Examples of dredged or fill material for the SCARP projects that would be subject to USACE regulation would include earthmoving associated with temporary water diversions, temporary access roads, and below-ground biomass removal. Different permitting options are available through the USACE. For example, Regional General Permit (RGP) 41 is an existing permit for no or minimal impact invasive plant removal projects for infestations greater than 50 percent cover. Project sites with infestations lower than 50 percent or which have more than minimal impacts require another type of 404 permit such as a nationwide or individual permit.

9.2 U.S. Fish and Wildlife Service

Species listed as endangered or threatened by the USFWS are protected under the Federal Endangered Species Act (FESA). If listed species could be affected by removal activities, consultation with the USFWS is required. Consultations result in a set of formalized protection measures that become a part of the project.

9.3 California Department of Fish and Game

Streambed Alteration Agreement

Pursuant to Section 1602 2 of the Fish and Game Code, the CDFG has jurisdiction over activities that affect the "bed, channel, or bank of any river, stream, or lake that has or benefits fish or wildlife". CDFG jurisdiction includes streamside (riparian) habitat on top of banks as well as the drainage itself.

California Endangered Species Act

The California Endangered Species Act (CESA) provides protection to endangered and threatened species in California. If a project may affect state-listed species, coordination with CDFG is required. In some cases, an incidental take permit may be required.

9.4 Regional Water Quality Control Board

A project that requires a Section 404 permit from the USACE will also require a Water Quality Certification (401 certification) from the RWQCB. A 401 permit certifies that the proposed activity will not violate state or federal water quality standards.

9.5 Southern California Air Quality Management District

Projects that propose controlled burning or incineration of biomass require consultation of the Southern California Air Quality Management District.

9.6 California Department of Transportation Encroachment Permit

The use of California State highways for other than normal transportation purposes may require written authorization from the Department of Transportation. As the responsible Department for protecting the public's investment in the State highway system, CalTrans reviews all requests from utility companies, developers, volunteers, nonprofit organizations, etc., desiring to conduct various activities within the right of way.

9.7 Los Angeles Department of Public Works Encroachment Permit

Project sites that utilize areas owned by or having easements by the Los Angeles Department of Public Works will require an encroachment permit. Road Construction permits are necessary for the construction of driveways, curb drains, sidewalks, curbs and gutters and other types of surface construction. Road Excavation permits are necessary when digging within the road right-of-way, which often includes the portion of land beyond the curb and all the way to the sidewalk. Road Encroachment permits are necessary when you wish to place anything in the road right-of-way temporarily or long term.

9.8 Los Angeles County Grading Permit

The Los Angeles County Building Code requires a grading permit to perform any grading except for the following work:

An excavation that: 1) is less than 2 feet (61 cm) in depth or; 2) does not create a cut slope greater than 5 feet (1.5 m) in height and steeper than 1 unit vertical in 2 units horizontal (50% slope) and does not exceed 50 cubic yards (38.3 m^3).

A fill not intended to support structures and which does not obstruct a drainage course if such fill (a) is placed on natural grade that has a slope not steeper than five horizontal to one vertical and is less than 1 foot (30.5 cm) deep, or (b) is less than 3 feet (91.4 cm) in depth at its deepest point, measured vertically upward from natural grade to the surface of the fill, and does not exceed 50 cubic yards (38.2 m^3), or (c) does not exceed 20 cubic yards (15.3 m^3) on any one lot.

9.9 California Environment Quality Act

The California Environmental Quality Act (CEQA) is intended to provide information to public agencies, decision-makers, and the public regarding the environmental impacts from implementation of a proposed project. CEQA compliance is required for all local and state public agencies, municipalities, and private entities that undertake an activity, which requires a permit, or discretionary approval from a government agency, or that may cause either a direct physical change in the environment or a reasonably foreseeable indirect change in the environment.

The environmental review process was established to enable public agencies to evaluate a project in terms of its environmental consequences, to examine and implement methods of eliminating or reducing any potentially adverse impacts, and to consider alternatives to the project. While CEQA requires major consideration be given to avoid environmental impacts, the lead agency and other responsible public agencies must balance adverse environmental effects against other public objectives, including social and economic goals, in determining whether and in what manner a project should be approved.

Projects using the methods in this long-term plan may utilize the SCARP programmatic EIR once the programmatic permit structure has been developed. Other projects may require a CEQA exemption, negative declaration, mitigated negative declaration, or environmental impact report.

9.10 National Environmental Protection Act

The National Environmental Protection Act (NEPA) requires federal agencies to consider potential environmental consequence of proposed actions in their decision-making process. The law's intent is to protect, restore, or enhance the environment through well-informed federal decisions. Projects which require a permit or discretionary approval from a federal agency will also require NEPA compliance.

The regulatory process may involve a significant investment of time. Table 5 is provided as a planning aid and offers an example illustration of the amount of time applicants can expect to use for this phase of their projects.

Table 5: Guide to Regulatory Compliance

Timeline	Task
1-2 months	Use SCARP to develop project and choose removal or control method.
1-6 months depending on scope and scale of project, engineered design, and other project elements.	Develop project description, including analysis of impacts, avoidance, and minimization measures.
1- 2 months	Complete and submit application materials for: 404 permit (USACE); 401 certification (RWQCB); 1602 Streambed Alteration Agreement (CDFG)
1-3 months depending on agency availability	Agencies require additional information or modification to application or project description. Coordinate with agencies to modify application or project description as necessary.
1-2 months	Agencies accept revised application or project description.
After receipt of complete application	USACE begins consultation with USFWS
3 months to over a year depending on type of consultation	USFWS issues Letter of Concurrence or Biological Opinion.
Usually within 3 months of completed applications and completed consultation with USFWS	Agencies issue permits.
Upon receipt of all permits	Implement project

10.0 Removal Methodology

A wide range of techniques is currently used in the control and removal of arundo and tamarisk. These include hand removal, mechanical removal, herbicide application, tarping, controlled burning, and biological control, as well as various combinations of these techniques. Based upon a review of available literature and contact with different agencies and specialists, it has been determined no single method has been proven most effective for every situation. Different agencies and organizations involved in control of arundo and tamarisk tend to favor differing approaches to control and removal based on their experience, resources, and local environmental and policy circumstances. This is also reflected in the literature, where different researchers have noted variable findings for the effectiveness of different techniques.

For example, the Santa Margarita and San Luis Rey Watersheds Weed Management Area (SMSLRWMA) rely primarily on a fall-period foliar spray application, followed by spring biomass removal for arundo removal. The SMSLRWMA reports this method as having the highest success rate for their arundo infestation problem (Giessow 2005). In contrast, in its initial focused projects, the VCRCD has used various methods, including foliar spray application or the cut and daub technique accompanied by biomass removal, with chipping and reuse of the arundo mulch outside the stream channel. Other groups, such as Circuit Rider Productions, prefer tarping as a non-herbicidal approach, and have found it highly effective on smaller stands of arundo.

Ultimately, the selection of the appropriate removal method for each project will depend upon:

- the time of year
- severity of infestation
- the presence of native plants and wildlife
- the degree of intermixing of invasive species with sensitive native habitats
- the presence of sensitive native species
- access
- proximity to surface water
- budget
- permitting standards

Regardless of the method chosen, all projects will require follow-up treatments and monitoring, and have the potential to impact sensitive species in certain habitat areas. Due to the range of variables that influence the control and removal of these invasive species, and the differences among opinion on which techniques are the most effective and environmentally appropriate for a given circumstance, the SCARP presents a menu of options for different removal techniques. Each technique is described in terms of typical procedures involved and the general circumstances where it is usually employed including a discussion of the general pros and cons of each approach, which is summarized in Table 6.

The general analysis of the pros and cons of available control options is further refined in terms of their potential utility for application to various reaches of the Santa Clara River and its associated tributaries. For planning purposes, the Santa Clara River has been subdivided into six reaches (Chapter 3) based on similar traits such as channel morphology, water availability, vegetation types, and surrounding uses and access. Each major tributary is treated individually with the major tributaries broken into upper, middle, and lower reaches where appropriate based on differing physical characteristics.

The Santa Clara River's reaches and its tributaries vary considerably not only in terms of physical and ecological characteristics, but also in degree of infestation, intermixing of invasive species with native habitats, environmental sensitivity, and access. These factors in turn guide, but not entirely limit, the choice of removal options preferable for a certain reach. For example, the environmental sensitivity of a certain reach may warrant use of more labor intensive but environmentally sensitive techniques (e.g., cut and daub) and limit the widespread use of more intrusive techniques (e.g., mechanical clearing), particularly during the bird breeding season. However, sub-sections of this reach may be less sensitive and warrant consideration of mechanical clearing or other more invasive approaches. For this reason, the methods section is generally inclusive in terms of available techniques. However, regardless of the technique selected, all potential options are accompanied by an extensive list of BMPs in Chapter 14.

Table 6: Summary of Removal Method Options

Method	Appropriate Use	Timing	Tools	Instructions	Advantages	Disadvantages
Hand Removal (Above-Ground only)	Small infestations where there is concern regarding herbicide use.	Removal can be performed anytime, but most effective time to cut arundo and tamarisk is during the growing season (spring through fall). Rain and high water can limit wet season access.	Loppers, machete, chainsaw, bladed weed whipper, or similar equipment.	Stems, canes, and trunks are cut as close to the ground as possible. Cut biomass is generally removed from the project site and chipped, burned, or disposed of at a landfill to prevent reestablishment of cuttings. Roots and rhizomes are left in the ground.	Specific, minimizes damage to native plants/ animals. Minimizes soil disturbance.	Labor and time intensive. Very low mortality rates require repeated re-treatment (>5 years) to be effective which increases the project cost and frequency of disturbance to sensitive areas. Extensive debris removal.
Hand Removal (Above and Below-Ground)	Young plants and small stands, or when there is concern about herbicide use.	Removal can be performed anytime. Rain and high water can limit wet season access.	Pick-axe, mattock, shovel, loppers, machete, chainsaw, picks, or similar equipment.	Above-ground trunks, stems, or canes are first cut near the base. After clearing the material, roots and rhizomes are dug up using hand tools.	Specific, minimizes damage to native plants/animals. Effective if rhizomes and root masses are thoroughly cleared from site.	Labor and time intensive. Requires careful cleaning of roots/ rhizomes and debris removal. Soil disturbance and erosion potential.
Mechanical Removal (Above-Ground only)	Areas with easy access for heavy equipment and on stands not intermixed with native plants.	Removal can be performed anytime, but most effective time to cut arundo and tamarisk is during the growing season (spring through fall). Rain and high water can limit wet season access.	Tractor-mounted mower, towed disc, plow, flail mower, or similar equipment.	The stalks, stems, and canes are cut using the mower, disc or plow as close to the ground as possible. Cut biomass is removed from the project site immediately following cutting to prevent reestablishment of the cut material. Roots and rhizomes will remain in the ground.	Effective biomass removal for extensive stands.	Very low mortality rate requires repeated re-treatments. Extensive manual debris removal necessary when biomass is large enough to resprout. Requires site access by equipment.
Mechanical Removal (Above and Below-Ground)	Areas with easy access for heavy equipment and on stands not intermixed with native plants.	Removal can be performed anytime. Rain and high water can limit wet season access.	Backhoe, excavators or other heavy machinery.	A backhoe or tractor is to be used to simultaneously remove the plants and their root system. If roots/rhizomes remain, the equipment can be used to excavate these larger segments. Hand crews using shovels can dig out smaller fragments.	Effective if rhizomes and root masses are thoroughly cleared from site. Effective for removing very large establishments in open and accessible terrain.	Extensive debris removal. Major soil disturbance and erosion potential. Possible impacts to native wildlife and plant species. Requires site access by equipment.
Tarping	Small stands (<0.25 acres) not intermixed with native plants.	Tarps applied in late spring/ early summer and remain for up to 5 months, usually from June to November.	Chainsaws, machetes, loppers, or similar equipment to cut plants. Opaque thick tarps or pond liners, stakes or weights to hold tarps down.	Stalks and branches should be cut within inches of the ground. Chipped biomass should be placed over cut stalks. The opaque tarp or pond liner is laid over the cut material and secured with stakes or weights. The tarp remains on the target area for a period of five months and is then removed. Dead biomass is removed from the project area and roots and rhizomes are left in the ground.	High success rate when properly applied. Available for active channel areas. Minimizes soil disturbance. Effective on small stands.	Application of method is limited by size of stand. May damage soil microorganisms. Not appropriate for areas that may flood (i.e. channel).
Foliar Spray or Basal Bark Treatment	Any size stand not intermixed with native plants or where herbicide applicators can avoid native plants.	Apply herbicide anytime, but most efficient in early fall through winter when plant energy is transferred to roots. Herbicide should be applied on dry days and during low winds.	Herbicide, applicators such as backpack sprayer, ATV-mounted boom sprayer, spray rig, helicopter, or similar equipment.	Crews apply herbicide using sprayers or wicking on leaves and stems of arundo and foliage or basal bark of tamarisk. Follow herbicide label instructions. Personnel must be trained in the use and handling of herbicides. Timing of application is dependent upon type of herbicide used.	Short duration of labor. Low concentrations of herbicide. Effective on any size of stand. Minimizes soil disturbance.	Risk of drift to non-target plants and wildlife or adjacent sensitive receptors. Herbicide application should not be used in areas where there is great concern regarding herbicide use. Weather conditions must be suitable for herbicide application.

Method	Appropriate Use	Timing	Tools	Instructions	Advantages	Disadvantages
Cut and Paint/Daub	Any size stand. Allows– allows controlled application of herbicide on stands heavily intermixed with native plant species.	Apply herbicide anytime, but most efficient in early fall through winter when plant energy is transferred to roots. Herbicide should be applied on dry days and during low winds.	Chainsaws, loppers, or similar equipment can be used for cutting. Herbicide. Paintbrushes, sponge daubers, or similar equipment for herbicide application.	Trunks, stems, and canes of arundo and/or tamarisk are cut within one foot of the ground and removed. Herbicides is applied to the cut stem surface using brushes or daubers. Timing of application is dependent upon herbicide used. Follow herbicide label instructions. Personnel must be trained in the use and handling of herbicides.	Very high mortality rate. Efficient use of herbicide. Highly selective with little risk of drift of herbicide onto non-target plants or sensitive wildlife species. Little soil disturbance.	Very labor intensive. High concentrations (90-100%) of herbicide. Extensive debris removal is often required. Higher initial labor and herbicide costs than other methods, although less retreatment is required. Weather conditions must be suitable for herbicide application.
Cut, Resprout, and Spray or Paint/Daub	Any size stand not intermixed with native plants or where herbicide applicators can avoid native plants.	Cut one to two months prior to spraying. Apply herbicide when resprouts are 2-4 feet tall, but most efficient in early fall through winter when plant energy is transferred to roots. Herbicide should be applied on dry days and during low winds.	Loppers, chainsaws, flail mower, or similar equipment for cutting. Herbicide. Paintbrushes, sponge daubers,, applicators such as backpack sprayers, ATV-mounted boom sprayers, spray rigs, helicopter, or similar equipment for herbicide application.	Trunks, stems, and canes of arundo and/or tamarisk are cut within one foot of the ground and removed. Herbicide is applie Apply herbicide after a sufficient period has elapsed (approximately one to two months) to allow for re-sprouting. Follow herbicide label instructions. Personnel must be trained in the use and handling of herbicides.	Low soil disturbance associated with this method if hand tools are used. Less risk of herbicide drift than when spraying full-grown canes.	Waiting for resprouts after cutting can be impractical when working in remote areas. Large equipment (such as flail mowers) can substantially disrupt the soil and damage native, non-target species and habitat. Weather conditions must be suitable for herbicide application.
Cut and Spray	Any size stand not intermixed with native plants or where herbicide applicators can avoid native plants.	Apply herbicide anytime, but most efficient in early fall through winter when plant energy is transferred to roots. Herbicide should be applied on dry days and during low winds.	Loppers, chainsaws, flail mower, or similar equipment for cutting. Herbicide. Backpack sprayers, applicators such as backpack sprayer, ATV-mounted boom sprayers, spray rigs, or similar equipment for herbicide application. .	Crews will cut plant to four or five feet and then apply herbicide using hand held sprayers on leaves and stems of arundo and foliage or basal bark of tamarisk. Personnel must be trained in the use and handling of herbicides.	Moderate mortality rate. Minimizes soil disturbance. Minimizes risk of drift onto non-target species.	Biomass removal is labor intensive. Stalks intended for spraying may be trampled. Weather conditions must be suitable for herbicide application.
Controlled Burning	Large stands of pure arundo and tamarisk or for girdling of individual tamarisk trees.	Removal can be performed anytime.Anytime. Burning is most effective during growing season.	Flamethrowers weed burners, or similar equipment. Fuel.	Crews to either broadcast burn large stands or employ flamethrowers or weed-burners to spot treat small clusters, or heat-girdle stems at the base of individual plants. For larger controlled burns, fire crews would likely be required to monitor fires to prevent unintentional spread. . Fires applied during the rain season may help prevent spread of wildfires.	Highly effective in removing biomass.	Requires permits to perform burns and repeated burning to control biomass. Low mortality rates make it ineffective as sole or primary tool. Large potential for regrowth. Potential for associated collateral impacts to native habitat and wildlife. Risk of fire spread to non-intended targets. Arundo and tamarisk readily recover from fire which allows them to out-compete native riparian vegetation in post-fire circumstances.

Method	Appropriate Use	Timing	Tools	Instructions	Advantages	Disadvantages
Controlled Burning with Herbicide Treatment	Large stands of pure tamarisk.	Removal can be performed anytime.Anytime. Burning is most effective during growing season. Herbicide application most effective in the fall through winter.	Flame throwers or weed burners, or similar equipment. Fuel. Herbicide, sponge daubers, paintbrushes, and backpack sprayers.	Crews Controlled burning involves using crews to either broadcast burn large stands or employ flamethrowers or weed-burners to spot treat small clusters, or heat-girdle stems at the base of individual plants. For larger controlled burns, fire crews would likely be required to monitor fires to prevent unintentional spread. Fires applied during the rain season may help prevent spread of wildfires. Herbicide is then may be applied to cut canes or stumps, or applied to resprouts after a sufficient period has elapsed (approximately one to two months). Personnel must be trained in the use and handling of herbicides.	Highly effective in removing biomass.	Requires permits to perform burns. Potential for associated collateral impacts to native habitat and wildlife. Risk of fire spread to non-intended targets. Weather conditions must be suitable for herbicide application.
Grazing	Large stands of pure arundo or tamarisk where herbicide use is a concern.	Anytime. Most effective during growing season.	Grazing animals such as goats, temporary fencing.	Although grazing can be used to reduce or eliminate tamarisk sprouts and reduce arundo growth, this technique requires focusing the grazers on areas with high densities of the target vegetation. This may require fencing, herding, or other techniques to ensure that the method is effective and that grazers do not target native vegetation.	If grazing animals are readily available, then may be effective temporary control of new growth. Provides animal forage.	Labor and time intensive. Very low mortality rates require repeated re-treatment (>5 years) to be effective which increases the project cost and frequency of disturbance to sensitive areas. May be difficult to focus grazing on target species. Concentrated areas of animal waste may cause negative impacts to treatment areas.
Biological Control	Control of large infestations.	Dependent upon pathogen or species released.	Dependent upon pathogen or species released.	Biological control would involve the controlled release of a pathogen, or insect species from these plants' native range to feed upon, create disease in, or otherwise impair the growth, spread, and/or reproduction of arundo and tamarisk. All such biological controls are monitored and regulated by the USDA and it would be necessary to coordinate with that agency.	When implemented, biological control is expected to be effective in controlling the spread of infestations, but may not be extremely effective in the eradication of the target species populations.	No biological control agent is approved for use in the upper Santa Clara River for either arundo or tamarisk as of this writing.

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11.0 Herbicides

The range of herbicides available for use on arundo and tamarisk infestations is limited due to the label restrictions of application to wildlands. However, application of herbicides can be one of the most effective tools for control and eradication of these invasive plants. Most herbicides work by disrupting amino acid production in plants. As humans and wildlife do not share these same metabolic pathways, herbicide function is not directly relevant to health risk assessment. Herbicides are effective when used alone to control infestations, but are often used in conjunction with other techniques such as cutting or mowing. The use of herbicides can substantially increase mortality rates of persistent invasive plants, reducing the need for invasive hand or mechanical excavation of roots and rhizomes and associated soil disturbances. However, the utility of herbicide application in control of arundo and tamarisk can be affected by its relatively high initial cost, restrictions on use in proximity to water, the degree of intermixing of invasive plants with natives, and the presence of sensitive species. These factors can all restrict the type of herbicide allowed, the location and timing of use, and the method of application.

The success of herbicide application primarily depends upon selecting the appropriate herbicide for the task and closely adhering to label directions. Many herbicides are prohibited for use around open water and all may exhibit seasonal variations in effectiveness. The most effective method of application can vary between brands and types of herbicides. Most herbicides require the use of a surfactant, which may be included in the product or added prior to application to increase effectiveness. Colorants are also often added to herbicide solutions to enable spray crews to see where they have sprayed after initial evaporation of the solution. The USEPA and the California Department of Pesticide Regulation (CDPR) must register the herbicides prior to their use in California. Further, the large-scale application of herbicides must be overseen by a licensed professional. Appendices 9 and 10 contain detailed descriptions of herbicides, issues surrounding application, and appropriate techniques for application.

The three herbicides most commonly used in the eradication of arundo and tamarisk in riparian areas of Southern California are glyphosate, triclopyr, and imazapyr. While these herbicides are available under a variety of brand names, the focus of our discussion pertains specifically to these respective active ingredients. Formations of glyphosate and triclopyr for use near aquatic habitats are available, and a formulation of imazapyr is pending for use near water. Different mixtures of these herbicides are effective under different circumstances as discussed in more detail in Appendix 9.

11.1 Glyphosate

Glyphosate can be used to treat arundo and tamarisk is the active ingredient in the retail products such as Aquamaster®, Rodeo®, Glypro®, and Roundup®. The USEPA has approved Rodeo® and Aquamaster® for use in aquatic environments, making glyphosate one of the primary herbicides currently available for use when surface water is present. Roundup®, conversely, is only approved for use in areas where water is not present.

Glyphosate is most effective when used on perennial plants, such as arundo and tamarisk, when applied in the late summer and fall when the plant is entering dormancy, as this permits transmission of the herbicide to the plant's root system (Sonoma Ecology Center 1999).

11.2 Imazapyr

Imazapyr can also be used to treat arundo and tamarisk and is the active ingredient in Stalker® and the new aquatic habitat formulation, Habitat®. Imazapyr is a non-selective herbicide used for the control of a broad range of weeds including terrestrial annual and perennial grasses and broadleaved herbs, wood species, and riparian and emergent aquatic species (Tu, et al. 2001). a low potential for leaching into groundwater. It has low toxicity to invertebrates and is non-toxic to fish, mammals, and birds (USFS 1995). Unlike glyphosate, it can damage adjacent non-target plants, with the exception of conifers, by transfer between root networks.

11.3 Triclopyr

Triclopyr can be used to treat tamarisk and is a selective systemic herbicide. It has little or no impact on

grasses (e.g. arundo). Triclopyr is the active ingredient in Garlon® and Pathfinder® formulations, and is known as Access® in other states. Garlon® 4 and Pathfinder® II are approved for terrestrial habitats. Garlon® 3A is approved for use in closed aquatic habitats such as wetlands and lakes. It is not allowed for use on streams and rivers. It is recommended for use within 300 feet of water by the USFWS.

11.4 Adjuvants

Herbicides generally need to be applied with an adjuvant. There are several types of adjuvants including surfactants, non-foaming agents, and colorants. A surfactant is any compound that is added to an herbicide formulation or tank mix to facilitate the emulsifying, dispersing, spreading, wetting, or other properties of a liquid by modifying its surface characteristics (Vencill 2002). Surfactants, also known as stickers/spreaders, are similar to detergents in their action, reducing water surface tension to allow wetting and penetration of the plant tissues. The surfactant helps to achieve optimum herbicide adsorption into and adherence from the herbicide onto the plant. Surfactants may also improve an herbicide's efficacy so that the concentration or total amount of herbicide required to achieve a given effect is reduced, sometimes as much as five- or ten-fold (Tu et al. 2001). In this way, adding an appropriate surfactant can decrease the amount of herbicide applied and lower total costs for weed control (Tu et al. 2001). All herbicide labels recommend surfactants and other additives to improve herbicide effectiveness. In some cases, the herbicide will already have the surfactant included, but in other cases, it will be necessary to buy one. Herbicide applicators should check the label prior to adding surfactant. USEPA regulated adjuvants should be approved by the regulatory agencies. Non-ionic surfactants, such as Agridex®, are recommended by the USFWS.

12.0 Access and Staging Areas

Staging areas are often utilized during larger removal projects. Staging areas are used for the storage of and servicing of equipment, the chipping and temporary storage of biomass, and the subsequent loading of chipped material onto trucks for removal from the project area. Staging areas are typically 0.25 to 0.5 acres in size.

Staging area selection is based on available space, ease of access from surrounding roads, ease of access to the eradication site, and the least potential to conflict with adjacent land uses. Permission for use of each staging area may need to be coordinated with the appropriate landowner. Staging areas are typically enclosed with orange construction fencing, or by a six-foot-tall chain link fence to prevent unauthorized access and to ensure public safety.

Staging areas should be located outside of the 25-year floodplain on the upper terrace, levee, or bank of the river or tributary where removal is occurring. In staging areas where chipping is not compatible with surrounding land uses (i.e., near residences, schools, and parks), chipping should occur at the nearest staging area that is appropriate for chipping. Each staging area may be used to accommodate equipment storage and maintenance, portable sanitation facilities, emergency decontamination kits, and handheld equipment when not in use. Unsecured herbicides should be removed from the staging areas each night. All handheld equipment, including chainsaws and backpack sprayers, should be removed from the staging area at the end of each work day and not left at the project site. If large equipment, including ladders, tractors, chippers, and booms, are to be left at the work site overnight, they should be stored in the staging area. Large equipment should also be kept in the staging area when not in use. All maintenance and refueling activities should be performed within the staging areas to minimize risk of leakage/spills.

13.0 Disposal Options

Arundo and tamarisk biomass may be disposed of in a variety of ways.

13.1 Drying

Treated biomass is stacked at staging areas and completely dried, so it is no longer viable and able to resprout. The dried biomass can be left at the site, burned, chipped, or taken to a landfill for permanent disposal. Biomass may be left in piles in upland areas outside the 25-year floodplain to enhance wildlife habitat for small mammals only if cut prior to seed production. If left on site, biomass should be monitored for re-growth. Drying may not be appropriate for rhizomes due to their ability to resprout when exposed to moisture, even after long periods of drying,

13.2 Chipping

A chipper is used at the staging area, or on the banks of the river or tributary, or within the river channel itself (often directly into the back of trucks) to shred the arundo canes or smaller tamarisk branches. The chipper should be placed at an appropriate distance from potentially sensitive groups and all noise reduction accessories should be employed. The biomass may either be stacked and dried before being fed into the chipper, or may be fed into the chipper while still green. It is recommended that a large chipper be used as arundo can break the blades of smaller chippers. Chipped arundo biomass is suitable for beneficial reuse as mulch if chips are less than four inches, as longer segments often still remain viable Chipped tamarisk biomass may be contaminated with seed or salt (from foliage). It is recommended that tamarisk mulch be allowed to dry for two weeks to ensure seeds are no longer viable. Chipped biomass of arundo or tamarisk may also be disposed of off-site in a landfill for permanent disposal.

13.3 Incineration

Disposal of biomass occurs by burning cut material (that has not been chemically treated) at the staging area after the biomass has dried. Incineration requires obtaining a permit from the Los Angeles County Fire Department and the Los Angeles Air Quality Management District and would only be appropriate outside of fire season. Incineration should only be used under low wind conditions. Necessary fire control equipment (e.g., extinguishers, water hoses, etc.) should be on hand to prevent any unintended spread of the fire.

13.4 Landfill Disposal

The cut biomass is transported off-site to a landfill for permanent disposal. Chiquita Canyon Landfill is the closest landfill to the project area available for use. Landfills typically charge per load or by ton, which can add to the overall project cost.

13.5 Beneficial Re-use

13.5.1 Commercial and Cottage Industries

Removed arundo stalks may occasionally be sold for commercial purposes. Manufacturers of reeds for woodwind instruments, as well as those producing pressed board and paper products often have an interest in aquiring cut arundo canes. Arundo biomass may also be used to handcraft flutes, walking canes, and other such items as part of a cottage industry. However, as the overall goal of any removal project is to eradicate arundo, the sale of cut arundo for profit, and the development of commercial distribution channels is not encouraged. Project applicants who are approached by commercial entities who either wish to acquire the cut biomass, or who offer cutting/harvesting services, should only undertake such arrangements after entering into contract negotiations with the commercial entity. Appendix 12 lists guidelines that should be included in such a contract.

13.5.2 Cogeneration

Dried arundo and tamarisk biomass may be used as an environmentally friendly fuel in cogeneration power plants. However, and as mentioned above, the establishment of arundo for commercial applications is not encouraged as the overall goal is to eradicate arundo.

14.0 BEST MANAGEMENT PRACTICES AND MITIGATION MEASURES

Although the primary goal of arundo and tamarisk eradication programs is to improve habitat quality, some eradication techniques have the potential to negatively impact native habitat surrounding, and within, the project footprint. BMPs are intended to reduce the ecological cost of eradication projects and minimize deleterious impacts, while allowing the most appropriate eradication techniques to be used. Regulatory permits require implementation of BMPs. Most BMPs are implemented at the time work is conducted in the field, however some can be implemented prior to commencement of work.

The BMP project checklist provided below (Table 7) is designed to facilitate the application of BMPs for all possible projects. The list is based on three elements that will need to be considered for each project before it is implemented:

(1) how invasive species are to be removed from the project site;
(2) how the biomass of dead invasive plants will be disposed of and removed from the project site after treatment; and
(3) what types of sensitive species are either present or have the potential to be present on the site.

Note that all general BMPs shall be applied to all projects, no matter how small, in order to ensure that removal of invasive species does not adversely affect the remaining habitat quality. To use the checklist, answer the questions in gray bars, and see the text sections of the SCARP referred to next to the answer.

14.1 General BMPs

The following general BMPs are applicable to all removal scenarios and must be implemented for all related projects.

14.1.1 Limits to Site Disturbance

- All projects will coordinate with the regulatory agencies to obtain appropriate permits.
- Work area will be limited to smallest area possible.
- Vehicle use will be limited to the maximum extent possible. If vehicles are to be used, rubber-tired vehicles are preferred over tracked equipment.
- Soil disturbance will be limited to the maximum extent possible.
- Native vegetation and tree damage or removal will be limited to the maximum extent possible.
- No project activities will occur in flowing or ponded water.
    - If water must be crossed, an appropriate spanning method such as a temporary bridge consisting of planks or a steel grate/plate is to be used.
    - If work must occur in areas of flowing or ponded water, approved techniques for water diversion are to be used prior to beginning project activities.
- Staging areas will be located outside the active channel on the upper terrace, levee, or bank of the river or tributary.
- Staging areas will be located in compacted and de graded areas, preferably near access points when site conditions allow.
- Movement of personnel and equipment will be limited to designated work zones, staging areas, and access roads.
- Access points will be located at pre-existing ramps/roads, in areas infested with non-native or invasive plant species, or in areas that are already degraded. Areas with compacted soil will be used preferentially over areas with loose soils. Soil from access points infested with noxious species will be compacted, and biomass from such access points will be mulched to avoid distribution of seeds.

14.1.2 Site and Personnel Management

- All OSHA (Occupational Safety and Health Administration) regulations will be followed by project personnel.
- Chemical toilets for personnel shall be kept in staging areas during removal activities.
- Project activities will be limited to normal business hours.
- Extraneous noise will be limited to the maximum

extent possible (e.g., radios for entertainment).

- Equipment and machinery use will comply with all applicable local noise ordinances and policies.
- Smoking will not be allowed on site.
- Pets of project personnel will not be allowed on site.
- Prior to removal activities, treatment areas will be marked, and signs will be clearly posted along access points to the project site.
- Signs will be posted on affected trails for a sufficient time to warn trail users of heavy-duty equipment crossings. The signs will be posted on either side of the active access and shall be maintained for the entire period of project-related trail use.
- Signs and flaggers shall be used in areas where equipment use would access high speed roads (e.g. blind corners).
- All neighbors within 100 feet of proposed areas will receive notice of proposed projects one month before start of work.

14.1.3 Personnel Education

- All project personnel will be briefed on environmental concerns regarding the project, including the use of herbicides, appropriate work practices (including spill prevention and response mesures), and other measures needed to minimize project impacts. Personnel will be informed of the

Table 7: BMP Checklist

*	All general BMPs (Section 14.1 and all sub sections) must be adhered to at all times.	
1	How will invasive species be removed from the project site?	
	Biomass Removal	14.2.1
	Herbicides	14.2.2
	Foliar Application	14.2.3
	Cut and Paint	14.2.4
	Cut and Spray Resprouts	14.2.5
	Tarping	14.2.6
	Controlled Burning	14.2.7
	Biological Control	14.2.8
	Grazing and Herbivory	14.2.9
2	What method of biomass disposal will be used?	
	Drying	14.3.1
	Chipping	14.3.2
	Incineration	14.3.3
	Landfill Disposal	14.3.4
3	If sensitive species are present on site, what type? (For a description of sensitive species see Section 4.0, Biological Resources.)	
	Birds	14.4.1
	Amphibians/Reptiles	14.4.2
	Fish	14.4.3
	Plants	14.4.4

locations of foot and vehicle access paths, areas that are sensitive, and areas that are closed to access. The construction contractor shall monitor all construction-related activities to ensure that all of the environmental protection measures are followed throughout initial project activities and subsequent activities.

- All project personnel will participate in an educational program to identify the target plant species (arundo or tamarisk), incidental noxious plant species on the site, and native plant species on the site prior to proposed activities.
  This training will include how the target and incidental plant species are distributed in order to prevent spread of viable biomass.
- If special status plant or wildlife species (or species of concern) occur on site, a qualified biologist will conduct an educational program on how to avoid impacts to these species for all project personnel prior to proposed activities. This training will cover a description of all listed species (or species of concern), which occur within the project boundary and their habitats. This training shall also include a description of the applicable regulations such as the ESA and the State Fish and Game regulations, the need to adhere to these regulations, penalties associated with violations, and measures being implemented to conserve the species within the project area.

14.1.4 Air and Water Quality And Site Contaminant Prevention and Control

- All vehicles will observe a maximum speed limit of 15 miles per hour or lower at the project site and staging areas to avoid generation of dust.
- Appropriate dust suppression methods will be used during on-site removal activities. Recommended methods include application of water, use of wind break enclosures, covers on soil piles and dump truck loads, use of silt fences, and suspension of earth-movement activities during high wind conditions.
- Emissions from construction equipment will be controlled by adherence to the recommended maintenance schedules for each individual equipment type. Repairs to malfunctioning equipment will be made as soon as possible.
- All trash items will be enclosed in sealed containers and regularly removed from the site.
- Disposal of project waste materials such as trash, used equipment, oil, grease, and chemicals will be done in accordance with federal, state, and local regulations.
- Erosion control measures (e.g., silt fencing, mulch, matting, soil binder, seeding) will be implemented as appropriate to inhibit sediment transport into the waterways.
- If work is to occur during the rainy season, no work will occur unless there is a three-day clear weather forecast. No work will occur during rain events.
- No unchipped biomass greater than four inches in length will be left overnight within the stream channel.
- Stockpiled biomass, loose soil, or other debris will not be left overnight within the stream channel or on its banks. If stockpiled biomass must be left overnight, it will be moved to staging areas.
- All equipment and clothing will be inspected and cleaned at the end of each work day to prevent the further spread of invasive species.
- Herbicide storage during application, and the fueling and lubrication of mechanical equipment will be confined to staging areas.
- All vehicles and equipment shall be moved to a staging area or removed from the site overnight.
- Immediate control, containment, and cleanup of fluids and herbicides due to spills or equipment failure (broken hoses, punctured tanks, etc.) will be implemented. All contaminated materials will be disposed of promptly and properly to prevent contamination of the site. To reduce the potential for spills, the refueling of portable equipment shall occur within a contained area. Where that is not possible, barriers shall be placed around the site where the fuel nozzle enters the fuel tank. The barriers shall be such that spills shall be contained and easily cleaned up. Refueling activities shall ensure that the potential for spillage from overfilling, nozzle removal, or other action is minimized to the extent feasible.

14.1.5 Biological Resources (If Listed Species or Species of Concern Have Potential to Occur)

- If listed species or species of concern have potential to occur in the area, the project manager shall coordinate with the appropriate resource agencies and a qualified biologist to conduct surveys and implement measures to avoid impacts.
- If listed species or species of concern are known to occur in the area, a qualified biologist will be retained to recommend measures to protect these species such as the project scheduling, delineation of the work area, staging area, and access points.
- If listed species are present, a qualified biologist will monitor project activities as directed by regulatory agencies.
- Impacts to nesting birds per Migratory Bird Treaty Act (MBTA) will be avoided by:
- the cessation of work during bird breeding season (March 15 – September 15);
- the performance of surveys by a qualified biologist to determine presence/absence of nesting birds prior to undertaking work;
- the establishment of appropriate exclusionary buffers around nests, if present.

14.2 Technique-Specific BMPs

14.2.1 Biomass Removal

- Target species' canes/trunks will be cut to less than twelve inches in height and straight across to prevent sharp points from injuring project personnel or the public.

14.2.2 Herbicides

- A DPR licensed Pest Control Advisor (PCA) will prepare a written recommendation for the use of all materials/herbicides on agricultural areas (as defined by CDPR); the recommendation will be submitted to the Los Angeles County Agricultural Commissioner's Office.
- All material/herbicide usage on agricultural areas (as defined by CDPR) will occur only as directed by the written recommendation from a licensed PCA.
- Only herbicides registered for use in California by the EPA and the DPR will be used.
- Only herbicides approved for aquatic use may be used within the banks of rivers and tributaries. Roundup® may not be used within the active channel of rivers and tributaries.
- All adjuvants will be registered by the EPA and approved for use by the resource agencies.
- Herbicide application will be conducted only by personnel with an operator identification number from the Agricultural Commissioner's Office or supervised by a DPR certified or licensed Qualified Applicator (QAC or QAL).
- Herbicide usage will be limited to the minimum amount required to be effective.
- Herbicides shall be applied according to the manufacturer's label specifications.
- Herbicides will be colored with a biodegradable dye to facilitate visual control of application.
- Avoidance measures such as pulling back or temporarily tarping desired vegetation will be used to the extent feasible to prevent unintended herbicide impacts.
- Herbicides will be secured or removed from staging areas at night.

14.2.3 Foliar Application (Full Stands, Cut Stands, Resprouts)

- Herbicide will not be applied when conditions are windless or greater than ten miles per hour (mph).
- Herbicide will not be applied if air temperature exceeds volatization limits of herbicide, unless adjacent native species are protected (e.g., tarped).
- Tarps shall be used to cover desired vegetation (to the extent feasible) to prevent unintended herbicide impacts.
- Booms or ladders will not be employed for foliar spraying within 200 feet of residences, parks, schools or similar sensitive receptors. Foliar spray applications shall be limited to the cut and spray technique within this setback.

14.2.4 Cut-and-Paint

- See BMPs for biomass removal and herbicides.

14.2.5 Cut and Spray Resprouts

- See BMPs for biomass removal and herbicides.

14.2.6 Tarping

- Target species' canes/trunks will be cut to less than twelve inches in height and straight across to prevent sharp points from injuring project personnel or the public.
- Mechanical equipment will not be driven over tarped areas.
- Tarps shall be manually transported into seasonally and perennially wet areas.
- Tarping material will be removed and disposed of properly after completion of the project.

14.2.7 Controlled Burning

- This method will be used in compliance with all local laws and regulations and will be conducted in conjunction with the local fire department and AQMD.
- Adjacent land uses and land ownership will be considered prior to implementing controlled burns.
- All controlled burns will be conducted during the rainy season.
- All controlled burns will be supervised by qualified fire personnel.
- All controlled burns will be conducted during low-wind conditions.
- Adjacent landowners will be notified prior to implementing controlled burns.

14.2.8 Biological Control

- Biological control vectors will not be released without USDA approval.

14.2.9 Grazing and Herbivory

- The use of grazing animals shall be restricted to areas outside of flowing water with a minimum setback of 50 feet for grazing from any flowing water.
- Grazing will be controlled by erection of temporary fencing to restrict grazing animal to the target area.

14.3 Storage and Disposal Methods

14.3.1 Drying

- Drying of biomass will occur outside of the active channel at designated staging areas.

14.3.2 Chipping

- All chipped biomass will be disposed of off site in a landfill or will be used as mulch.
- All measures shall be taken to reduce the noise of chipper and to prevent noise disturbance to potentially sensitive receptors.
- Necessary measures shall be taken to reduce and control dust generated by chipping.
- Chipping shall occur on staging areas only with prior approval of the appropriate landowner and/or agency.

14.3.3 Incineration

- All federal, state, and local laws and provisions regarding incineration of biomass shall be followed, including those of the local fire department and AQMD.
- All incineration will take place at appropriate designated locations.

14.3.4 Landfill Disposal

- Cut biomass is transported off-site to a landfill for permanent disposal. Chiquita Canyon Land fill is the closest landfill to the project area avail able for use. Landfills typically charge per load or by ton, which can add to the overall project cost.

14.4 Threatened and Endangered Species-Specific BMPs

14.4.1 Birds (Western Yellow-Billed Cuckoo, Southwestern Willow Flycatcher, California Condor, Least Bell's Vireo, Coastal California Gnatcatcher)

- Project activities (e.g., application of herbicide, mechanical trimming, and/or removal, etc.) shall be conducted between 15 September and 15 March to avoid impacts to listed bird species such as least Bell's vireo and southwestern willow

flycatcher during the breeding season, or shall provide a 500 foot radius buffer around each nest, if either species is present.

- Noise levels will not exceed 60 dBA (A-weighted decibel scale) within 500 feet of nests.

14.4.2 Amphibians (Arroyo Toad, California Red-legged Frog)

- No work will be conducted within areas of known or potential arroyo toad habitat during the breeding season (February to August).
- Vehicles and equipment shall be removed from the habitat before sunset in sensitive amphibian areas.
- Stockpiles of biomass will not be kept in habitat areas, but will be moved to upland areas outside the 25-year floodplain immediately to minimize amphibian and reptile usage.

14.4.3 Fish (Unarmored Threespine Stickleback, Santa Ana Sucker)

- No work will occur in flowing or ponded water.
- Grading and excavation will be set back a minimum of 50 feet from the edge of the active channel. Grazing areas will be fenced to prevent animals from entering water. The boundaries of excavated projects will be demarcated by temporary construction fencing or flagged stakes.

14.4.4 Plants (e.g., Nevin's Barberry, Slender-Horned Spineflower, Spreading Navarretia)

- All listed plant locations will be fenced to avoid disturbance and accidental damage/mortality.
- Herbicides will not be used near known or probable locations of sensitive plant species.

Areas identified as potential special status plant habitat will be surveyed by a qualified botanist prior to commencing work.

15.0 Maintenance and Monitoring

Arundo and tamarisk are aggressive invasive plants with an extraordinary ability to spread, reproduce, and thrive under a wide range of conditions. As such, any removal program for substantial infestations requires a long-term commitment of resources, repeated treatments, and ongoing monitoring in order to be successful (Table 8). This adds to the overall cost of removal efforts, but without such repeated treatments and monitoring, successful removal projects can quickly experience reinvasion, with the potential for a treated area to return to a pre-removal condition, sometimes within a few years.

The issue is exacerbated within the upper Santa Clara River watershed because extensive infestation increases the chance of re-infestation from offsite sources. Therefore, all removal methods will require at least three years of continuous monitoring and follow-up treatments. Even approaches with high initial mortality rates such as cut and daub/paint will require this extent of monitoring, and likely follow-up treatments in spots. For methods with lower mortality rates, monitoring times and the number of required re-treatments may increase to five years. Monitoring site visits are recommended quarterly for the first year and biannually for years two to five.

Table 8: Comparison of Re-Treatment Requirements of Removal Methods

Method	Average 1st Year Mortality Rate	Level of Re-Treatment Effort Required	Average Number of Re-Treatments Required
Hand Above-Ground Removal	<50%	Same as initial treatment.	>5
Hand and Mechanical Above-Ground Removal	5-50%	Varies depending on success of initial treatment. Potentially the same as initial treatment.	>5
Mechanical Above-Ground Removal	<50%	Same as initial treatment.	>5
Mechanical Above- and Below-Ground Removal	5-50%	Varies depending on success of initial treatment. Potentially the same as initial treatment.	>5
Tarping	50-95%	Few resprouts – little effort.	At least 3
Foliar Spray	50-95%	Few resprouts – little effort.	3-5
Cut and Spray or Paint/Daub	50-90%	Few resprouts – little effort.	3-5
Cut, Resprout, and Spray	~50%	Some resprouts – close to the same amount of effort as initial treatment.	3-5

The level of intensity, duration, and frequency of required re-treatment depends on many factors such as the skill of the crews involved, initial budget, etc. As such, this table is provided for general reference only.
Source: Sonoma Ecology Center 1999.

16.0 Habitat Restoration and Revegetation

There are two types of revegetation: passive and active. Passive revegetation means there will be natural recruitment from native species while active revegetation means introducing native species by planting seeds, cuttings, or container stock.

Passive revegetation means replanting by natural processes. Surrounding native plant habitats provide seed sources for propagation. Once the competition of arundo or tamarisk is removed, native species will continue to propagate and grow there. This method requires the least effort and expertise to restore native riparian vegetation. It also doesn't require repeated disturbance for maintenance and ensures the revegetation of local genetic stock. However, passive revegetation may take several years or more to become established. If invasive plants are established upstream of the project area or in surrounding areas, the site is at risk of being repopulated by invasive plants.

Passive revegetation is most appropriate when:

- There are native plant and seed sources, either on-site or upstream.
- The site does not contain extensive disturbed, unvegetated, exposed ground that would attract non-native pest plants.
- The soils are stable and at low risk of erosion.
- The site tends to flood each year, allowing nearby native plant material to settle and become established.

If these conditions exist, passive revegetation may be a more appropriate use of time and resources than active revegetation.

Active revegetation means collecting and planting seeds, cuttings, or container stock. Active revegetation is recommended for sites are located on upper banks where natural recruitment is unlikely to occur or on areas which have erosion problems. Project sites should be monitored during removal activities for natural recruitment of native species. Supplemental water or irrigation may be required. Active revegetation is often planned after removal activities have been completed to avoid impacts to newly planted vegetation. Active revegetation may take from three to five years.

Active revegetation is most appropriate when:

- The site is located downstream from, or near invasive plant species. In such cases, prompt revegetation with natives may be necessary to prevent reinvasion of the treated site.
- The soil or stream bank is unstable and at high risk of erosion.
- A landowner strongly desires a privacy screen.
- There are special status species utilizing the project area.
- Natural recruitment is not providing species diversity.

There are several different revegetation techniques. Depending upon the project site conditions and desired habitat diversity, a combination of revegetation techniques may be used. Active revegetation alone may not provide sufficient soil or bank stabilization. Soil retention materials and stabilizing structures may be needed to adequately prevent erosion and bank failure. In such cases, materials such as erosion control fabrics and engineered structures should be considered before engaging in invasive plant removal. For structural changes, consult with a professional engineer or landscape architect, or a government agency such as Resource Conservation Districts.

Depending upon the level of habitat restoration desired and various individual project factors, the project costs will vary. A successful revegetation project will provide habitat, include a diverse set of plant types and species, reduce erosion, and require minimal annual management (CDFG 2003). If revegetation of a project site is intended, it is advisable to plan ahead to obtain local native plant material, grow container stock if necessary or prepare seeds for planting, and create a schedule for planting and maintenance. Planting cuttings or container stock usually works well for species that do not germinate well from seed or need intensive seed preparation. Seeding can be applied to species that germinate well from seed. It is important to consider the species diversity and local genetics when planning the plant palette. Native plant material such as seeds and cuttings should be obtained from the project site or as close as possible. Site preparation may include reducing the weed seed bank in the soil by herbicide application or disking prior to seed set. If there is a large

weed seed bank, this process may be performed several times. Planting or seeding is usually performed in the fall season to take advantage of rains for germination and encourage root growth. If rains are late, revegetation may occur in the winter or early spring. If planting or seeding is performed at another time of year, supplemental water or irrigation should be considered (Sonoma Ecology Center 1999).

Revegetation techniques include:

- Hand broadcasting of native grass, forb, and/or shrub seed mixes
- Hydroseeding of native grass, forb, and/or shrub seed mixes, may also contain binders for erosion control
- Drill, imprint, or pit seeding
- Direct planting of tree or shrub seeds
- Planting of tree and/or shrub cuttings
- Planting of tree, shrub, forb, and/or grass container plants

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16.1 Planting Methods

16.1.1 Broadcast Seeding

Broadcast seeding can be performed by hand, with hand-held or rolling broadcast seeders, or larger broadcasters towed by all-terrain vehicles or tractors. The soil bed should be prepared prior to seeding. If there is compaction, the soil should be disked or tilled. Also, the soil should be raked before and after seeding to incorporate the seeds into the soil. If available, large equipment such as a harrow and a ring roller can assist with working the seeds into the soil and enhance soil compaction after seeding. The seeding rate for broadcast seeding is usually 25 to 30 pounds per acre.

Drill or Imprint Seeding

Dry seeding can also be performed with large equipment such as drills, imprinters, or pitters. A tractor-drawn drill makes small furrows, deposits seeds in the furrows, and covers the seed with soil. Drills come in different sizes and types with attachments to improve seeding different species. Imprinters have a hydraulic wheel system with different seed boxes and a roller with teeth. These allow for diverse seed mixes and fertilizer or mycorrhizal inoculum to be applied at the same time. Both of these seeding applications can be faster and more uniform than broadcast seeding. The seeding rate for drilling or imprinting is usually 12 to 18 pounds per acre.

16.1.2 Hydroseeding

Hydroseeding uses hydraulic equipment to spread a wet mixture of seeds, fertilizer, mycorrhizae, erosion control binder, and green daya dye. This method can seed a large area quickly. The hydroseed mixture can be applied from a turret on top of a truck while driving or with a hose. Hydroseeding is most effective during the fall or early spring when rains will encourage germination. However, if supplemental water is available, it can be applied at other times of the year. It is important for the components of the hydroseed mixture to be correctly combined in appropriate proportions and the soil

bed is prepared prior to application. The California Native Grass Association recommends a two step process: 1) applying seed, a small amount of virgin wood fiber mulch, mycorrhizal inoculum, compost , and an organic time-released fertilizer first and; 2) applying a second layer of wood fiber and compost to cover. If erosion control is necessary on steep slopes, apply a third layer of rice or native straw with a tackifier.

16.1.3 Transplanting Emergent Plants

Rushes, sedges, and tulles are often called "emergent" plants since they usually emerge from water. These plants may grow from seeds or spread by rhizomes, which makes them good candidates for transplanting. Plants with intact rhizomes should be harvested in the winter or early spring. Several small clumps from a variety of larger clumps should be taken to ensure the parent population will survive and to include genetic diversity in the new planting area. Collected plant material should be stored in moist soil and transplanted within a reasonable time. Collected specimens should be planted in a large enough hole to accommodate the entire rhizome, soil should be packed around the rhizome, and thoroughly watered. Above ground portions of plant should be trimmed to stimulate growth.

16.1.4 Planting Cuttings

Willows, cottonwoods, Mexican elderberry, and many other riparian species can be planted from cuttings. These plants have the ability to grow roots from stems. Cuttings should be made when plants are dormant during winter months. Cuttings should be sliced so that the inner side of the branch is at an angle to indicate the end that will be planted in the ground. The cuttings may be a variety of sizes with different diameters and lengths depending upon the plant species and the location of the planting. Cuttings should have several viable buds along the stem in order to ensure new growth. Cuttings may be stored in water until ready to use, grown in water until roots appear, or planted as container stock. Cuttings should be planted in soil with angled, cut side down (buds should be pointing up) with three-quarters of the cutting in the ground and one-quarter exposed. If holes are augured, fertilizer or mycorrhizal innoculum may be added to the hole or mixed with the backfill soil before planting. Cuttings can also be driven into the ground with a mallet if soil is soft. Damage to the top of cuttings may be, sliced off.

16.1.5 Planting Container Plants

Container plants may be ordered in a wide variety of species from a native plant nursery. Ideally, container stock with be grown from locally collected plant material. Container plants will require supplemental water – from either winter rains or irrigation. Holes should be dug twice as wide and twice as deep as the container plant. In addition, fertilizer or mycorrhizal innoculum may be added to the hole or mixed with the backfill soil before planting. The hole should be firmly backfilled to depth of the rootball, and then the container plant placed inside.

17.0 Developing a Budget and Schedule

17.1 Cost of Removal

Removal costs vary greatly and are influenced by many factors including the extent and degree of infestation, labor rates, the ease of site access, the removal method employed, the frequency, duration, and level of effort required for follow-up treatments, biomass transport distances, and disposal techniques. Typical costs associated with various arundo and tamarisk removal methods are not well documented and can vary greatly from project to project. Removal of minor or isolated stands of arundo or tamarisk can often be accomplished relatively inexpensively (less than $2,000 per acre). However, current available methods which are suitable for successful removal of major infestations are all relatively expensive, ranging in price from approximately $2,500 to $9,500 per acre, depending on many variables. Techniques with the highest initial mortality rates and the lowest resultant follow-up monitoring and re-treatment costs tend to be the most expensive in terms of up-front costs, but the least expensive over longer periods. A project checklist is provided in Table 9.

Because such a wide range of factors affect removal project cost, it is not possible to provide precise estimates. Similar removal methods employed under generally similar circumstances can even exhibit variations in cost if just one key factor, such as difficulty of access or material transport, increases substantially due to factors such as distance or variable landfill tipping fees.

17.2 Cost Effectiveness

The SCARP proposes several methods for removal. Each method has advantages and disadvantages in different respects. Public agencies need to balance needs across the entire geographic area under their jurisdiction, as issues of social justice and environmental justice are important considerations in public and private policy and planning. (LAWMA 2005).

Although there may be certain concerns over the use of herbicides in the environment, this method may be more cost-effective in terms of funds and time. However, local communities or organizations may choose non-chemical methods of control, which may not be as cost-efficient. These groups have options to obtain additional funding for alternative methods of control such as volunteer programs and grants.

Development of a project schedule is an integral component to any removal project. Table 9 is provided as a planning aid and offers examples of the steps applicants can expect to incorporate in their projects.

18.0 Funding

There are several ways to fund invasive plant removal projects. Local agencies and non-profit organizations may apply for funding through grants, restoration loans, cost-share programs, in-lieu fees, mitigation banking, or through alternative sources. Individual landowners should contact their local agencies or NGOs for grant or cost-share opportunities.

18.1 Grants

Grants are provided by governmental agencies or NGOs. There is usually a lengthy process for the application of grants. The process may take up to two years before funding is obtained. Each source will have different applications and contract requirements. There may be a two-part application, which consists of a pre-proposal or conceptual proposal and a final proposal if the pre-proposal is accepted. Grants often need to have matching funds provided by donated cash, labor, or equipment.

Some agencies and organizations that provide grants are listed below:

- State Water Resources Control Board
- National Fish and Wildlife Foundation
- State Resources Agency
- California Department of Parks
- Recreation Land and Water Conservation Fund
- Habitat Conservation Fund
- Natural Resource Conservation Service

Websites, which provide information regarding available grants, are listed below:

- http://www.epa.gov/watershedfunding
- www.calwatershedfunds.org
- http://www.invasivespecies.gov/toolkit/grants-info.shtml

Table 9: Project Checklist

PREPARATION	
	Choose site - from headwaters down
	Obtain Landowner Cooperative Agreement
	Perform site assessment - level of infestation, potential for wildlife, staging areas, access
	Prepare project description - site plan, maps, choose removal/disposal methods, BMPs
	Survey project boundary
	Determine level of CEQA and which permits are necessary
	Complete vegetation/habitat surveys
	Complete wildlife surveys
	Complete sensitive species surveys
	Prepare CEQA - Initial Study, Negative Declaration, Mitigated Negative Declaration, Environmental Impact Report
	Contact resource agencies and prepare permits, including fees - CDFG, USACE, RWQCB, USFWS, AQMD, LADPW
	Prepare SWPPP
	Prepare specifications - safety, access to water, ingress/egress, removal methods, transport, disposal
	Prepare maintenance and monitoring plan
	Prepare bid package
	Contact youth groups such as CCC or City Corps for labor
	Notify and educate any surrounding residents via postcards, brochures, or handouts.
CONSTRUCTION	
	Mobilization - move in equipment, portable restrooms, signage, security fencing
	Clear & grub - staging areas, access roads, debris removal
	Construct access roads - equipment, dust/weed issues, watering truck for dust control
	Dewatering, if necessary
	Remove invasive species - labor, equipment, & herbicides
	Biological monitoring
	Transportation - to staging area (equipment & labor)
	Disposal - landfill, chipping/landfill, chipping - onsite/offsite mulch, incineration (equipment, landfill fees, transportation costs)
	Clean up, deconstruct access roads
	Demobilization - move out equipment, portable restrooms, signage, security fencing
MAINTENANCE & MONITORING (3- 5 years)	
	Remove invasive species - labor, equipment, & herbicides
	Biological monitoring
	Transportation - to staging area (equipment & labor)
	Disposal - landfill, chipping/landfill, chipping - onsite/offsite mulch, incineration (equipment, landfill fees, transportation costs)
	Annual reports to resource agencies
	Management

- http://www.wcb.ca.gov
- http://www.cdfa.ca.gov/phpps/ipc/weedmg-mtareas/Funding/funding_hp.htm

Further information regarding available public and private grants can be obtained from the Foundation Center Libraries (http://fdncenter.org). Locations of these libraries include:

Ventura County Community Foundation
Funding and Information Resource Center
1355 Del Norte Road
Camarillo, CA 93010
(805) 988-0196

California Community Foundation
Funding Information Center
606 S. Olive St. Suite 2400
Los Angeles, CA 90014-1526
(213) 413-4042

Los Angeles Public Library
West Valley Regional Branch Library
19036 Vanowen Street
Reseda, CA 91335
(818) 345-4393

Santa Monica Public Library
1343 Sixth Street
Santa Monica, CA 90401-1603
(213) 458-8859

18.2 Resource Loans

The State Water Resource Control Board has low interest loans for restoration and conservation projects. The Federal Water Pollution Control Act (Clean Water Act or CWA), as amended in 1987, provides for establishment of a State Revolving Fund (SRF) loan program. The program is funded by federal grants and State bond funds. The purpose of the SRF loan program is to implement the CWA and various State laws by providing financial assistance for the construction of facilities or implementation of measures necessary to address water quality problems and to prevent pollution of the waters of the State. The SRF Loan Program provides low-interest loan funding for construction of publicly-owned wastewater treatment facilities, local sewers, sewer interceptors, water reclamation facilities, as well as, expanded use projects such as implementation of non-point source (NPS) projects or programs, development and implementation of estuary Comprehensive Conservation and Management Plans, and storm water treatment. There is more information available on the website: http://www.swrcb.ca.gov/funding/srf.html.

18.3 Cost-Share Programs

The NRCS has two cost-share programs to assist private landowners perform restoration and conservation projects.

18.3.1 Environmental Quality Incentives Program – EQIP

The Environmental Quality Incentives Program (EQIP) provides a voluntary conservation program for farmers and ranchers that promote agricultural production and environmental quality as compatible national goals. EQIP offers financial and technical help to assist eligible participants install or implement structural and management practices on eligible agricultural land.

EQIP offers contracts with a minimum term that ends one year after the implementation of the last scheduled practices and a maximum term of ten years. These contracts provide incentive payments and cost-shares to implement conservation practices. Persons who are engaged in livestock or agricultural production on eligible land may participate in the EQIP program. EQIP activities are carried out according to an environmental quality incentives program plan of operations developed in conjunction with the producer that identifies the appropriate conservation practice or practices to address the resource concerns. The practices are subject to NRCS technical standards adapted for local conditions. The local conservation district approves the plan.

EQIP may cost-share up to 75 percent of the costs of certain conservation practices Incentive payments may be provided for up to three years to encourage producers to carry out management practices they may not otherwise use without the incentive. However, limited resource producers and beginning farmers and ranchers may be eligible for cost-shares up to 90 percent. Farmers and ranchers may elect to use a certified third-party provider for technical assistance. An individual or entity

may not receive, directly or indirectly, cost-share or incentive payments that, taken together, exceed $450,000 for all EQIP contracts entered during the term of the Farm Bill.

18.3.2 Wildlife Habitat Incentives Program - WHIP

This program is available for all landowners with less than $2 million income. The Wildlife Habitat Incentives Program (WHIP) is a voluntary program for people who want to develop and improve wildlife habitat primarily on private land. Through WHIP, USDA's Natural Resources Conservation Service provides both technical assistance and up to 75 percent cost-share assistance to establish and improve fish and wildlife habitat. WHIP agreements between NRCS and the participant generally last from five to 10 years from the date the agreement is signed.

WHIP has proven to be a highly effective and widely accepted program across the country. By targeting wildlife habitat projects on all lands and aquatic areas, WHIP provides assistance to conservation minded landowners who are unable to meet the specific eligibility requirements of other USDA conservation programs.

18.4 In-Lieu Fee Program

The in-lieu-fee program is a program run by the USACE to offset impacts to Waters of the United States, which are permitted under Section 404 of the CWA. In-lieu-fee mitigation occurs in circumstances where a permittee provides funds to an in-lieu-fee sponsor instead of either completing project-specific mitigation or purchasing credits from a mitigation bank approved under the Banking Guidance. Funds collected from the permittees under in-lieu-fee arrangements are used for replacing wetland and riparian functions and values and are not used to finance non-mitigation programs and priorities such as education projects or research. Currently no in-lieu-fee program agreements exist within the SCARP project area. To further research the in-lieu-fee program option or to develop an in-lieu-fee program, contact the USACE Los Angeles District office.

18.5 Mitigation Bank

Invasive weed removal can serve as compensatory mitigation for certain projects affecting aquatic resources and can be incorporated into the BMPs of many projects. The USACE, RWQCB, and CDFG can require permittees whose activities involve temporary or construction-related disturbance of aquatic areas to ensure that the disturbed areas are not invaded by arundo, tamarisk, or other weeds. This can help reduce proliferation of infestation, as often happens in recently disturbed areas. When on-site mitigation is not appropriate, the Corps can direct permittees to mitigate the impacts of their activities by removing invasive weeds in strategic areas of the watershed; thereby contributing to the overall control program. Wetland mitigation banks strive to establish large, contiguous wetland areas, which can be used to mitigate for a number of independent impacts. This allows eligible permittees to purchase compensatory mitigation credits from another entity that has already produced and banked them, thereby eliminating the need to produce compensatory mitigation areas on-site (ELI and IWR 1994). Mitigation banks advance effective regional habitat conservation by encouraging the bundling of mitigation "credits" at sites recognized to be high priorities for habitat protection and restoration in watersheds and ecosystems and provide a mechanism that assigns a monetary value to habitat, which in turn allows a landowner to obtain a financial return for conserving land rather than developing it. The USACE has been an active participant in the establishment a mitigation bank in the Santa Ana River, which is focused on invasive weed removal. The goal of the Santa Ana River Mitigation Bank (SARMB) is to reestablish native riparian ecological diversity and other riparian functions through the removal of invasive weeds. Currently, a mitigation bank has not been established for the Santa Clara River, although the SARMB may serve as a template for the development of one in the future.

19.0 Resources

The following list of resources provides further information and guidance to project applicants.

19.1 Local Agency and NGO Contacts

Large amounts of material already exist on the problems posed by arundo and tamarisk including the benefits of removal, and general approaches and techniques to successful removal. When combined with the detailed information contained in the SCARP document, ample information is available both to the public and to future project applicants. The primary points of contact for the public would be:

Ventura County Resource Conservation District
P.O. Box 147 (Mailing address)
3380 Somis Road (Street Address)
Somis, Ca 93066
(805) 386-4685

Antelope Valley Resource Conservation District
44811 N. Date Ave., Suite G
Lancaster, CA 93534
(661) 945-2604

Other agencies and organizations that can provide assistance are provided in Table 10.

Table 10: Agencies and Organizations Assistance

Agency or Group Name	Assistance Available	How to Contact
Los Angeles County Agricultural Commissioner	Regulates herbicide use. Provides information to obtain certification or licenses. Also provides Operator Identification Number and safety training for application of non-restricted materials.	(626)575-5471 12300 Lower Azusa Road Arcadia, CA 91006-5872 http://acwm.co.la.ca.us/
Southern California Air Quality Management District	May require permit for controlled burning or incineration of biomass. Advises days when burning can occur.	(909)396-2000 21865 Copley Dr Diamond Bar, CA 91765 http://www.aqmd.gov/
County or Local Water Districts	May require a permit to access properties.	(661)259-3610
California Conservation Corps (CCC) (Camarillo/Los Angeles/ Norwalk)	Eradication of invasive plants and restoration of native plants	(805)484-4345 1878 South Lewis Rd. Unit 60 Camarillo, CA 93010 http://www.ccc.ca.gov/
Los Angeles Conservation Corps	Eradication of invasive plants and restoration of native plants	(213)747-1872 P.O. Box 15868 Los Angeles, CA 90015 http://www.lacorps.org/
Concerned Resource Environmental Workers (CREW)	Eradication of invasive plants and restoration of native plants	(805)646-5085 P.O. Box 1532 Ojai, CA 93024 (No Website)
California Department of Fish and Game (San Diego)	Issues Streambed Alteration Agreements and consults for impacts to state listed species.	(916)445-0411 1416 Ninth Street Sacramento, California 95814 http://www.dfg.ca.gov/
California Invasive Plant Council	Provides information on non-native invasive plants in California.	(510)843-3902 1442-A Walnut St., #462 Berkeley, CA 94709 http://www.cal-ipc.org/

Agency or Group Name	Assistance Available	How to Contact
Los Angeles County or local Fire Department	Provides information for fire safety. May issue a burn permit.	(818)890-5783 12605 Osbourne St Pacoima, CA 91311 http://www.lacofd.org/
Natural Resource Conservation Service (Lancaster)	Provides information for erosion control, non-native plant removal, habitat restoration, and funding	(661)945-2604 44811 N. Date Avenue, Suite G, Lancaster, CA 93534 http://www.ca.nrcs.usda.gov
Antelope Valley and Ventura County Resource Conservation District	Provides information for non-native plant removal, habitat restoration, permitting, and funding	(805)386-4685 P.O. Box 147 Somis, CA 93066 http://www.vcrcd.org
Los Angeles County Public Works	Issues encroachment permits	(626)458-4300 900 South Fremont Avenue Alhambra, CA 91803 http://ladpw.org/wmd/
Team Arundo del Norte (Sonoma Ecology Center)	Provides information on eradication techniques, biology, grant information, regional eradication coordination	(707)996-0712 P.O. Box 1486 Eldridge CA 95431 http://www.sonomaecologycenter.org/
Arundo Task Force	Provides information on eradication techniques, biology, and grant information.	(805)386-4685 P.O. Box 147 Somis CA 93066 http://www.arundotaskforce.org
US Army Corps of Engineers (Los Angeles Region)	Issues Section 404 permit (for earthmoving or fill in stream)	213) 452-3908 P.O. Box 532711 Los Angeles CA 90053-2325 http://www.spl.usace.army.mil/
US Fish and Wildlife Service (San Diego)	Provides consultations for potential impacts to federal listed species and may have potential funding through Partners for Wildlife or Santa Clara River Trustee Council	1-800-344-WILD 2493 Portala Road, Suite B Ventura, CA 93003 http://www.fws.gov/
Regional Water Quality Control Board (Los Angeles)	Provides information on water quality issues and issues 401 Water Quality Certification (for earthmoving or fill in stream)	(213) 576-1364 P.O. Box 2815 Sacramento, CA 95812-2815 http://www.calepa.ca.gov/
US Bureau of Land Management	Potential funding through War on Weeds	(202) 452-5125 1849 C Street, Room 406-LS Washington, DC 20240 http://www.blm.gov/nhp/index.htm
City of Santa Clarita, Environmental Services Division	Provides information on City activities	(661)222-7222 23920 Valencia Boulevard, Ste. 300 Santa Clarita, California 91355 http://www.santa-clarita.com/
Los Angeles Weed Management Area	Provides information on weed management	(626)575-5471 12300 Lower Azusa Road Arcadia, CA 91006-5872 http://acwm.co.la.ca.us/

Agency or Group Name	Assistance Available	How to Contact
The Nature Conservancy	Provides information on eradication methods	(805)642-0345 3639 Harbor Boulevard, Suite 201 Ventura, CA 93001 http://www.tnccalifornia.org
California Native Plant Society (Ventura)	Provides information on California native plants	(916) 447-2677 2707 K Street, Suite 1 Sacramento, CA 95816-5113 http://www.cnps.org/
Society for Ecological Restoration (SER Cal)	Provides information on California native habitat restoration	2701 20th Street Bakersfield, CA 93301-3334 Tel. (661) 634-9228 http://www.sercal.org/
Chiquita Canyon Landfill	Closest landfill to the project area	3 miles west of Interstate 5 on State Route 126 in Santa Clarita Valley. http://www.chiquitacanyon.com

19.2 Books

The Nature Conservancy Handbook:

Weed Control Methods Handbook: Tools & Techniques for Use in Natural Areas

Cal IPC Handbook:

The Weedworker's Handbook: A Guide to Techniques for Removing Bay Area Invasive Plants

Team Arundo del Norte Handbooks:

Arundo: A Landowner Handbook

Controlling Arundo in Your Watershed: A Guide For Organizations

19.3 Web Resources

ARUNDO

NPS PCA	http://www.nps.gov/plants/alien/fact/ardo1.htm
SAWPA	http://www.sawpa.org/arundo/
SMSLRWMA - Arundo Biology	http://www.nps.gov/plants/alien/fact/ardo1.htm
Team Arundo del Norte	http://teamarundo.org/
TAdN Arundo Reference Library	http://teamarundo.org/research_reference/index.html#biblio
TNC - Arundo Stewardship Abstract	http://tncweeds.ucdavis.edu/esadocs/documnts/arundon.html
TNC - Arundo Images	http://tncweeds.ucdavis.edu/esadocs/arundona.html
USDA	http://plants.usda.gov/cgi_bin/plant_profile.cgi?symbol=ARDO4
USACE - Arundo Removal	http://www.wes.army.mil/el/pmis/plants/html/arundo_d.html

TAMARISK

CAIN NBII - Tamarisk	http://cain.nbii.gov/crisis/crisiscat/viewResource?resource=http://cain.nbii.gov%2Fcrisis%2Finvasive_terms%23Tamarix
Earlham College	http://www.earlham.edu/~biol/desert/invasive.htm
Invasive Species.gov - Saltcedar profile	http://www.invasivespecies.gov/profiles/saltcedar.shtml
Proceedings Saltcedar Workshop June 12, 1996	http://www.invasivespecies.gov/education/workshopJun96/index.html
NPS	http://www.nps.gov/plants/alien/fact/tama1.htm
TNC – Tamarisk Stewardship Abstract	http://tncweeds.ucdavis.edu/esadocs/tamaramo.html
USFS	http://www.fs.fed.us/database/feis/plants/tree/tamspp/all.html
WA NWCB	http://www.nwcb.wa.gov/weed_info/saltcedar.html
USACE	http://www.wes.army.mil/el/pmis/plants/html/tamarix_.html

INVASIVE PLANT ORGANIZATIONS

Cal IPC	http://www.cal-ipc.org/
California Weed Management Areas	http://www.cdfa.ca.gov/phpps/ipc/weedmgtareas/
L.A. County Weed Management Area	http://acwm.co.la.ca.us/scripts/wma_2.htm
Santa Barbara County Weed Management Area	http://www.countyofsb.org/agcomm/wma/
Santa Margarita & San Luis Rey Weed Mgmt	http://smslrwma.org/
Invasive Species Information Node (ISIN) of the NBII	http://invasivespecies.nbii.gov/
Noxious Weed Information Project	http://www.cdfa.ca.gov/phpps/ipc/noxweedinfo/noxweedinfo_hp.htm
Center for Invasive Plant Management	http://www.weedcenter.org/
NPS - Monitoring Invasives	http://science.nature.nps.gov/im/monitor/invasives.htm
USACE Aquatic Plant Control	http://www.wes.army.mil/el/aqua/
SFWI NIS Guidebook	http://www.sfei.org/nis/NISguidebook.pdf
TNC Weed Removal Handbook	http://tncweeds.ucdavis.edu/handbook.html
Global Invasive Species Specialists Groups	http://www.issg.org/

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DRAFT
2013 Comprehensive Water Resources Report

Prepared for:

CITY OF VENTURA

Prepared by:

RBF Consulting,
a Company of Michael Baker Corporation

RBF CONSULTING
A Baker Company

2013 COMPREHENSIVE WATER RESOURCES REPORT

DRAFT Report

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February 2013

EXECUTIVE SUMMARY

Introduction

On July 26, 2010 Public Works conducted a workshop with City Council that included information on the City's current water supply issues. It was presented that with continued years of drought, tightening water restrictions and environmental responsibilities, Ventura's water supply was being impacted by several factors. These factors included and continue to include the following:

- The City's historical water rights to the Ventura River may be significantly limited as concern for the health of the endangered Southern California Steelhead and its habitat ecosystem restrict how much and at what time of the year this water source is available. Storm events over the past 15 years have restricted our ability to withdraw historical amounts from this source.
- City allocation from two groundwater basins, Oxnard Plain Basin and Santa Paula Basin, are increasingly regulated and monitored. Studies being conducted by the oversight agencies have indicated that potential overdraft and water quality issues may occur in the near future.
- The Mound Groundwater Basin has experienced water quality degradation and projections for reliable supply may be lower than originally anticipated.

A recommendation from the workshop was to provide a comprehensive evaluation of current and projected water supply needs.

In addition, as a part of this year's City Council Priority Projects, the Community Development (Planning) Department and Ventura Water have focused their time and energy on streamlining and documenting the development review process as it pertains to water and wastewater services. More specifically, we are working to:

- Ensure transparency and consistency to our customers,
- Create equity in assigning costs; and
- Protect the reliability of our water and wastewater infrastructure.

In order to provide a comprehensive evaluation of the City's current and projected water supply needs, Ventura Water has been engaged with the City's Planning Department to provide their input and expertise on what development has taken place since the 2005 General Plan, the pace of proposed development and what water demands those developments may require. This Report will review previously developed water demand projections, anticipated water supplies and planned development projects and compare

them to where the City is today for each of these three categories. City staff is collaboratively looking forward to help plan the City's water resources to accommodate future development in the most responsible manner for its customers.

Purpose

The main purpose of this report is twofold. The report will identify water demand and water supply conflicts in various reports and will evaluate how current and future anticipated water demands match current and future anticipated water supply. Ventura Water and Planning recognize the need to develop a process that tracks proposed development projects, consistently calculates the anticipated increase in water demand associated with each proposed development project, and the evaluates the impact on the current water supply. This Comprehensive Water Resources Report ("Report") is intended to be a tool in the development review process as it pertains to water supply and demand.

Water Supply

The City's potable water supply is derived from local groundwater basins, Lake Casitas and sub-surface water from the Ventura River. The City also has a 10,000 acre-foot per year allocation from the California State Water Project. To date the City has not received any of this water because there are no facilities to get the water to the City. There are presently five local water sources that provide water to the City water system:

- Casitas Municipal Water District (Casitas)
- Ventura River Foster Park Area (Foster Park)
    - Surface Water Intake
    - Upper Ventura River Groundwater Basin/Subsurface Intake and Wells
- Mound Groundwater Basin (Mound Basin)
- Oxnard Plain Groundwater Basin (Fox Canyon Aquifer)
- Santa Paula Groundwater Basin (Santa Paula Basin)

The City also provides recycled water from the Ventura Water Reclamation Facility (VWRF).

Estimated Water Demand

Based on the known supply conditions and the calculated water demand for the present condition, it appears that the current water demand exceeds the available supply. However, it is apparent that the "calculated" water demand for the current condition (22,754 AFY) is overly conservative. The current water demand figures calculated within this Report utilize a baseline water demand from 2005 of 20,808

AFY. Based on the FY 2011-2012 water consumption data, it is likely that the City's current water demands are closer to 17,300 AFY, below the current available supply of 19,600 AFY.

Utilizing development projections developed as a part of the 2005 General Plan, the anticipated growth in water demand through 2025 is 4,020 AFY, which results in a total projected water demand of 26,774 AFY, well above the predicted 24,200 AFY of supply (which is on the high end of the range). The future water demand projections utilize the water demand factors published in the 2005 General Plan FEIR. The demand factors are "planning-level" numbers, and therefore are on the conservative side. It is likely that the actual water demand factors are much lower than those used to project the future demands.

Figure ES-1 provides a graphical representation of the current water consumption, water demand projections and water supply range.

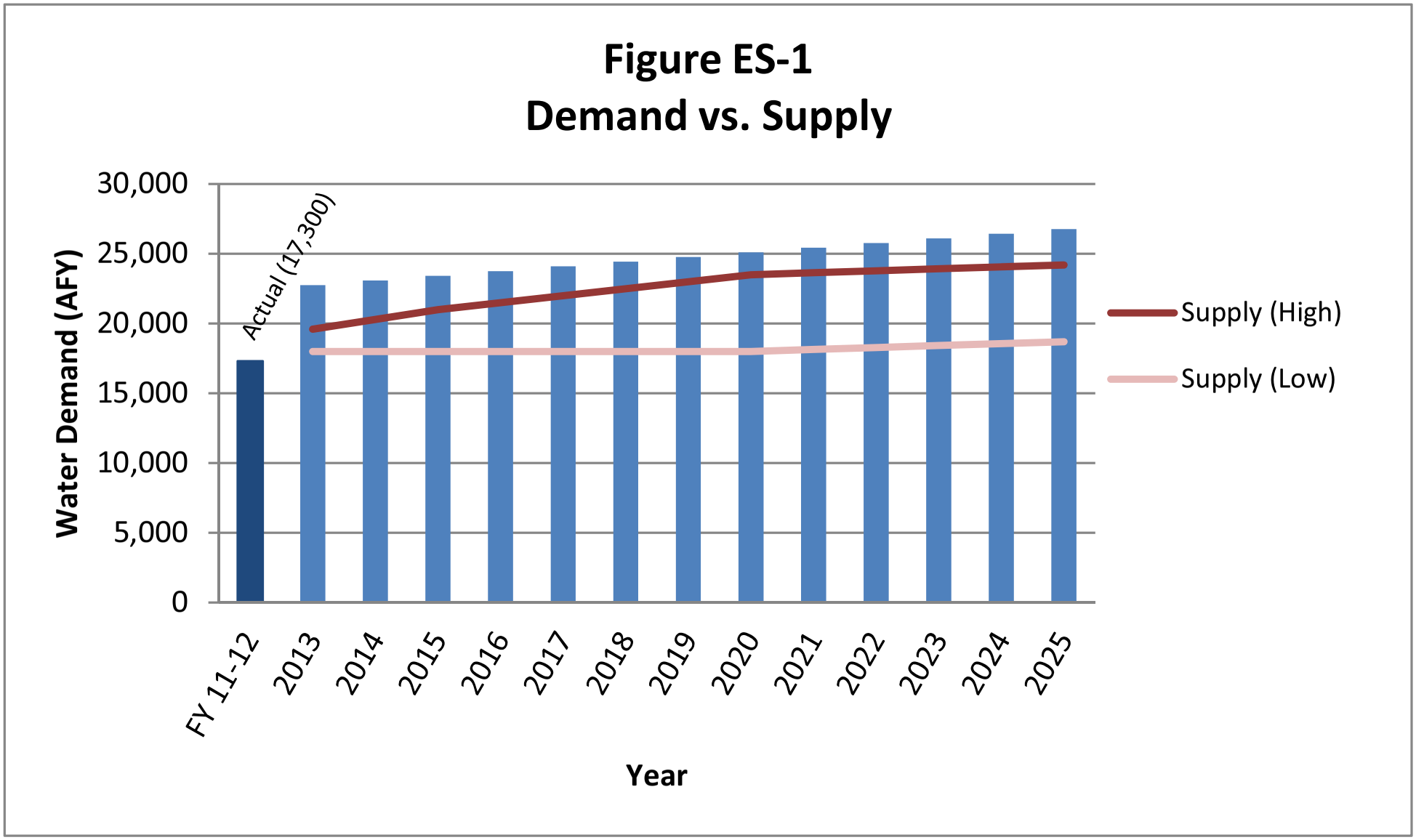
Figure ES-1
Demand vs. Supply
30,000
25,000
20,000
15,000
10,000
5,000
0
Water Demand (AFY)
Actual (17,300)
FY 11-12
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
Year
Supply (High)
Supply (Low)

Recommendations

Moving forward, it is recommended that the City utilizes current consumption data to develop both the existing demand condition, and also develop more realistic demand factors for the various land uses within the City. In order to develop more realistic demand factors, the City will need to accurately define the existing land use conditions for the various land use categories within the City. In addition, the water consumption data will need to be attributed to the correct land use categories. This can be accomplished by mapping the water billing classifications with the General Plan land use categories, and perhaps developing a new set of water demand factor classifications. By utilizing current water consumption data, and current land use data, a more accurate set of water demand factors can be determined. The more accurate demand factors will allow for a more realistic projection of future water demands where the development plan has been identified.

Due to the wide range of demand and supply estimates in this initial analysis, it is clear that a thoughtful and multi-faceted approach to managing and planning for Ventura's water supply will be absolutely critical in the coming years to support economic growth and quality of life.

1. INTRODUCTION

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- The Mound Groundwater Basin has experienced water quality degradation and projections for reliable supply may be lower than originally anticipated.

A recommendation from the workshop was to provide a comprehensive evaluation of current and projected water supply needs.

In addition, as a part of this year's City Council Priority Projects, the Community Development (Planning) Department and Ventura Water have focused their time and energy on streamlining and documenting the development review process as it pertains to water and wastewater services. More specifically, we are working to:

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input and expertise on what development has taken place since the 2005 General Plan, the pace of proposed development and what water demands those developments may require. This Report will review previously developed water demand projections, anticipated water supplies and planned development projects and compare them to where the City is today for each of these three categories. City staff is collaboratively looking forward to help plan the City's water resources to accommodate future development in the most responsible manner for its residents.

B. PURPOSE OF REPORT

The main purpose of this report is twofold. The report will identify water demand and water supply conflicts in various reports and will evaluate how current and future anticipated water demands match current and future anticipated water supply. Ventura Water and Planning recognize the need to develop a process that tracks proposed development projects, consistently calculates the anticipated increase in water demand associated with each proposed development project, and then evaluates the impact on the current water supply. This Comprehensive Water Resources Report ("Report") is intended to be a tool in the development review process as it pertains to water supply and demand.

Over the past several years, the City has prepared various documents that address water demand and water supply. More specifically, there are three documents that have been used as a reference document for both historical figures and future projections. The three documents are:

- 2005 General Plan, 2005 General Plan FEIR and 2007 Supplement
- 2010 Urban Water Management Plan (amended in 2011)
- 2011 Water Master Plan

The following section provides the background on each report and includes a summary table to compare the reports information. Each report was completed at a different time and for a specific purpose therefore, the following section includes the following information on each report: the purpose of the report; the resources utilized for the report; the water demand factors utilized and the estimated water demands based on those factors in each report and the anticipated current and future water supply in each report.

C. STUDY AREA

The City of San Buenaventura is located 62 miles north of Los Angeles and 30 miles south of Santa Barbara along the California coastline. The City is located within the County of Ventura, and bound by the City of Oxnard to the south, by unincorporated Ventura County to the east and north, and by the Pacific Ocean to the west. The northwest portion of the City is bound by the Ventura River, while the southern portion is bound by the Santa Clara River. The Ventura Freeway (101) bisects the City in the north-south direction, while the Santa Paula Freeway (126) runs east to west through the center of the City. The Ojai Freeway (33) runs along the northwestern edge of the City. The City currently occupies an estimated 21 square miles and has an estimated population of 109,000 persons. Exhibit 1-1 identifies the City of San Buenaventura boundary, the Sphere of Influence and General Plan boundary.

Ventura Water provides potable water service to a population of approximately 113,500 persons and has approximately 32,000 service connections. The City's existing water service area includes all portions within the City limits, as well as portions of unincorporated Ventura County that meet the City's policy for water connections outside City limits (Municipal Code Section 22.110.055).

Ventura Water also operates the Saticoy Country Club (SCC) water system, which consists of residences and country club facilities that are located east of the City. They have their own stand-alone system, which includes two groundwater wells, a booster pump station and two storage tanks. The ownership responsibility for the system is shared between the City and SCC (1/3 and 2/3, respectively). The SCC system has a separate Domestic Water Supply Permit from the California Department of Public Health.

On January 16, 2013, the Ventura County Local Agency Formation Commission (LAFCo) adopted resolution LAFCo 13-01S, which updated the City of Ventura Sphere of Influence (see Appendix). The Sphere of Influence (SOI) included in this Report depicts the updated SOI.

CITY OF VENTURA

City Overview

Legend

- Location Sites
- Ventura City Limit
- General Plan Boundary
- City Sphere of Influence

0 0.5 1
Miles

Source: Eagle Aerial, 2010

RBF CONSULTING

Exhibit 1-1

M:\Mdata\10104392\January_2013\EXI_1_CityOverview_L11x17.mxd 2/19/2013-- DJ

D. DOCUMENT COMPARISON

1. 2005 General Plan, General Plan FEIR and 2007 Supplement

State law requires each California city to adopt a comprehensive, long-term General Plan for the physical development of the community that guides local decision-making by expressing community goals about the future distribution and character of land uses and activities. The General Plan serves as a long-term guide, establishing policies for day-to-day land use decisions over a 20-year planning horizon. The General Plan is a policy document that sets over-arching goals for the future development of the City and specifies policies and actions to achieve these over-arching goals.

The 2005 General Plan Final Environmental Impact Report (FEIR) provides an analysis of the potential environmental impacts associated with the potential development identified in the General Plan.

The City prepared a supplement to the FEIR in 2007 to address the impact of an additional 329,000 square feet of non-residential development in the Ventura Harbor area.

<u>Land Use</u>

Chapter 3 of the City's 2005 General Plan defines the City's plan for growth over the 20-year planning horizon (through 2025). Specifically, Table 3-2 of the General Plan provides the estimated amount of development that could reasonably be expected to occur within the City and the Sphere of Influence by 2025, and together with Figure 3-1 provides a picture of where such change might occur. The 2007 FEIR Supplement included an additional potential of 329,000 square feet of non-residential development in the 20-year planning horizon.

<u>Water Supply</u>

Chapter 4.13 of the 2005 General Plan FEIR addresses the impacts of the General Plan on the public utilities, which includes the water system. Table 4.13-7 summarizes the City's historic and projected water supply. The source used in preparation of Table 4.13-7 is the City's 2004 Biennial Water Supply Report, which provides projections for the

City's future water supply and demand based on current information at the time (thru 2003).

Water Consumption (Demands)

Table 4.13-8 summarizes the City's historical and projected water consumption. The source used in preparation of Table 4.13-8 is the City's 2004 Biennial Water Supply Report. Projected demands are based on the post-mandatory water conservation demand factor of 0.179 AFY/capita, the 2000 U.S. Census and the City growth rate of 0.9%. However, the table only projects out to Year 2020. In order to identify the water demand projections for Year 2025, you must utilize the projected water demands developed in Table 4.13-15 (5,806 AFY) in conjunction with the calculated demand increase (115 AFY) identified in the 2007 FEIR Supplement. The demand projections in Table 4.13-15 are based on a set of water demand factors to be discussed later in this Section.

2. 2010 Urban Water Management Plan

An Urban Water Management Plan (UWMP) is a long-term planning tool that provides water purveyors and their customers a broad perspective on water supply issues. The UWMP is a management tool, providing the framework for action, but not functioning as a detailed project development plan. Preparation of the UWMP is a requirement of the California Urban Water Management Planning Act. UWMP's must be prepared every five years. The primary goals of the UWMP are to: 1) plan the water supply over a 20-year period, 2) identify and quantify water supply for future demands in normal, single-dry and multiple-dry year conditions, and 3) implement conservation and efficient water use practices in urban settings.

Land Use

The UWMP does not evaluate land use. The UWMP projects water demands based on population projections. The population projections are based on historical data provided by the California Department of Finance (2000 Benchmark). Future projections are based on the 0.88 percent annual growth rate as identified in the City's 2005 General Plan, and are shown in Table 2-1 of the 2010 UWMP.

Water Supply

Table 3-1 in the 2010 UWMP provides a summary of the existing and projected water supply. The water supply data are based on historical production data and estimates of current water supply sources available and operational constraints.

Water Consumption (Demands)

Table 2-5 in the 2010 UWMP provides a summary of the past, current and projected water demands. The 2005 and 2010 water demand data are the actual metered demands based on billing records. The water demand projections are based on the per capita water demand factor of 168 gallons per capita day, multiplied by the population growth projections identified in Table 2-1 of the UWMP.

3. 2011 Water Master Plan

A Water Master Plan (WMP) is a document that is typically prepared every 5-10 years. They are not mandated by state law, but most water purveyors prepare a WMP to document the plan for improvement or expansion of the existing water distribution system. The master plan provides a comprehensive evaluation of the water system infrastructure to determine the systems' capacity to meet the current and future water demand, and evaluates the operational efficiency of the system. The primary focus of a master plan is to evaluate the capacity of the system facilities (pipelines, pump stations, reservoirs, wells, etc.) to provide a safe and reliable water supply to the customers at minimum specified criteria. The criteria will include system pressure, pipe velocity, fire flow availability, reservoir storage, pump capacity, etc., which are based on guidelines provided by the American Water Works Association (AWWA), Environmental Protection Agency (EPA), and California Department of Public Health (DPH). The primary goal of a WMP is to develop a capital improvement program that identifies specific projects, costs and priorities for system improvements.

Land Use

The 2011 Water Master Plan utilized the land use data provided in Table 3-1 of the 2005 General Plan to establish the existing land use condition. The future "near-term" land use conditions were based on the City's 2006 Pending Project list. The ultimate land use condition was based on the remaining vacant land as identified in the 2005 General Plan,

less the proposed projects listed on the 2006 Pending Project list. The figures are summarized in Tables II-1 thru II-4 in the 2011 Water Master Plan.

Water Supply

The summary of the current (2010) water supplies are identified in Table V-14. The current water supply is shown as a historical supply projection range from 18,760 – 25,800 AFY.

Water Consumption (Demands)

The existing water demands identified in the 2011 Water Master Plan are based on actual billing records taken from a two-year period from January 2004 through December 2005. The actual billing records, coupled with the existing land use identified in the 2005 General Plan were used to develop "actual" water demand factors. The actual demand factors were increased by approximately 10% to account for water loss. The demand factors were applied to the 2006 Pending Project list and then to the remaining vacant land to calculate the future water demands.

The water supply and water demand figures provided within each document are summarized on Table 1-1. The table includes the source of the data used to develop the figures presented within each document, and the various factors and methods used to come up with the projections. As you will note, the water supply projections in the 2005 General Plan documents are the most optimistic and the water demand projections in the 2005 General Plan documents are the most conservative. This is likely due to the fact that these projections were made based on actual data available through Year 2003, and obviously could not factor in the economic conditions of later in the decade, nor the drought and water supply limitations of the same time frame.

It is prudent to point out that comparing the demand and supply projections within each of these three documents is not an "apples to apples" comparison, as each document was prepared at a different time using actual data from different time periods, incorporating current information regarding water supply sources at that specific time, using different methodologies (land use based vs. population based) to calculate future projections, using different demand factors and making different assumptions.

E. DEMAND FACTOR COMPARISON (from previous documents)

Demand factors are used to calculate the future water demand projections. Demand factors are either land use based (per area (acre/ksf) or per dwelling unit) or population based (per capita). Demand factors are typically derived from actual water consumption data, and a safety factor is applied for planning purposes. Demand factors were used in each of the three documents described above to arrive at the future demand projections presented within each report. As briefly described above and shown in Table 1-1, the demand factors and methodologies used within each document vary. Since each document uses different methodologies and demand factors, an “apples to apples” comparison is difficult. Table 1-2 lists the demand factors used within each report. In an attempt to show an “apples to apples” comparison, the residential demand factors have been converted to similar units and are shown on Table 1-3.

The Appendix includes water usage factors from other local agencies with similar characteristics – population, climate and water supply sources. These include Simi Valley, Thousand Oaks, Irvine Ranch Water District and Santa Margarita Water District.

Table 1-1
Summary of Previous Documents

Total Water Supply (AFY)							
Document	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**Data Source & Factors**
2005 General Plan, GP FEIR and 2007 Supplement	*21,566* [1]	26,300	28,262	28,262	28,262	28,262	Table 1 of the 2004 Biennial Water Supply Report - Based on actual water production data thru 2003 - Future projections based on assumptions and limitations for each supply source known at the time (2004) - [1] Figure includes 1,129 AFY for raw water and oil operation use - Figures do not include recycled water
2010 Urban Water Management Plan	n/a	n/a	20,600	22,000	24,600	24,700	Table 3-2 of the 2010 UWMP - Water production data for 2010 is based on annual average data from 2000 - 2009 as presented in Table V-14 of the 2011 WMP - Future projections based on assumptions and limitations for each supply source known at the time (2011) - Figures do not include raw water and oil operation use - Figures include 700 AFY of recycled water annually
2011 Water Master Plan	n/a	n/a	n/a	n/a	n/a	25,800	Tables V-1, V-2, V-7, V-10, V-13 and V-14 of 2011 WMP - Based on actual water production data thru 2009 - Future projections based on assumptions and limitations for each supply source known at the time (2011) - Figures do not include raw water and oil operation use - Figures do not include recycled water

Total Water Demand / Consumption (AFY)							
Document	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**Data Source & Factors**
2005 General Plan, GP FEIR and 2007 Supplement	*20,437*	20,594	21,724	22,918	24,181	27,421 [2]	Tables 2, 3 and 4 of the 2004 Biennial Water Supply Report - Based on actual water consumption data thru 2003 - Historical population based on 2000 U.S. Census - Growth rate in City = 0.9%, outside City = 0.6% - Water Use Factor = 0.179 AFY/capita - [2] Year 2025 projections based on demand factors provided for FEIR
2010 Urban Water Management Plan	n/a	*20,808*	*17,351*	22,286	23,256	24,270	Table 2-5 of the 2010 UWMP - Based on actual water consumtion data through 2010 - Historical population based on California Department of Finance Table E-4 Population Estimates for Cities, Counties and the State (2000 Benchmark) - Growth rate in City = 0.88%, outside City = 0.1258% in connections - Water Use Factor = 168 gpcd = 0.188 AFY/capita
2011 Water Master Plan	n/a	*16,190*	17,896	n/a	n/a	22,708	Table IV-5 and Figure IV-2 of the 2011 WMP - Based on actual billing records from 2004-2005. - Near-term projections (allocated to 2010) based on actual billing data from 2004-2005, calculated demand factors from the same period applied to the 2006 Pending Projects list. - Long-term projections (allocated to Year 2025) based on applying the calculated demand factors to the remaining developable land as identified in the 2005 GP, excluding the land accounted for in the 2006 Pending Projects list.

Table 1-2
Summary of Water Demand Factors in Previous Documents

General Plan FEIR, August 2005

Land Use Description	Density (DU/Acre)	Demand Factor [1]	Unit
Residential	n/a	450	gpd/du
Retail	-	250	gpd/ksf
Office	-	250	gpd/ksf
Industrial	-	315	gpd/ksf
Hotel	-	500	gpd/ksf

[1] Provided in email corrspondence from Chandra Chandrashaker, City CD, (January 8, 2013). Only used to calculate the year 2025 projections.

Note: Future projections through year 2020 based on population data and 0.179 AFY/capita factor

2010 Urban Water Management Plan

Land Use Description	Density (DU/Acre)	Demand Factor [1]	Unit
Single-Family	n/a	0.33	AFY/Acct
Multi-Family	n/a	1.71	AFY/Acct
Commercial	-	1.69	AFY/Acct
Industrial	-	10.87	AFY/Acct
Institutional/Governmental	-	2.80	AFY/Acct
Landscape	-	4.86	AFY/Acct
Petroleum Recovery	-	465	AFY/Acct
Other	-	0.83	AFY/Acct

[1] Adapted from 2005 data in Tables 2-5 and 2-6 of the 2010 UWMP.

Note: Future projections based on population data and 168 gpcd factor = 0.188 AFY/capita

Water Master Plan, March 2011

Land Use Description [1]	Density (DU/Acre) [1]	Demand Factor [2]	Unit
Neighborhood Low (NL)	0-8	1.20	gpm/acre
Neighborhood Medium (NM)	9-20	2.00	gpm/acre
Neighborhood High (NH)	21-54	5.00	gpm/acre
Commerce (C)	-	1.60	gpm/acre
Industry (I)	-	1.60	gpm/acre
Public and Institutional (PI)	-	0.75	gpm/acre
Parks and Open Space (POS)	-	0.10	gpm/acre
Downtown Specific Plan	21-54	2.55	gpm/acre

[1] Source: 2005 General Plan

[2] Per Table III-1 of WMP. Factors are calculted based on 2004-2005 billing data, and 2005 General Plan land use data.

Table 1-3
Comparison of Residential Water Demand Factors in Previous Documents

Comparison of Residential Demand Factors					
2005 General Plan FEIR		**2010 UWMP [2]**		**2011 Water Master Plan [1]**	
Residential	450 gpd/du	Single-Family	293 gpd/du	Low (NL)	432 gpd/du
				Medium (NM)	199 gpd/du
		Multi-Family	1530 gpd/du	High (NH)	192 gpd/du

[1] Assumes the average density (du/acre)
[2] Assumes 1 account = 1 du

F. CURRENT PLANNING DATA

The Community Development Department maintains a database of all projects that are in the planning, design or construction phase. These projects are known as the "Pending Projects." The pending projects database is updated constantly as new projects are proposed or existing projects are modified.

Table 3-2 in the 2005 General Plan predicted the anticipated development intensity and pattern throughout the City through 2025. The Community Development Department provided actual development data for the period from 2005 – 2012. This Report will take into account the actual development data provided by the City for years 2005-2012 to determine the current land use condition. This Report will utilize the date provided in Table 3-2 of the 2005 General Plan, less the actual development data from 2005-2012 to determine the remaining developable land through year 2025.

G. 2012 LAFCo Municipal Service Review

It should be noted that in 2012, the Ventura Local Agency Formation Commission (LAFCo) completed the Municipal Service Review for nine Ventura County cities, including the City of San Buenaventura. LAFCos exist for each county in California. LAFCos are responsible for achieving three primary objectives: encouraging the orderly formation and expansion of local government agencies; preserving agricultural land and open space resources; and discouraging urban sprawl. To accomplish these objectives, LAFCos are responsible for coordinating logical and timely changes in local government boundaries, conducting special studies that review ways to reorganize and streamline government structure and preparing a sphere of influence for each city and special district over which they have authority.

LAFCos are required to review, and as necessary, update the sphere of influence for each city or special district every five years. Prior to updating a sphere of influence, LAFCo is required to conduct a Municipal Service Review (MSR). MSRs consist of written determinations relating to seven different factors, one of which is the "present and planned capacity of public facilities, adequacy of public services, and infrastructure needs or deficiencies related to … municipal and industrial water… within or contiguous to the sphere of influence."

The MSR for the City of San Buenaventura (City) was accepted by the LAFCo Board on November 14, 2012. LAFCos findings regarding the potable water system concluded the City's current potable water demand is 88 percent of the supply, with approved development projects it increases to 94 percent of the supply, with proposed development projects it increases to 96 percent of the supply, and in drought conditions the normal water demand exceeds supply.

A copy of the MSR for the City is included as an Appendix.

H. REFERENCE DOCUMENTS

The following documents were used as reference for the preparation of this Comprehensive Water Resources Report. Specific excerpts and data sources from these documents used in the preparation of this Report are included in the Appendix.

2004 Biennial Water Supply Report

2005 Ventura General Plan (August 2005), City of San Buenaventura.

2005 Ventura General Plan Final EIR, Volumes I and II (August 2005), City of San Buenaventura.

2007 General Plan FEIR Supplement

2010 Urban Water Management Plan (June 2011), Kennedy/Jenks Consultants.

Water Master Plan (March 2011), RBF Consulting.

Municipal Service Reviews for Nine Ventura County Cities (November 14, 2012), Ventura Local Agency Formation Commission (LAFCo).

2. LAND USE

A. EXISTING LAND USE

In order to determine the existing land use make-up within the City's water service area as of year-end 2012, existing land use data from the 2005 General Plan was used in conjunction with the "Development Entitlement Report 2005-2012" as provided by the City Planning Department (see Appendix). It should be noted that the "Development Entitlement Report 2005-2012" includes a listing of all development areas that have been constructed, are currently under construction, or are approved for construction. Since a breakdown of the construction status for the development areas listed in the table are not available at this time, then all of the development area listed is assumed to be "existing" as of the end of year 2012 for the purposes of this Report.

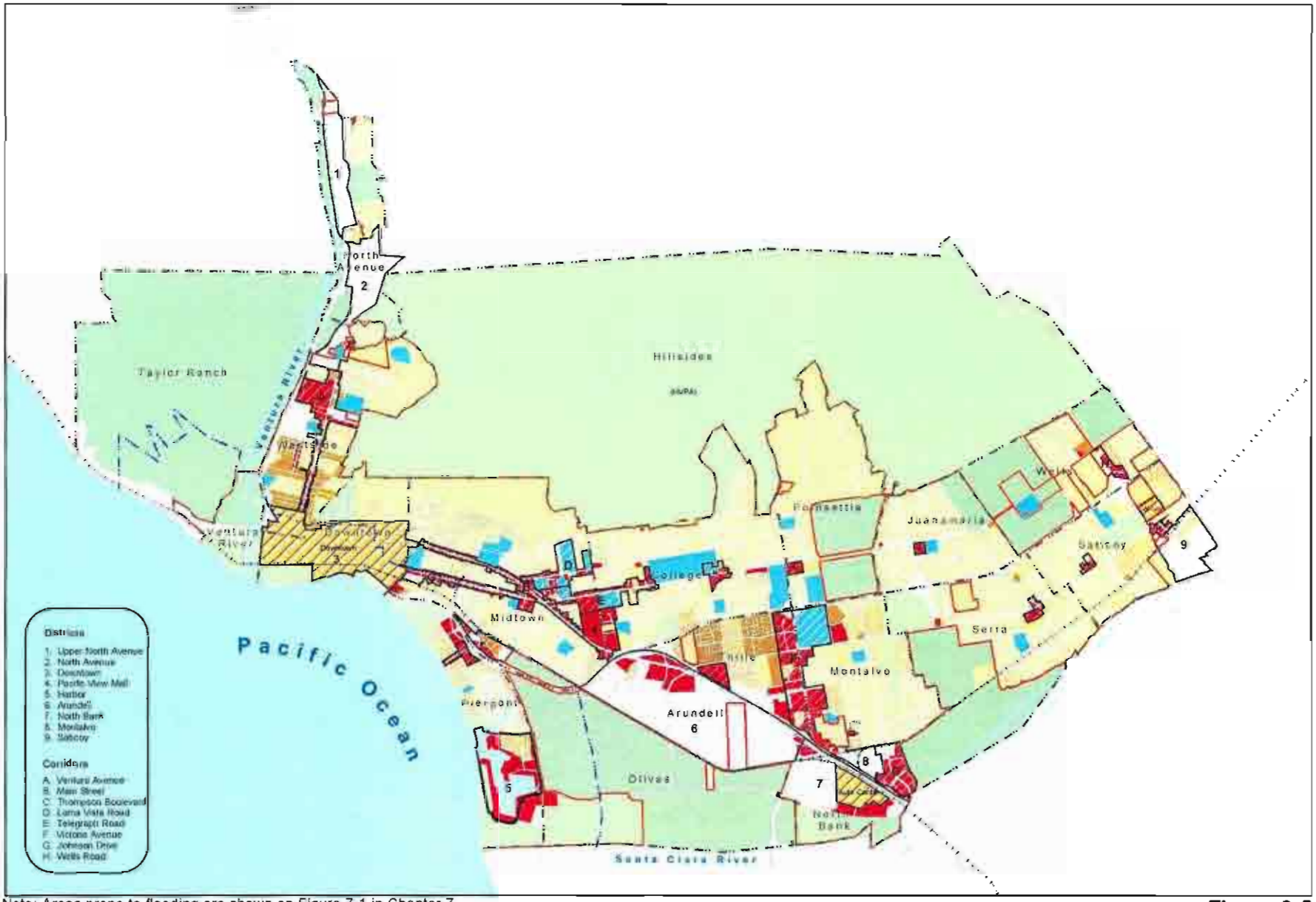
Table 3-1 of the 2005 General Plan (see Appendix) identifies the existing land uses (as of year-end 2004) in dwelling-unit count and square-footage, and the additional potential development area within the General Plan boundary. Table 2-1 herein provides a summary of the existing development as of year-end 2004 and the potential future development within the General Plan land use categories. Exhibit 2-1 (a copy of Figure 3-5 from the General Plan) depicts the land use designations throughout the City as identified in the 2005 General Plan.

Table 2-2 summarizes the existing development identified in the 2005 General Plan into Residential and Non-residential categories. The development information for years 2005-2012 provided by the City was added to the existing land use information from the 2005 General Plan to determine a snap-shot of the current land use condition for year-end 2012.

Table 2-1
Existing Land Uses per 2005 General Plan [1]

Planning Designation	Allowed Density (du/acre)	Existing Development as of 2004		
		Single Family (units)	Multi Family (units)	Comm/Ind (sf)
Neighborhood Low	0-8	19,425	3,335	49,386
Neighborhood Medium	9-20	1,163	8,965	149,513
Neighborhood High	21-54	814	2,468	194,143
Commerce		257	490	4,995,248
Industry		29	31	8,299,840
Public and Institutional		4	0	54,422
Park and Open Space		6	0	15,491
Agriculture		4	0	19,550
Downtown Specific Plan	21-54	332	1,543	1,795,401
Harbor District		0	310	350,160
Total		**22,034**	**17,142**	**15,923,154**

[1] Source: Table 3-1 of 2005 Ventura General Plan



Note: Areas prone to flooding are shown on Figure 7-1 in Chapter 7.

Figure 3-5

GENERAL PLAN DIAGRAM

Neighborhood
- Low (up to 8 du/ac)
- Medium (9-20 du/ac)
- High (21-54 du/ac)

- Commerce
- Industry
- Public and Institutional

- Agriculture
- Parks and Open Space
- Specific Plan Area

- Corridors, Neighborhood Centers (NC)
- Districts

- City Limits
- Planning Communities
- California Coastal Zone Boundary

This map is a product of the City of San Buenaventura, California. Although reasonable efforts have been made to ensure the accuracy of the map, the City of San Buenaventura cannot guarantee its accuracy.

Exhibit 2-1

Table 2-2
Summary of Existing Land Use

	Residential Development (units)	Non-Residential (sf)
Existing (as of 2005 General Plan) [1]	39,176	15,923,154
Constructed (2005 thru 2012) [2]	3,035	1,280,823
Total Existing Land Use (through 2012)	**42,211**	**17,203,977**

[1] Source: Table 3-1 of 2005 General Plan.
[2] Source: Attachment D: Development Entitlement Report (2005-2012) (Approved, Under Construction and Built Projects), provided by City 02/26/2013.

B. FUTURE LAND USE

Table 3-2 of the 2005 General Plan (see Appendix) identifies the predicted development intensity and pattern that was anticipated to occur within the General Plan boundary through the planning horizon of year 2025. As mentioned previously, the City provided information as to the development areas that have been constructed, are currently under construction, or are approved for construction since the 2005 General Plan through the end of year 2012. Table 2-3 provides a summary of the 2005 General Plan predicted development, a summary of the 2005-2012 development report, and calculates the remaining developable land through the 2025 planning horizon. It should be noted that in each of the referenced tables, the residential unit count is not divided up by the density.

Table 2-3
Summary of Predicted Development, Actual Development and Remaining Development

	Residential Development (units)	Non-Residential				
		Retail (sf)	Office (sf)	Industrial (sf)	Hotel (sf)	Total (sf)
2005 General Plan Prediction [1]	8,318	1,241,377	1,213,214	2,235,133	530,000	5,219,724
Actual Development (through 2012) [2]	3,035	258,974	485,733	449,116	87,000	1,280,823
Remaining Developable Land (through 2025)	**5,283**	**982,403**	**727,481**	**1,786,017**	**443,000**	**3,938,901**

[1] Source: Table 3-2 of 2005 General Plan.

[2] Source: Attachment D: Development Entitlement Report (2005-2012) (Approved, Under Construction and Built Projects), provided by City 02/26/2013.

3. WATER DEMANDS

A. Existing Demand Condition

Typically, the existing demand condition can be determined by evaluating the most recent historical water consumption records maintained by the City. Water consumption data is available through FY 2011-2012, however, as discussed in Section 2, the land use data is not currently available to directly correlate the FY 2011-2012 water demand data with the occupied land use at that time. For that reason, it makes it more difficult to project the future demands. Therefore, in order to determine the existing water demand condition, and also to project the future demand conditions, this Report will utilize water consumption data from water demands with data for the year 2005, which can be directly correlated to the land use data at that time. The "existing" water demand will be projected based on the 2005 consumption and land use data, the current land use condition as described in Section 2, and water demand factors identified in the 2005 General Plan FEIR (see Appendix).

The City's water production to meet the annual metered consumption of its customers in 2005 was approximately 20,808 AFY, per the 2010 UWMP. In comparison, the FY 2011-2012 water consumption was approximately 17,300 AFY. Utilizing the development data provided by the City for 2005-2012, and applying the water demand factor for each land use as identified in the 2005 General Plan FEIR, the estimated current water demand in the City water service area is 22,754 AFY (see Table 3-1).

B. Future Demand Projection (through 2025)

The 2005 General Plan FEIR water demand factors were then applied to the remaining developable area, per Table 2-3, to calculate the anticipated water demand increase. Per Table 3-2, the water demand is projected to increase by 4,020 AFY, resulting in an estimated future water demand in the City water service area of 26,774 AFY in 2025.

Table 3-1
Current Water Demand Projection

	Usage Factor [1]	Quantity [2]	Estimated Average Annual Water Demand	
2005 Water Demand [3]				20,808 AFY
Water Demand Projections (2005-2012)				
Residential	450 gpd/du	3,035 du	1,365,750 gpd	1,530 AFY
Retail	250 gpd/ksf	259 ksf	64,744 gpd	73 AFY
Office	250 gpd/ksf	486 ksf	121,433 gpd	136 AFY
Industrial	315 gpd/ksf	449 ksf	141,472 gpd	158 AFY
Hotel	500 gpd/ksf	87 ksf	43,500 gpd	49 AFY
Total Current Water Demand				***22,754 AFY***

[1] Per Table 1-2 "General Plan FEIR" water demand factors.

[2] Per Table 2-3.

[3] Per Table 2-5 of 2010 UWMP.

Table 3-2
Future Water Demand Projection (through 2025)

	Usage Factor [1]	Quantity [2]	Estimated Average Annual Water Demand	
Current Water Demand [3]				22,754 AFY
Future Water Demand Projections (thru 2025)				
Residential	450 gpd/du	5,283 du	2,377,350 gpd	2,663 AFY
Retail	250 gpd/ksf	982 ksf	245,601 gpd	275 AFY
Office	250 gpd/ksf	727 ksf	181,870 gpd	204 AFY
Industrial	315 gpd/ksf	1,786 ksf	562,595 gpd	630 AFY
Hotel	500 gpd/ksf	443 ksf	221,500 gpd	248 AFY
Total Future Demand Projection				***26,774 AFY***

[1] Per Table 1-2 "General Plan FEIR" water demand factors.

[2] Per Table 2-3.

[3] Per Table 3-1.

4. WATER SUPPLY

A. INTRODUCTION

The City's potable water supply is derived from local groundwater basins, Lake Casitas and sub-surface water from the Ventura River. The City also has a 10,000 acre-foot per year allocation from the California State Water Project. To date the City has not received any of this water because there are no facilities to get the water to the City. There are presently five local water sources that provide water to the City water system:

- Casitas Municipal Water District (Casitas)
- Ventura River Foster Park Area (Foster Park)
    - Surface Water Intake
    - Upper Ventura River Groundwater Basin/Subsurface Intake and Wells
- Mound Groundwater Basin (Mound Basin)
- Oxnard Plain Groundwater Basin (Fox Canyon Aquifer)
- Santa Paula Groundwater Basin (Santa Paula Basin)

The City also provides recycled water from the Ventura Water Reclamation Facility (VWRF). The six current water supply sources are presented in the following section. Please refer to Exhibit 4-1 for the locations and boundaries of the City's current supply sources.

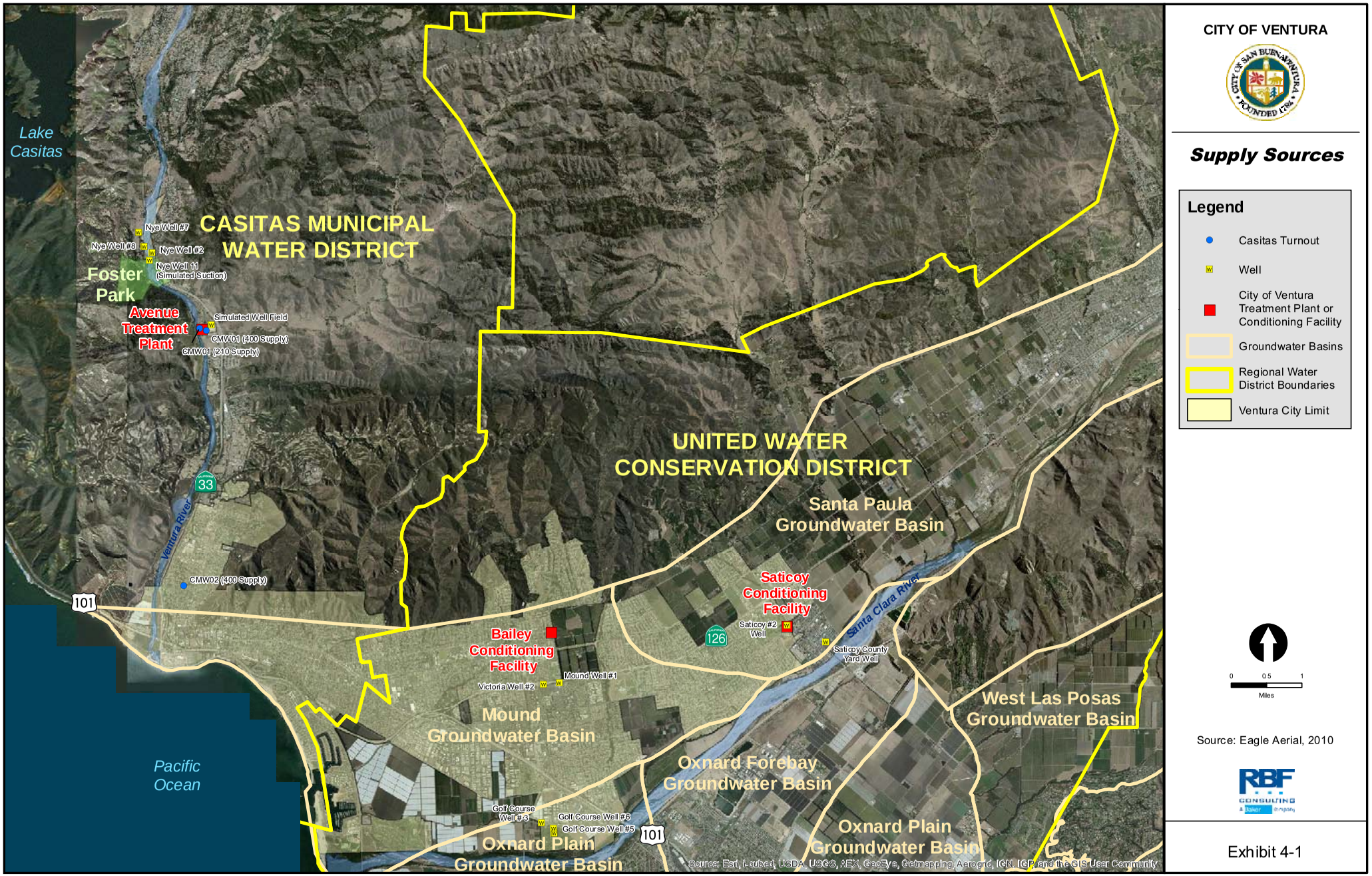


Exhibit 4-1

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B. CURRENT WATER SUPPLY SOURCES

1. Casitas Municipal Water District (Casitas)

The City purchases treated water from Casitas Municipal Water District to provide water supply to a portion of the City. In the western portion of the City approximately 30 percent of the City's water accounts are located within the Casitas service area. Storm water runoff from local watersheds is stored in Lake Casitas, located approximately 10 miles northwest of the City, then treated and delivered to customers by Casitas. Casitas supplies potable water to agricultural, domestic, municipal, and industrial users within its service area. The Casitas service area includes the Ojai Valley, the western part of the City, and the coastal area between the City and Santa Barbara County. Use of Casitas water is restricted to areas within its boundaries.

The "'safe yield" of Lake Casitas is defined to be the amount of water that can be removed from the lake each year without excessive risk that the lake will become dry. The safe yield of Lake Casitas is currently estimated to be 21,920 acre-feet per year (AFY), based on the critical historical dry period from 1944 to 1965. Studies by Casitas' engineering department have shown that this period represents the most critical dry spell for the lake's watershed of all the years which historical data is available.

To maintain the future operation of Lake Casitas at safe yield, Casitas established an allocation program for its customers in 1992. The City's allocation can be as high as the in-District demand for Stage I (wet or average year or 8,000 AFY), or reduced to 7,090 AFY for Stage 2 (dry conditions). This amount is incrementally reduced during Stages 3 and 4 dry weather conditions and results in 4,960 AFY for Stage 5 (extremely dry conditions). Stage 2 is initiated when Lake Casitas storage drops below 95,000 AF and Stage 5 is initiated when levels drop below 65,000 AF. The lower allocation remains in effect until the storage is recovered to 90,000 AF. A possible future impact to the multistage allocation system may be the operation of the fish ladder at the Robles Diversion. Casitas is currently reviewing its allocation program and this may limit the amount of water available to the City.

In July 1995, the City signed the present operating agreement with Casitas establishing the City's minimum annual purchase at 6,000 AFY, which is subject to the allocation program described above during drought periods. However, due to recent demand reductions within the Casitas boundary City customers are currently using approximately 5,000 AFY. The City is presently renegotiating the water supply agreement with Casitas. While additional supply (up to 8,000

AFY) may be available to the City in future years, the present annual supply used within the Casitas district boundary of the City service system is approximately 5,000 AFY. Therefore the City's current reliable water supply from Casitas is 5,000 AFY.

2. Ventura River Surface Water Intake and Upper Ventura River Groundwater Basin/Subsurface Intake and Wells (Foster Park)

Surface water from the Ventura River is collected via surface diversion, subsurface collector, and shallow wells and delivered to the Avenue Treatment Plant through the City's Foster Park facilities. Production from this source is a function of several factors including diversion capacity, local hydrology, environmental impacts, and the storage capacity of the Ventura River alluvium and upstream diversions.

The Ventura River water source is dependent upon local hydrology. Currently, the surface intake structure at Foster Park is unused due to the natural channeling of the active river channel bypassing the structure. Each year the flows can change the position of the active river channel in relation to the intake structure. According to a model of the Ventura River developed in 1984 and modified in 1992, the Upper Ventura River Basin fills after one or more years of above average rainfall. Once full, it takes three successive years of drought, with below average rainfall to deplete the river basin subsurface storage and cause river water production to drop until the drought ends. More recent ongoing studies are looking at the interaction between groundwater diversion and surface water flow in the Foster Park reach.

The Foster Park facilities produce groundwater throughout the year. However, due to storm flows, the wells are subject to inundation and erosion. The early 2005 winter storms destroyed Nye Well 1A and damaged Nye Wells 2, 7 and 8. The pipeline between Nye Wells 7 and 8 along the west bank of the river and the pipeline that crosses the river from Nye Well 8 to the intake pipeline for the Avenue Treatment Plant were also damaged during the storms. Nye Wells 7 and 8 were repaired in late 2006, the pipeline across the river was repaired in late 2007 and the pipeline repair between Nye Wells 7 & 8 was completed in early 2009. To date, Nye Well 2 has not been repaired.

With input from resource agencies and consultants in 2008, the City began conducting studies of the Ventura River flow conditions and is presently operating the Foster Park facilities in an environmentally responsible manner. Presently the City operations staff has voluntarily adopted a

well production schedule that limits its pumping based on annual rainfall conditions. The City intends to work with experts to ascertain a pumping regime that will balance production demands with environmental concerns and is presently studying the relationship between groundwater production and surface flows.

Estimations of approximately 6,000 AFY on average is available based on this operational scenario and is comparable to the 50-year average historical City production records between 1960 and 2009. However, current operational constraints allow a diversion efficiency of up to 70 percent (average 4,200 AFY) to be obtained under the City's operations schedule, which can be considered reliable for planning purposes and is roughly equal to the annual average for the last 10 years. Therefore the City's current reliable water supply from the Ventura River / Foster Park is 4,200 AFY. This supply number may further be drastically reduced by proposed regulatory and environmental constraints.

3. Mound Groundwater Basin (Mound Basin)

The Mound Groundwater Basin has historically provided water for overlying beneficial uses and satisfies agricultural, municipal, and industrial demands. Historical use has been documented to temporarily exceed the yield of the basin and result in water levels that have fallen below sea level and created a threat of seawater intrusion. To abate this threat the City abandoned its historical coastal well facilities and located groundwater extraction near the center of the Mound Basin. A report (Fugro, 1997) compiled as part of a 1996 study of the basin indicated that historical data supports a basin yield of at least 8,000 AFY during drought conditions as long as pumpage is reduced during wet years to allow water levels to recover.

The 1983 to 1996 average annual production from the Mound Basin was approximately 5,000 AFY (Fugro, 1997). While the resulting water levels in the basin over that time period reportedly ranged from significantly below sea level to a sufficient elevation about sea level to control seawater intrusion, the basin water level trend did not indicate an average production significantly above 5,000 AFY could be sustained without creating adverse conditions.

Currently, two wells withdraw water from the Mound Groundwater Basin; Victoria Well No. 2, which was installed in 1995, and Mound Well No. 1, which began production in April 2003. Victoria Well No. 1, which was installed in 1982, is considered an inactive well at this time due to maintenance and water quality issues and is scheduled for destruction.

Historical agricultural and private well uses have typically extracted about 2,000 AFY while the City's average annual extraction for the last ten years has been approximately 4,000 AFY. Therefore the City's current reliable water supply from the Mound Basin is 4,000 AFY.

4. Oxnard Plain Groundwater Basin (Fox Canyon Aquifer)

Wells near the Buenaventura Golf Course have drawn from the Oxnard Plain Groundwater Basin since 1961. Currently, two wells, Golf Course Wells No. 5 and 6, produce potable water for the City's system and a third well (Golf Course Well No. 3) is out of service for major rehabilitation. This third well could be used as an emergency source and will only return to service during a drought, following the replacement of wellhead, pump, electrical and raw water connection. These wells pump from the Fox Canyon Aquifer of the Oxnard Plain Groundwater Basin.

The Fox Canyon Groundwater Management Agency (GMA) was created by state legislation in 1982 to manage local groundwater resources in a manner to reduce overdraft of the Oxnard Plain and stop seawater intrusion. A major goal of the GMA is to regulate and reduce future extractions of groundwater from the Oxnard Plain aquifers, in order to operate and restore the basin to a safe yield. In August 1990, the GMA passed Ordinance No. 5, which required existing groundwater users to reduce their extractions by five percent every five years until a 25 percent reduction was reached by the year 2010.

The City's historical allocation was set by the GMA at 5,472 AFY, which was the average extraction from the Golf Course Wells for the base period 1985 to 1989. Beginning in 1992, historical extractions set by the GMA were reduced by five percent (5%) to 5,198 AFY, in 1995 it was reduced to 4,925 AFY, in 2000 it was reduced to 4,651 AFY and further reduced in 2010 to the current allocation of 4,100 AFY. Therefore the City's current reliable water supply from the Oxnard Plain Basin is 4,100 AFY.

5. Santa Paula Groundwater Basin (Santa Paula Basin)

The Saticoy Water Company was acquired by the City in 1968, which included Saticoy Well No. 1 that produced water from the Santa Paula Basin. Due to casing failure, the well was destroyed and replaced in 1991 with a new well designated as Saticoy Well No. 2. Well No. 2 was placed in

the same general location as Well No. 1. In May 2003, Saticoy Well No. 2 was rehabilitated. After rehabilitation, the resulting sustainable well supply was 1,600 AFY.

In March 1996, the City ended a five-year stalemate over the use of the Santa Paula Basin. Under a court stipulated judgment, the United Water Conservation District (United), the Santa Paula Basin Pumpers Association (an association of ranchers and businesses) and the City all have an interest in the Santa Paula Basin. The City can pump on average 3,000 AFY from the Santa Paula Basin. The City is not limited to this allocation in any single year, but may produce seven times its average annual allocation (21,000 AF) over any running seven-year period. In addition, the City may pump an additional 3,000 AFY in case of an emergency resulting from a long-term drought situation.

If the court finds that the safe yield of the basin is less than the total pumping allocations, then the City may have reductions in pumping allocations. Stage 2 reduces the City's pumping to 1,141 AFY, Stage 3 reduces the City's pumping allocations to 641 AFY, Stage 4 reduces the City's pumping allocations to 481 AFY and Stage 5 reduces the City's allocations to zero.

However, due to the existence of only the one well, the City can only reliably count on the production of that well to provide supply at this time. Therefore the City's current reliable water supply from the Santa Paula Basin is 1,600 AFY.

6. Recycled Water

The City collects and treats wastewater at their Ventura Water Reclamation Facility (VWRF). The reclamation facility has a current capacity of 12 MGD. Average annual flows to the reclamation facility total approximately 9 MGD. A portion of the effluent is pumped to recycled water customers and the remaining effluent is discharged to the Santa Clara River Estuary (Estuary). The recycled water produced from the VWRF is used for general irrigation of the two golf courses, a City park and landscape irrigation areas located along the existing distribution alignment. The City's average annual recycled water demand is approximately 700 AFY.

The City's existing water supply portfolio is summarized in Table 4-1.

Table 4-1
Summary of Current Water Supply

Water Supply Source	Current Supply (AFY)
Casitas Municipal Water District	5,000
Ventura River / Foster Park	4,200
Mound Groundwater Basin	4,000
Oxnard Plain Groundwater Basin	4,100
Santa Paula Groundwater Basin	1,600
Recycled Water	700
Total	**19,600**

C. FUTURE WATER SUPPLY

1. Casitas Municipal Water District (Casitas)

While additional supply (up to 8,000 AFY) may be available to the City in future years, the present annual supply used within the Casitas district boundary of the City service system is approximately 5,000 AFY. Since the estimated future water demands within the Casitas district boundary of the City will only nominally increase, the anticipated future water supply from Casitas will remain approximately 5,000 AFY.

2. Ventura River Surface Water Intake and Upper Ventura River Groundwater Basin/Subsurface Intake and Wells (Foster Park)

In conjunction with the Matilija Dam Ecosystem Restoration Project, two additional wells were installed at Foster Park as part of the mitigation measures. The wells, identified as the Foster Park Wellfield Restoration Project (Wells no. 12 and 13), were constructed by and funded through a grant received by the Ventura County Watershed Protection District for the City in order to mitigate for water lost as a result of increases in turbidity due to the removal of Matilija Dam. To date these wells have not been activated and are not to be operated until the project related impacts after removal of Matilija Dam necessitate the activation of these new wells. These two wells will be operated in accordance with the National Marine Fisheries Biological Opinion for the project.

It is anticipated that future construction of the Foster Park Wellfield Production Restoration Project and the expansion of the Avenue Treatment Plant to its maximum capacity will increase the supply from this source in the future. These improvements are anticipated to restore historical production capabilities to produce up to 6,700 AFY.

3. Mound Groundwater Basin (Mound Basin)

The City anticipates conducting a study within the next few years to review the perennial yield of the Mound Basin and determine if the annual average yield of the basin is still believed to be accurate. The anticipated future water supply from the Mound Basin will remain approximately 4,000 AFY.

4. Oxnard Plain Groundwater Basin (Fox Canyon Aquifer)

The anticipated future water supply from the Oxnard Plain Basin will remain as 4,100 AFY per the discussions in the previous section on the basin.

5. Santa Paula Groundwater Basin (Santa Paula Basin)

In March 1996, the City ended a five-year stalemate over the use of the Santa Paula Basin. Under an agreement with the United Water Conservation District (United) and the Santa Paula Basin Pumpers Association (an association of ranchers and businesses), the City can pump on average 3,000 AFY from the Santa Paula Basin. The City is not limited to this allocation in any single year, but may produce seven times its average annual allocation (21,000 AF) over any running seven-year period. In addition, the City may pump an additional 3,000 AFY in case of an emergency resulting from a long-term drought situation.

The City is currently constructing Saticoy Well No. 3, which will improve the water supply from the Santa Paula Basin. It is anticipated that Saticoy Well No. 3 will have an operational capacity of 2,000 gpm, thereby maximizing use of the City's 3,000 AFY allocation from the Santa Paula Basin in the near future.

However, as stated in the previous section on the Santa Paula Basin, there is potential for future reductions in the available supply. Therefore, the anticipated future water supply from the basin has a range from zero to 3,000 AFY.

6. Recycled Water

The City's existing Reclaimed Water Policy continues to encourage the use of recycled water. New development located near existing recycled water mains or within the defined recycled water focus area is required to use recycled water in lieu of potable water for irrigation and other uses as appropriate. In 2007, Kennedy Jenks Consultants completed a study on the potential recycled water market within the City. The total demand within the City limits that could potentially utilize recycled water was estimated at 1.3 MGD. Therefore, the anticipated future water supply from the VWRF at this time is 1,400 AFY.

The City's future water supply portfolio is summarized in Table 4-2.

Table 4-2
Summary of Future Water Supply
From Existing Sources

Water Supply Source [1]	2015 Supply (AFY)	2020 Supply (AFY)	2025 Supply (AFY)
Casitas Municipal Water District	5,000	5,000	5,000
Ventura River / Foster Park	4,200	4,200 - 6,700	4,200 - 6,700
Mound Groundwater Basin	4,000	4,000	4,000
Oxnard Plain Groundwater Basin	4,100	4,100	4,100
Santa Paula Groundwater Basin [2]	0 - 3,000	0 - 3,000	0 - 3,000
Recycled Water	700	700	1,400
Total	**18,000 – 21,000**	**18,000 – 23,500**	**18,700 – 24,200**

[1] None of these numbers preclude the City's water rights.

[2] The Santa Paula Basin Judgment allows the City to utilize on average 3,000 AF annually. There is potential for future reductions, therefore the supply range is shown from zero to 3,000 AFY.

D. POTENTIAL ADDITIONAL FUTURE SUPPLY SOURCES

This section will briefly describe any planned or proposed projects which may affect the water supply sources for the City.

1. State Water Project

The City has a 10,000 acre-foot per year allocation from the California State Water Project (SWP). The base contractual agreements concerning the City's annual entitlement to 10,000 acre-feet of SWP are: (1) the 1963 State Water Supply Contract of 20,000 acre-feet entitlement of SWP water between the Department of Water Resources (DWR) and Ventura County Watershed Protection District (VCWPD) known formerly as Ventura County Flood Control District (VCFCD); (2) the 1970 agreement between VCFCD and Casitas known formerly as the Ventura Municipal Water District that assigned the 20,000 acre-feet entitlement to Casitas; and (3) the 1971

agreements between Casitas and the City providing the City with an annual entitlement of 10,000 acre-feet and Casitas and United providing United with an annual entitlement of 5,000 acre-feet. Ventura's 10,000 acre-foot entitlement offers the City the potential future advantage of using the SWP entitlement to augment the current water supply. At this time the City does not have the facilities required to deliver SWP water into the distribution system. The City's goal has been to protect and provide the additional water supply for our community, while minimizing the financial impact of keeping this entitlement.

The City pays annual SWP Table A water fees to DWR, which cover construction costs for SWP facilities and administration to deliver allotments of water throughout the state. In addition, the citizens of Ventura voted November 3, 1993 in favor of desalinating seawater over importing water through the SWP, as the preferred supplemental water supply option. However, based on the City Attorney's review of the City's SWP Table A water, the City cannot unilaterally end its involvement in the SWP's financial obligations and SWP Table A water without great risk.

The Monterey Amendment to the State Water Contract in 1999 provided the City a formal mechanism to allow the City to place their SWP water into a "turn back" pool to be purchased by other SWP contractors. The City has taken part in the SWP "turn back" pool over the past several years which has provided a small annual revenue offset. The City has also worked recently with United who requested to receive the City's allocation at the "turn back" pool rate which provided water benefits to the County area as a whole.

Recent changes in the regulations and the current potential market for state water has provided a possible opportunity for the City to recover a more significant revenue offset. However, at the same time the annual costs associated with SWP water are anticipated to increase substantially while the available supply from the state has gone down resulting in a reduction of allocation to SWP Contractors in recent years to 40-50%. The higher costs and lower supplies are due to proposed projects in the Sacramento-San Joaquin Delta because of several years of drought and environmental concerns over protecting endangered species. The City is evaluating the existing policy on SWP water and the City's options related to short term and long term leases of its SWP entitlement.

2. Saticoy County Yard Well

In 2004 the County of Ventura proposed relocating their maintenance yard from the existing location to a site within the Saticoy Community contiguous to the City's water system. In exchange for City water service, which required an extraterritorial water service agreement, the County provided the City with a new well and pipeline facilities. The new well was provided to offset the County's anticipated water demand, as well as, provide significant additional water supply. The pipeline facilities provided by the County included approximately 2,320 feet of 14" pipeline from the new well to a location where the City would eventually complete the remainder of the raw water pipeline to the City's existing Saticoy Conditioning Facility for treatment.

A domestic pipeline was also provided that tied into the City's existing pipeline system at two locations. The County's' facilities were completed in 2006. The City's Capital Improvement Program (CIP) Plan included the City's portion of the raw water pipeline that connected the County provided raw water pipeline to the City's Saticoy County Yard Well. The City's' portion was completed in 2009. In November 2009 the City Council was to certify the Final EIR for the Saticoy & Wells Community Plan and Development Code. During the certification process the Fox Canyon Groundwater Management Agency (FCGMA) and United voiced concerns regarding the water supply anticipated from the Saticoy Yard Well for the project area. Consequently, the City approved a *Limitation and Tolling Agreement* whereby the parties agreed to a cooperative Operations Testing Plan to provide testing of the impact of the water drawn from the Saticoy County Yard Well. As a result of the testing under the Operations Plan it was determined that the April 2004 County of Ventura Saticoy Operations Yard EIR was not sufficient for the anticipated operations of the Saticoy County Yard Well and therefore additional environmental clearance is warranted for operation of the well.

Therefore, the anticipated future water supply from the Saticoy County Yard Well is unknown at this time. It should be noted that the City's 2005 Urban Water Management Plan (UWMP) and 2008 Biennial Water Supply Report included the Saticoy County Yard Well as a water supply source of up to 2,400 acre-feet per year.

3. Recycled Water

a. Ventura Water Reclamation Facility (VWRF)

As mentioned previously, currently the City's Water Reclamation Facility (VWRF) discharges most of its tertiary treated effluent to the Santa Clara River Estuary (Estuary) with approximately 700 acre-feet per year (AFY) diverted as recycled water for landscape irrigation by several users.

The City's current and past recycled water planning efforts have centered on issues related to the beneficial uses of the Estuary. These issues have required the City to consider whether or not discharge from the VWRF provided enhancements to the beneficial uses of the Estuary, and consequently affects the amount of recycled water that can supplement domestic water supply. The following describes the history and issues related to recycled water planning within the City's service area.

Historically, the VWRF has been permitted to discharge the majority of its effluent to the Estuary. However, during the 2008 re-issuance process, controversy arose on whether or not the City should be permitted to continue its current volume of discharge into the Estuary. The Discharge Permit issued by the RWQCB allowed continuation of the discharge but required the City to perform three extensive studies.

The studies included the Estuary Subwatershed Study (completed March 2011), Phase 1 Recycled Water Market Study (completed March 2010), and Treatment Wetlands Study (completed March 2010). The Discharge permit also identified a Phase 2 of the Recycled Water Study.

A draft of the Phase 2 Recycled Water Study was recently completed and a Stakeholder Workshop was held at the City on February 21, 2013. The intent of the study was to answer the following question, "What is the best use of the treated water resources from the VWRF to protect the health of the Estuary?" The previous studies mentioned and previous workshops narrowed potential project alternatives down to the most feasible and most beneficial. Some of the alternatives being considered in the Draft Phase 2 Recycled Water Study have the potential of providing the City with some amount of additional water supply in the future. This could be additional recycled water to offset

current potable uses or an additional water supply utilizing indirect or direct potable reuse.

b. Ojai Valley Sanitary District (OVSD)

In 2007, the City in partnership with the Ojai Valley Sanitary District (OVSD), completed a preliminary feasibility analysis for the re-use of effluent currently discharged from OVSD into the Ventura River. The discharge averages approximately 2 million gallons per day, and enters the river approximately 5 miles upstream of the Pacific Ocean. The first part of the analysis focused on environmental issues primarily related to impacts of reduced discharge flow on the receiving environment, and possible impacts to water quality as a function of reduced flows. The second part of the analysis considered engineering and market issues related to different levels of effluent re-use. Ultimately, from an economic perspective, the cost and difficulty of providing the infrastructure necessary to supply recycled water to potential users has to be balanced against the demand for such water, and the willingness of potential users to pay for it.

The engineering and market analysis identified a cost-effective combination of localized users that minimized the additional infrastructure necessary to supply the recycled water. The primary users identified were Aera Energy and local growers, with Aera accounting for the bulk of the demand. These users, which are currently supplied water from the City with a combination of untreated and potable water, could utilize recycled water in the future. The primary users in the 2007 study have reduced their water demands and the combined FY 2011-2012 water consumption of these users is approximately 300 AFY. Collectively, the environment, engineering and market analysis suggested that the re-use of at least a portion of the effluent is sufficiently feasible to justify further consideration, although full CEQA documentation and review will be necessary prior to implementation. The City and OVSD continue to discuss and work together to investigate the potential reuse of OVSD effluent.

4. Water Conservation Measures/Water Efficiency Plan

Water conservation measures may help sustain existing water use and delay the need for new water supplies. In 2011, City Council adopted a five-year Water Efficiency Plan that focuses, amongst other efforts, on educating the youth and reducing outdoor landscape watering. Outdoor

landscaping accounts for 40% to 60% of water use for residential units. The second year of the plan continues to focus efforts on reducing residential landscape watering. The efforts concentrate on appropriate watering for mature landscape as well as the planting of more sustainable gardens. Ocean Friendly Gardens provide potable water use savings as well as environmental sustainability capturing storm runoff. The City currently meets the State mandated 20% reduction target. City efforts now focus on maintaining this savings threshold and possibly providing a buffer in a three year drought period. This will be a continuing challenge for the City.

5. Establish Water Rights Ordinance

In September 2012, Ventura Water took the concept of a water rights ordinance to Council. As new development is proposed, a consistent methodology is important for securing water rights and projecting water demands. To maintain the City's supply levels and support long term sustainability, Ventura Water is drafting language for inclusion in a new water rights ordinance. The draft language includes providing rights, buying rights to offset new development demand, purchasing the City's rights as well as the payment of in-lieu fees. Parcels that are within the Fox Canyon Groundwater Management Agency (FCGMA) boundary that use groundwater for current water use have an opportunity to bring water rights with any proposed development. According to the FCGMA current policies, if a parcel has an "allocation" from a well within the boundary, the "allocation" may be transferred to the City so that the City's current allocation will be increased by that amount. This would generally be the case where the "allocation" is currently a municipal and industrial use (M&I). In the case where the parcel is in agriculture use and is utilizing the FCGMA's agriculture efficiency policy then the "allocation" that may be transferred to the City would be 1.5 acre-feet of groundwater "allocation" per acre of land. Parcels that are within the Santa Paula (SP) Basin boundary may have an allocation from an existing well that is serving that parcel or several parcels. Under the SP Basin Stipulated Judgment, the SP Basin Technical Advisory Committee has transfer procedures where a property owner may transfer water rights associated with the parcel to the City.

5. CONCLUSIONS & RECOMMENDATIONS

A. Conclusions

Based on the known supply conditions and the calculated water demand for the present condition, it appears that the current water demand exceeds the available supply. However, it is apparent that the "calculated" water demand for the current condition (22,754 AFY) is overly conservative. The current water demand figures calculated within this Report utilize a baseline water demand from 2005 of 20,808 AFY. Based on the FY 2011-2012 water consumption data, it is likely that the City's current water demands are closer to 17,300 AFY, below the current available supply of 19,600 AFY.

However, it is also well documented that current water demands are at historically low levels, mainly due to drought, environmental and economic factors. The City's average annual water demand for years 2005-2009 was 19,300 AFY, which is uncomfortably close to the current water supply available.

Utilizing development projections developed as a part of the 2005 General Plan, the anticipated growth in water demand through 2025 is 4,020 AFY, which results in a total projected water demand of 26,774 AFY, well above the predicted 24,200 AFY of supply (which is on the high end of the range). The future water demand projections utilize the water demand factors published in the 2005 General Plan FEIR. The demand factors are "planning-level" numbers, and therefore are on the conservative side. It is likely that the actual water demand factors are much lower than those used to project the future demands.

The City's available water supply is constantly changing, depending upon environmental and legal constraints. At any time, the available water supply for the City could drop to an annual average of 18,000 AFY.

Figure 5-1 provides a graphical representation of the existing and projected water demand

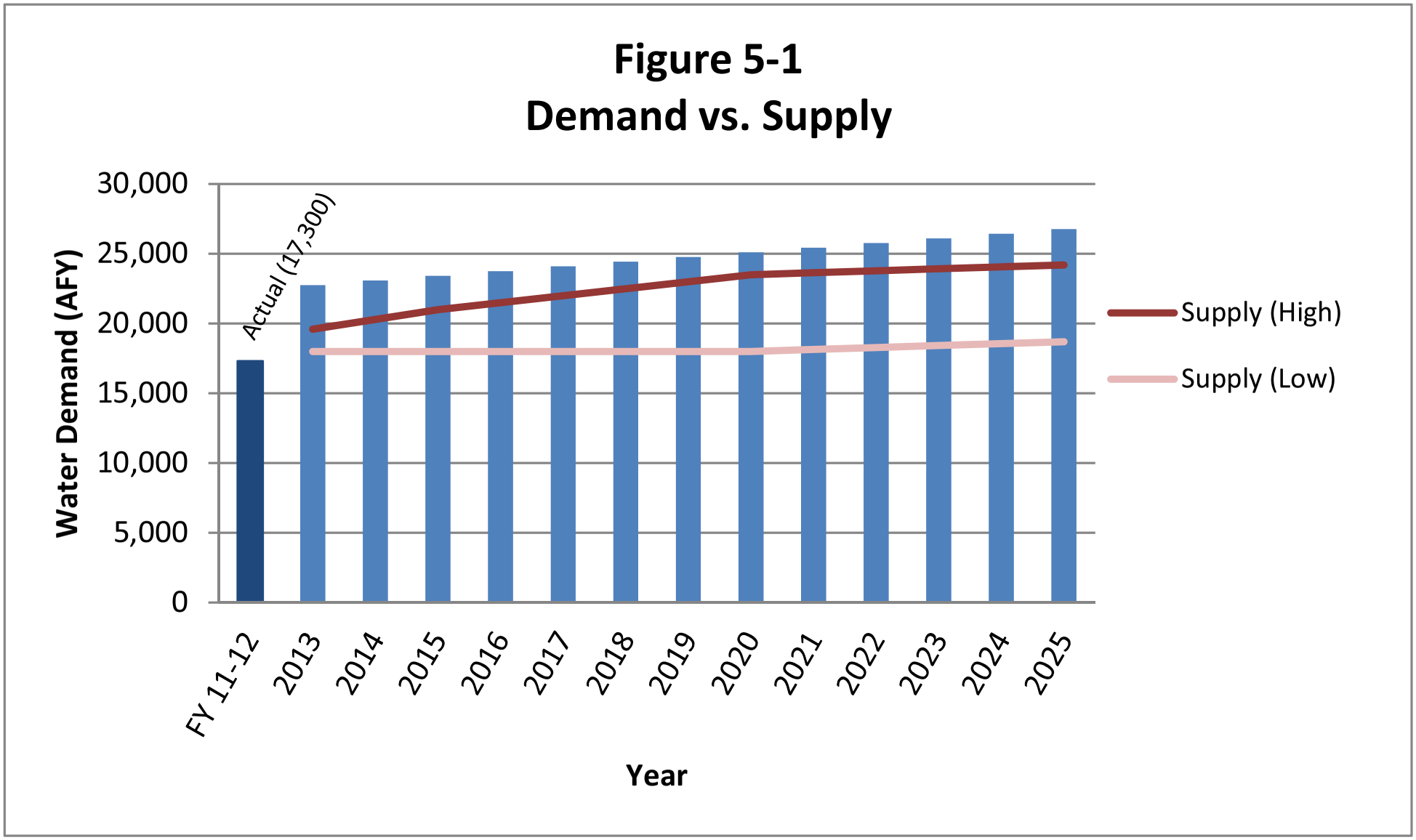
Figure 5-1
Demand vs. Supply
30,000
25,000
20,000
15,000
10,000
5,000
0
Water Demand (AFY)
Actual (17,300)
FY 11-12
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
Year
Supply (High)
Supply (Low)

B. Recommendations

Moving forward, it is recommended that the City utilizes current consumption data to develop both the existing demand condition, and also develop more realistic demand factors for the various land uses within the City. In order to develop more realistic demand factors, the City will need to accurately define the existing land use conditions for the various land use categories within the City. In addition, the water consumption data will need to be attributed to the correct land use categories. This can be accomplished by mapping the water billing classifications with the General Plan land use categories, and perhaps developing a new set of water demand factor classifications. By utilizing current water consumption data, and current land use data, a more accurate set of water demand factors can be determined. The more accurate demand factors will allow for a more realistic projection of future water demands where the development plan has been identified.

APPENDICES

Demand Factors from Other Agencies:
- Simi Valley (VCWWD No. 8)
- Thousand Oaks
- Irvine Ranch Water District
- Santa Margarita Water District

LAFCo 13-01S Sphere of Influence Report

2005 General Plan:
- Table 3-1
- Table 3-2
- Figure 3-1
- Figure 3-5

2005 General Plan FEIR:
- Table 4-13.7
- Table 4-13.8
- Table 4-13.15

2010 UWMP:
- Table 2-1
- Table 2-5
- Table 3-1

2011 Water Master Plan:
- Tables II-1 thru II-4
- Table V-14

LAFCo MSR Report

Attachment D: Development Entitlement Report 2005-2012 (Approved, Under Construction and Built Projects)

2005 General Plan FEIR Water Demand Factors (email correspondence)

C. Water Demand and Peaking Factors

The water demand factors for different land use types within the District are as follows:

Table III - 1: Water Demand Factors

Land Use Description	Density (DU/Acre)	Demand Factor*	Unit*
High Density Residential	10.1 – 18.1+	5.70	gpm/acre
Medium Density Residential	3.1 – 10	1.40	gpm/acre
Low Density Residential	0 – 3	1.10	gpm/acre
Detached Residential			
Small, up to 9,999 SF lot	--	420	gal/du/day
Medium, 10,000 to 22,000 SF lot	--	840	gal/du/day
Large, 22,001 to 1 Acre SF lot	--	1680	gal/du/day
Condominium	--	259	gal/du/day
Multi-Family Apartment	--	222	gal/du/day
Retirement Facility (per room)	--	92	gal/du/day
Senior Apartment	--	111	gal/du/day
Commercial – Light	--	1.75	gpm/acre
Commercial – Heavy	--	2.35	gpm/acre
Commercial – Office	--	2.00	gpm/acre
Industrial – Light	--	1.95	gpm/acre
Industrial – Heavy	--	9.20	gpm/acre
Industrial – Business Park	--	2.00	gpm/acre
Parks	--	1.10	gpm/acre
Hospitals	--	1.85	gpm/acre
Schools	--	1.20	gpm/acre
Community Services	--	1.35	gpm/acre

*Factor shall be applied to raw acreage and not building footprint.

Peaking factors are used to estimate maximum month, maximum day and peak hour demands. These factors, wherever possible, are based on actual water usage. When actual water data is not available, peaking factors are based on typical industry standards for water purveyors in Southern California.

Table 3-1 Land Use and Water Use Factors

		Land Use		Local Demands			Irrigation Demands	
Code	Land Use description	Agency	Average Density	Local Interior	Local Exterior	Total	% Irrigated Area	Irrigation Factor
1100	***Residential***		*DU/Ac*		*Gal/DU/Day*			*Gal/Ac/Day*
1111	Res - Rural Density	Orange	0.30	300	750	1,050	5	2,800
1121	Res - Estate Density	Orange	1.20	300	300	600	8	2,900
1131	Res - Low Density	Orange	4.00	300	300	600	15	2,900
1141	Res - Low-Medium Density	Orange	10.50	200	100	300	22	3,300
1161	Res - Medium Density	Orange	19.50	225	185	410	17	3,100
1122	Res - Estate Density	Irvine	0.50	300	600	900	7	2,800
1132	Res - Low Density	Irvine	3.00	225	180	405	16	3,000
1162	Res - Medium Density	Irvine	7.50	200	110	310	20	3,100
1172	Res - Medium-High Density	Irvine	17.50	165	15	180	25	3,600
1182	Res - High Density	Irvine	32.50	180	20	200	20	3,300
1133	Res - Low Density	Newport Beach	1.00	250	190	440	17	3,100
1153	Res - Medium-Low Density	Newport Beach	2.75	250	200	450	10	2,800
1163	Res - Medium Density	Newport Beach	5.00	190	60	250	22	3,300
1183	Res - High Density	Newport Beach	12.25	155	20	175	25	3,600
1134	Res - Low Density PC	Tustin	4.50	225	185	410	17	3,100
1164	Res - Medium Density PC	Tustin	11.80	155	15	170	25	3,600
1184	Res - High Density PC	Tustin	17.40	135	15	150	15	3,700
1115	Res - Rural Density	County	0.26	300	750	1,050	05	2,800
1135	Res - Suburban Density	County	9.25	225	180	405	16	3,000
1175	Res - Urban Density	County	29.00	165	15	180	25	3,600
1200	***Commercial***		*KSF/Ac*		*Gal/KSF/Day*			*Gal/Ac/Day*
1210	Comm - General Office		25.00	56	4	60	30	4,000
1221	Comm - Community		9.09	209	11	220	30	3,500
1222	Comm - Regional		10.53	180.5	9.5	190	20	5,000
1230	Comm - Recreation		8.33	54	6	60	30	4,500
1240	Comm - Institutional		8.88	39.38	5.62	45	50	2,750
1244	Comm - Hospital		8.70	218.50	11.50	230	25	2,850
1260	Comm - School		13.33	14.25	0.75	15	50	2,500
1273	Comm - Military Air Field							
1300	***Industrial***		*KSF/Ac*		*Gal/KSF/Day*			*Gal/Ac/Day*
1310	Industrial - Light		25.00	56	4	60	25	4,000
1320	Industrial - Heavy		25.00	4,500	500	5,000	25	4,000
	Open Space & Other							*Gal/Ac/Day*
1820	Park - Community						90	3,400
1830	Park - Regional						85	2,100
2100	AG - Low-Irrigated						100	1,800
2200	AG - High-Irrigated						100	3,100

Note: The database includes the following land use codes that do not use set factors or do not generate water demands: 0 = area not served by IRWD; 1411 = Airports; 1413 = Freeway and Major Roads; 1850 = Park-Wildlife Preserve; 1880 = Park-Open Space (Rec); 1900 = Vacant; 4100 = Water Body; 9100 = Mixed Use (uses a combination of factors)

Pipe velocities should be a minimum of 1 foot per second (fps) in order to adhere to required water quality regulations and maintain proper circulation throughout the system.

C. WATER DEMAND FACTORS

The City does not currently have published water demand factors for different land use types. For future planning projects, a more detailed list of conservative demand factors is recommended. The following demand factors, listed in Table III-1, are based on industry standards for water purveyors in the Southern California region.

Table III-1
Water Demand Factors

Land Use Description	Density (DU/Acre)	Demand Factor	Unit
High Density Residential	15-30	180	gal/du/day
Medium Density Residential	4.5-15	310	gal/du/day
Low Density Residential	2-4.5	405	gal/du/day
Very Low Density Residential	0-2	440	gal/du/day
Reserve Residential (ultimate need)	0-2	440	gal/du/day
Commercial/Residential (High Density)	15	200	gal/du/day
Commercial	-	130	gal/ksf/day
Industrial	-	60	gal/ksf/day
Institutional	-	45	gal/ksf/day
Elementary School	-	15	gal/ksf/day
Intermediate School	-	15	gal/ksf/day
High School	-	15	gal/ksf/day
Existing Parks, Golf Courses, Open Space	-	3400	gal/ac/day
Proposed Park and Recreation Areas	-	3400	gal/ac/day
Residential Developable Land (ultimate need)	0.2-1.0	440	gal/du/day

Table 3-1 Land Use and Water Use Factors

		Land Use		Local Demands			Irrigation Demands	
Code	Land Use description	Agency	Average Density	Local Interior	Local Exterior	Total	% Irrigated Area	Irrigation Factor
1100	*Residential*		*DU/Ac*		*Gal/DU/Day*			*Gal/Ac/Day*
1111	Res - Rural Density	Orange	0.30	300	750	1,050	5	2,800
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1210	Comm - General Office		25.00	56	4	60	30	4,000
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1222	Comm - Regional		10.53	180.5	9.5	190	20	5,000
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1240	Comm - Institutional		8.88	39.38	5.62	45	50	2,750
1244	Comm - Hospital		8.70	218.50	11.50	230	25	2,850
1260	Comm - School		13.33	14.25	0.75	15	50	2,500
1273	Comm - Military Air Field							
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1310	Industrial - Light		25.00	56	4	60	25	4,000
1320	Industrial - Heavy		25.00	4,500	500	5,000	25	4,000
	Open Space & Other							*Gal/Ac/Day*
1820	Park - Community						90	3,400
1830	Park - Regional						85	2,100
2100	AG - Low-Irrigated						100	1,800
2200	AG - High-Irrigated						100	3,100

Note: The database includes the following land use codes that do not use set factors or do not generate water demands: 0 = area not served by IRWD; 1411 = Airports; 1413 = Freeway and Major Roads; 1850 = Park-Wildlife Preserve; 1880 = Park-Open Space (Rec); 1900 = Vacant; 4100 = Water Body; 9100 = Mixed Use (uses a combination of factors)

Table IV - 1
Santa Margarita Water District
Improvement District Nos. 4C, 4E, 5 & 6 Plan of Works
Domestic Water Use Factors

Land Use	Demands			
	Interior	Exterior	Total	
A. Residential				
Detached Residential	300	150	450	gpd/ DU
Attached Residential	175	0	175	gpd/ DU
Apartments	175	0	175	gpd/ DU
Senior SFR	200	100	300	gpd/ DU
B. Non-Residential Uses				
Commercial/ Industrial			225	gpd/ 1000sf
Community Facilities			225	gpd/ 1000sf
Elementary School			10	gpd/ student
Middle School			10	gpd/ student
High School			15	gpd/ student

VENTURA LOCAL AGENCY FORMATION COMMISSION
STAFF REPORT
Meeting Date: January 16, 2013

Agenda Item 12

TO: LAFCo Commissioners

FROM: Kim Uhlich, Executive Officer KU

SUBJECT: LAFCo 13-01S City of San Buenaventura Sphere of Influence Review and Update

---

RECOMMENDATIONS:

Adopt attached Resolution LAFCo 13-01S making determinations and updating the sphere of influence for the City of San Buenaventura.

BACKGROUND:

For each city and special district LAFCo must determine and adopt a sphere of influence. A sphere of influence is defined as a plan for the probable physical boundaries and service area of a local agency, as determined by the Commission (Government Code §56076). Effective January 1, 2001 each LAFCo is required to review and, as necessary, update the sphere of influence ("sphere" or "SOI") of each city and special district on or before January 1, 2008, and every five years thereafter (Government Code §56425(g)). Prior to updating a SOI, LAFCo is required to conduct a municipal service review ("service review" or "MSR") (Government Code §56430).

On March 21, 2007 the Commission accepted a MSR report and, on June 13, 2007, updated the City of San Buenaventura sphere of influence to conform to assessor parcel boundaries and exclude all territory subject to the Hillside Voter Participation Act. Based on a work plan for the second round of sphere reviews adopted by the Commission in May 2008, a sphere of influence review for the nine cities was scheduled for completion in 2012. On November 14, 2012 LAFCo accepted the MSR report for nine cities in Ventura County, including the City of San Buenaventura.

COMMISSIONERS AND STAFF

COUNTY:	CITY:	DISTRICT:	PUBLIC:
Kathy Long	Carl Morehouse	Bruce Dandy	Linda Ford-McCaffrey
Linda Parks	Janice Parvin, Chair	Gail Pringle, Vice Chair	
Alternate:	*Alternate:*	*Alternate:*	*Alternate:*
Steve Bennett	Carol Smith	Elaine Freeman	Lou Cunningham
Executive Officer:	**Dep. Exec. Officer**	**Office Mgr/Clerk**	**Legal Counsel**
Kim Uhlich	Kai Luoma	Debbie Schubert	Michael Walker

DISCUSSION:

Based on the recently accepted MSR report for the nine cities, no significant changes to the sphere for the City of San Buenaventura appear to be necessary at this time. However, a minor amendment to the sphere of influence is being recommended to remove several agricultural and rail road right of way parcels located between Highway 101 and Channel Drive (Attachment 1). The reason is to correct a recently discovered mapping error. According to County Information Technology Services Department staff, the subject territory was erroneously included in the sphere when the County transitioned to GIS from a CAD (computer aided design) system prior to 2001. Since that time, each subsequent sphere map adopted by the Commission included the territory so any decision to exclude it may only be done through formal Commission action.

The County General Plan land use designation for the territory is "Agricultural-Urban Reserve" and it is zoned "Coastal Agriculture, 40 acre minimum". The City Comprehensive Plan land use designation is "Agriculture" and is therefore subject to the City SOAR ordinance which prohibits any amendment of the agricultural land use designation without an affirmative vote of the people. The area is currently in agricultural production, no City services are being provided and no proposals for development are pending with the City. As the territory has not been designated for non-agricultural use by the City's General Plan and is not likely to be developed within five years, removal of the area from the sphere would be consistent with the Commission's general policies pertaining to agricultural and open space preservation.

Attachment 2 is a December 20, 2012 letter from Jeffrey Lambert, Community Development Director for the City of San Buenaventura, acknowledging the recommended sphere of influence update and commenting that any future decision by the City to convert the affected territory to non-agricultural uses would be largely influenced by provisions of the California Coastal Act and the City's Local Coastal Program relating to the protection of coastal agricultural lands.

For CEQA purposes, the City of San Buenaventura sphere of influence update is exempt from CEQA under Section 15061(b)(3) of the CEQA Guidelines. This is the "general rule" exemption, meaning that it can be seen with certainty that there is no possibility that the activity in question may have a significant effect on the environment because the recommended sphere of influence update reduces the extent of territory planned to be included within the City's physical boundaries and service area.

Pursuant to Government Code Section 56425(e) it is recommended that the Commission consider and adopt written statements of its determinations with respect to each of the following:

(1) *The present and planned land uses in the area, including agricultural and open-space lands.* – The sphere of influence update for the City of San Buenaventura is to provide for all areas currently developed and within the City boundary to be

included in the City's sphere of influence, and to correct a previous mapping error which resulted in the inadvertent inclusion of agricultural and rail road right of way segments within the sphere. The affected territory is currently being used for agriculture and no changes in land use are anticipated at this time.

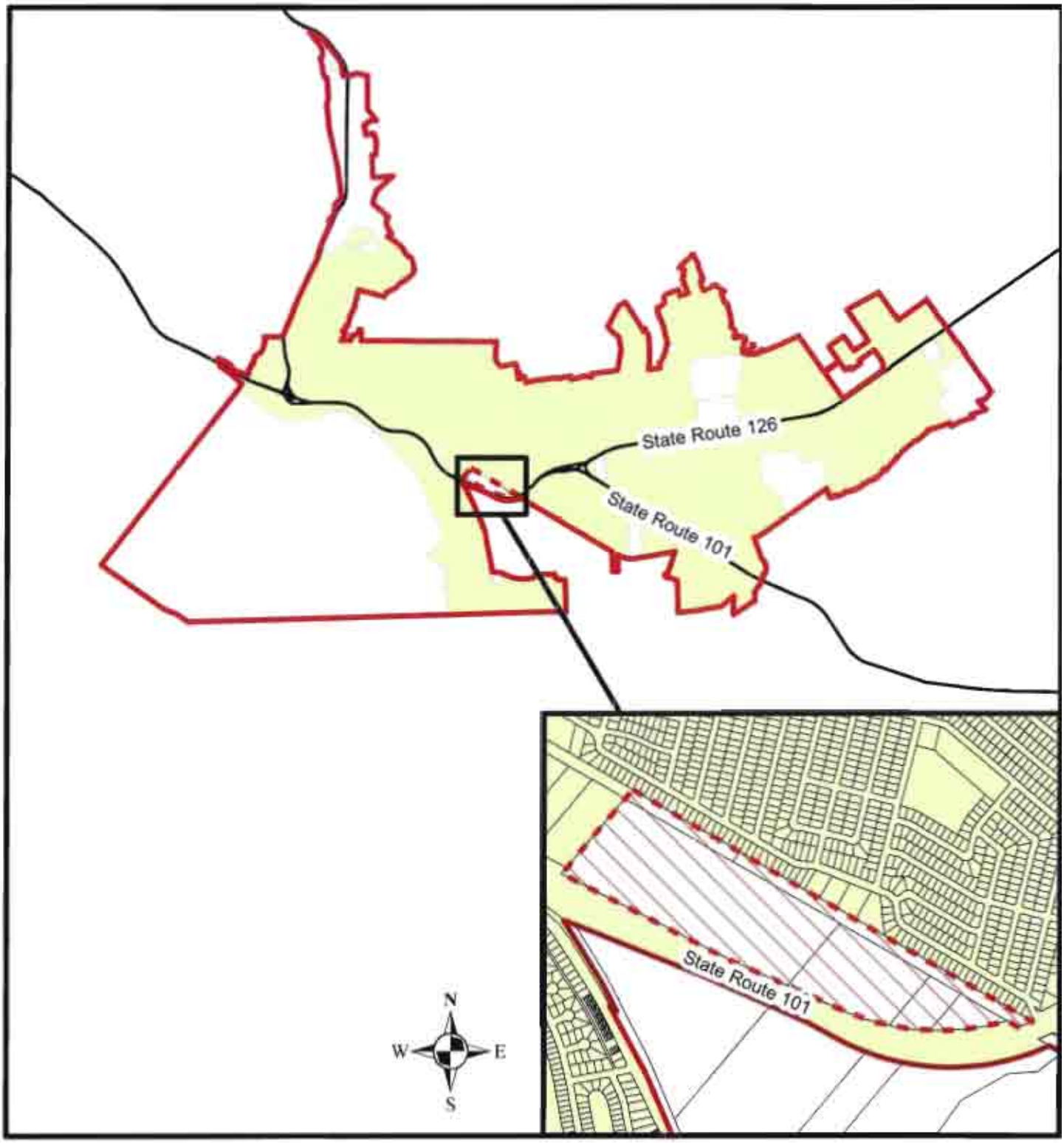
(2) *The present and probable need for public facilities and services in the area.* – No changes in public facilities or services provided by the City will result from this sphere of influence update.

(3) *The present capacity of public facilities and adequacy of public services that the agency provides or is authorized to provide.* – The sphere of influence update will not affect the present capacity of public facilities or the adequacy of the services provided by the City of San Buenaventura.

(4) *The existence of any social or economic communities of interest in the area if the commission determines that they are relevant to the agency.* - The sphere of influence update will not affect any social or economic communities of interest in the area.

(5) *The present and probable need for City sewer, municipal and industrial water, or structural fire protection services for any disadvantaged unincorporated communities within the existing sphere of influence.* – The Commission determined that the community of Saticoy, located within the City sphere of influence, is a disadvantaged unincorporated community (Commissioner's Handbook Section 3.2.5). Saticoy receives wastewater services from the Saticoy Sanitary District, an independent special district which serves only the community of Saticoy. Potable water services are provided by the City and customers are subject to the City's water surcharge for service provided outside of City limits. City policy generally precludes new or expanded water services greater than a ¾-inch meter, thus, limiting the amount of multi-family, commercial, and industrial development/redevelopment that can occur within the community. Law enforcement services are provided by the County Sheriff's Office and fire protection services are provided primarily by the City under a mutual aid agreement.

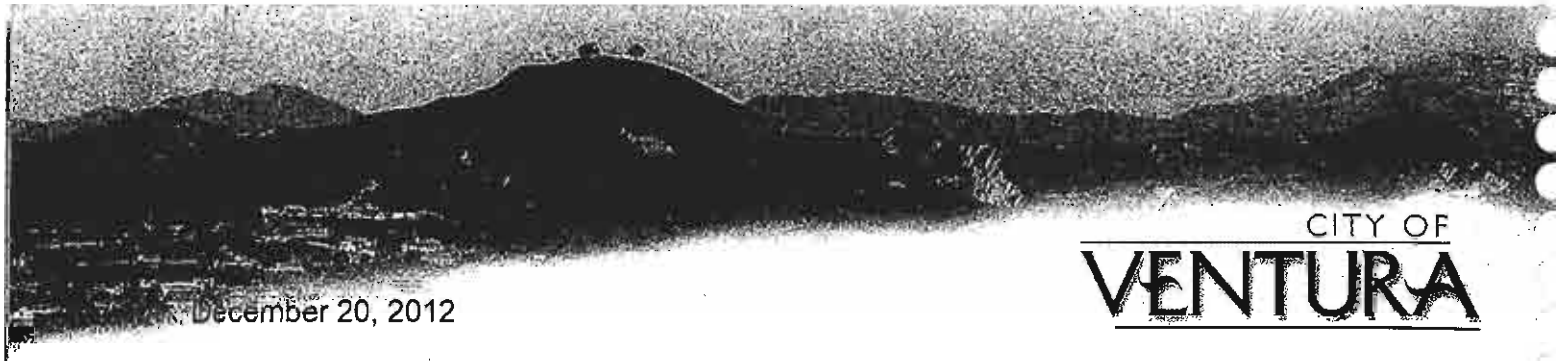
Attachments:
(1) City of San Buenaventura Sphere of Influence Map
(2) Letter from City of Ventura Community Development Director Jeff Lambert dated December 20, 2012
(3) Resolution LAFCo 13-01S – City of San Buenaventura Sphere of Influence Update



LAFCo 13-01S
City of San Buenaventura
Sphere of Influence Review/Update

Legend

- Current Sphere of Influence
- Area to be Excluded from Sphere
- City of San Buenaventura



CITY OF VENTURA

December 20, 2012

Ms. Kim Uhlick
Ventura LAFCo Executive Officer
800 South Victoria Avenue
Mail Stop 1850
Ventura CA 93009-1850

Subject: LAFCo Sphere of Influence (SOI) Review and Updates

Dear Kim:

City staff met recently with LAFCo staff to discuss your current effort to review and update the City of San Buenaventura Sphere of Influence (SOI). LAFCo is mandated to initiate and complete this review and your intent to provide the review and update to the Commission at their January 2013 hearing.

During your review process, you found that a mapping error has occurred during the conversion of hard maps to the County GIS system for the City's SOI boundary. The subject properties in question involve several agricultural and rail road right of way parcels located between Highway 101 and Channel Drive (see attached Map and County GIS/IT Services staff memorandum). Based upon the current review effort, LAFCo seeks to correct the SOI boundary by removing the subject properties. You also provided SOI boundary documentation maps from 1981 and 1991, in addition to a 1992 City letter from then Community Development Director Everett Millais, all of which identifies the properties outside of the SOI boundary. You concluded that the SOI map adopted on June 12, 2002 is when the properties were mistakenly included in the SOI.

The City has reviewed your request and researched our historical files regarding the property site and the SOI boundary. If the mapping error is correct, then the erroneous boundary has been tracking across many planning efforts at the City. For example, the City's 1989 Comprehensive Plan includes the subject properties, the 2002 re-adoption of the Ventura-Oxnard Greenbelt excludes the properties because they were identified in the SOI, and lastly the 2005 General Plan and EIR also included the sites within the SOI, are designated under County SOAR, and were studied as part of the City's Potential Expansion Areas. The City cannot make a conclusive determination of the error or not, and therefore the Commission will need to complete their review and decide their action.

Regardless of the SOI boundary line and any future LAFCo action to update it or not, these properties are within the City's coastal zone and as such are subject to the Local

Coastal Program (LCP) and Coastal Act provisions for agricultural resource protection. Conversion of this land to non-agricultural uses would require significant evidence and justification to overcome the strong agricultural resource protection findings of the LCP. Therefore in the framework of local/state land use regulations processes, the LCP and any necessary amendment is frankly the most important determinant for current and future land uses.

Sincerely,

Jeffrey Lambert, AICP
Community Development Director

c: Dave Ward, Planning Manager

Enclosure: County Memorandum and Map Exhibit, June 9, 2010

MEMORANDUM

DATE: 6-9-2010

TO: Kim Uhlich, Ventura LAFCo Executive Officer

FROM: David Hutchison, Sr. GIS Specialist, IT Services Department, GIS Division

SUBJECT: The Relationship of Assessor Parcels 080-0-020-150, -170, - 210, and - 290 to the City of Ventura Sphere of Influence Boundary as Reflected in the County's Initial GIS mapping records

---

The following is provided in response to your request for information about the subject territory in relation to the City of Ventura sphere of influence boundary at the time the County's Cadds data was first converted into a GIS format. As you are aware, the sphere boundary reflected in the original GIS mapping records included the subject territory and was the basis for the sphere boundary that LAFCo "re-adopted" for the City of Ventura in 2002.

The parcels in question are located between US 101 and Ventura city limits and include APNs 080-0-020-150, -170, - 210, and -290 and the freeway annexation LAFCO Resolution 69-44, Freeway Addition No. 1.

Process description: The dataset was initially developed by interpreting legal descriptions and matching boundaries to the existing parcel layer (property lines). Updates are made by merging or detaching recent city annexation or detachments polygons into the existing city sphere data.

In 1998 County GIS (formally – PWA, Engineering Mapping) started the conversion of Cadds data into a GIS format. Polygon parcels were created in ArcInfo (GIS format) from Cadds line work. City Boundaries and City Sphere boundaries were created using the same process.

In the latter months of 2001 County GIS began the process of converting City Annexations from a Cadds environment into a GIS environment. Cadds line work was imported into the GIS program and polygons were created. The polygons created were assigned attributes fields and those fields were populated. The program at the time did not allow for null polygons (holes or islands) within the boundaries. A field was created called "Island" and a value given. If the polygon was not an annexation or detachment with value fields the island field was populated with the value "y" which meant yes.

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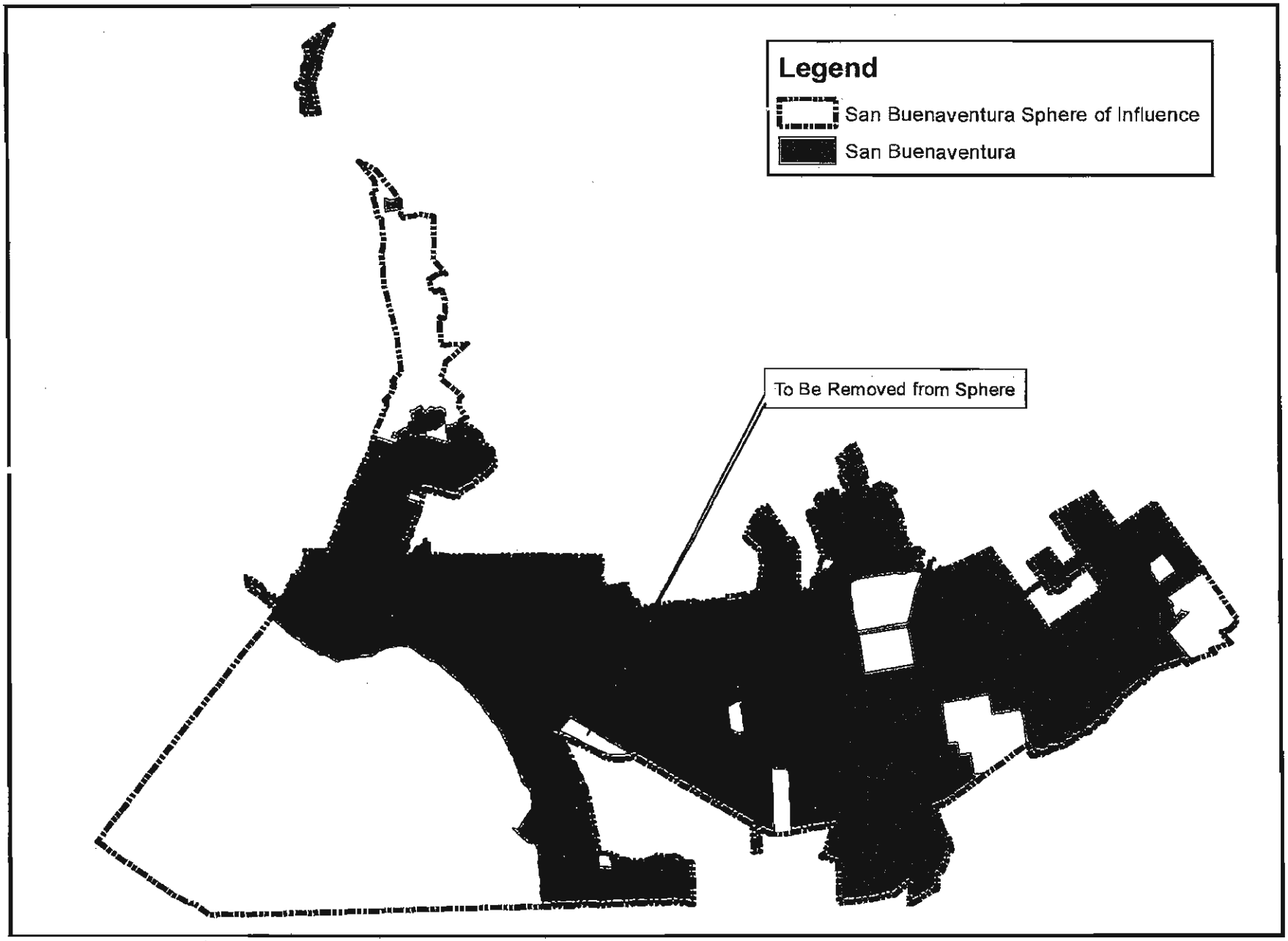
http://www.ventura.lafco.ca.gov

In order to minimize the update process for city boundaries and for the spheres to have coincident geometry for shared boundaries a work flow was developed to maintain the city annexations. The appropriate polygons were exported out to create the city boundaries and merged or detached from the sphere boundary.

The archive computer logs show:
During the creation of the city sphere for the City of Ventura the city annexations were merged to create the sphere boundary (where applicable). An island was missed as being excluded in this process (it is assumed as being missed as no documentation or correspondence can be found to support its' inclusion)* and incorporated into the sphere boundary.

*County GIS works closely with the Public Works Agency, Survey Engineering group and LAFCO to insure the accuracy of its data. After the data was converted into a GIS format the annexations, boundaries and spheres were internally checked by GIS then reviewed by Survey Engineering and LAFCO. There is no documentation or correspondence to support the inclusion of this area and it can only be assumed that at this time this was an overlooked error, as another island in a different area was not included.
It should also be noted that LAFCO Resolution 69-44 Freeway Addition No. 1 Ordinance No. 1592 Recorded on October 22, 1969 does not mention the inclusion of that area into the sphere either.


Legend
San Buenaventura Sphere of Influence
San Buenaventura
To Be Removed from Sphere

LAFCo 13-01S

RESOLUTION OF THE VENTURA LOCAL AGENCY FORMATION COMMISSION MAKING DETERMINATIONS AND APPROVING THE UPDATE OF THE SPHERE OF INFLUENCE FOR THE CITY OF SAN BUENAVENTURA

WHEREAS, Government Code Section 56425 et seq. requires the Local Agency Formation Commission (LAFCo or Commission) to develop and determine the sphere of influence of each local governmental agency within the County; and

WHEREAS, Government Code Section 56425(g) requires that LAFCo, as necessary, review and update the adopted sphere of influence boundaries on or before January 1, 2008 and every five years thereafter; and

WHEREAS, Government Code Section 56430 requires that a municipal service review be conducted prior to or in conjunction with a sphere of influence update; and

WHEREAS, LAFCo conducted a municipal service review of the services provided by the City of San Buenaventura and adopted written determinations as required by Government Code Section 56430 on November 14, 2012 for the services provided by the City; and

WHEREAS, the City staff has reviewed the changes proposed for this sphere of influence update and have no objections; and

WHEREAS, no change in regulation, land use or development will occur as a result of updating the City's sphere of influence; and

WHEREAS, at the times and in the manner required by law, the Executive Officer gave notice of the consideration of this action by the Commission; and

WHEREAS, the sphere of influence update action was duly considered at a public hearing on January 16, 2013; and

WHEREAS, the Commission heard, discussed and considered all oral and written testimony for and against the sphere of influence update including, but not limited to, testimony at the public hearing on January 16, 2013 and the LAFCo Executive Officer's staff report and recommendation;

NOW, THEREFORE, BE IT RESOLVED, DETERMINED AND ORDERED as follows:

(1) The Executive Officer's Staff Report and Recommendation for approval of the sphere of influence update for the City of San Buenaventura, dated January 16, 2013 is adopted.

(2) The Commission has considered the criteria set forth in Government Code §56425(e) and determines as follows:

a) *The present and planned land uses in the area, including agricultural and open-space lands.* – The sphere of influence update for the City of San Buenaventura is to provide for all areas currently developed and within the City boundary to be included in the City's sphere of influence, and to correct a previous mapping error. There will be no development, no change in land use and no impact to agricultural and open space lands as a result of the sphere of influence update.

b) *The present and probable need for public facilities and services in the area.* – No changes in public facilities or services provided by the City will result from this sphere of influence update. The City bases its public facilities and services on the extent of its existing infrastructure and its General Plan.

c) *The present capacity of public facilities and adequacy of public services that the agency provides or is authorized to provide.* – The sphere of influence update will not affect the present capacity of public facilities or the adequacy of the services provided by the City of San Buenaventura.

d) *The existence of any social or economic communities of interest in the area if the commission determines that they are relevant to the agency.* – The sphere of influence update will not affect any social or economic communities of interest in the area.

e) *The present and probable need for City sewer, municipal and industrial water, or structural fire protection services for any disadvantaged unincorporated communities within the existing sphere of influence.* – The Commission determined that the community of

Saticoy, located within the City's existing sphere of influence, is a disadvantaged unincorporated community (Commissioner's Handbook Section 3.2.5). Saticoy receives wastewater services from the Saticoy Sanitary District, an independent special district which serves only the community of Saticoy. Potable water services are provided by the City and customers are subject to the City's water surcharge for service provided outside of City limits. City policy generally precludes new or expanded water services greater than a ¾-inch meter, thus, limiting the amount of multi-family, commercial, and industrial development/redevelopment that can occur within the community. Law enforcement services are provided by the County Sheriff's Office and fire protection services are provided primarily by the City under a mutual aid agreement.

(3) The sphere of influence for the City of San Buenaventura is hereby updated to be the area shown as "proposed sphere of influence", as generally depicted on Exhibit A attached hereto.

(4) The Commission directs staff to have the official sphere of influence geographic information system data maintained for the Ventura LAFCo by the Ventura County Information Technology Services Department as the official sphere of influence record for the City of San Buenaventura updated consistent with this action.

(5) In accordance with the Executive Officer's determination, the Commission, as lead agency for the purposes of the California Environmental Quality Act (CEQA), hereby determines that the sphere of influence update for the City of San Buenaventura is exempt pursuant to Section 15061(b)(3) of the CEQA Guidelines.

(6) The Commission directs staff to file a Notice of Exemption as lead agency under Section 15062 of the CEQA Guidelines.

This resolution was adopted on January 16, 2013.

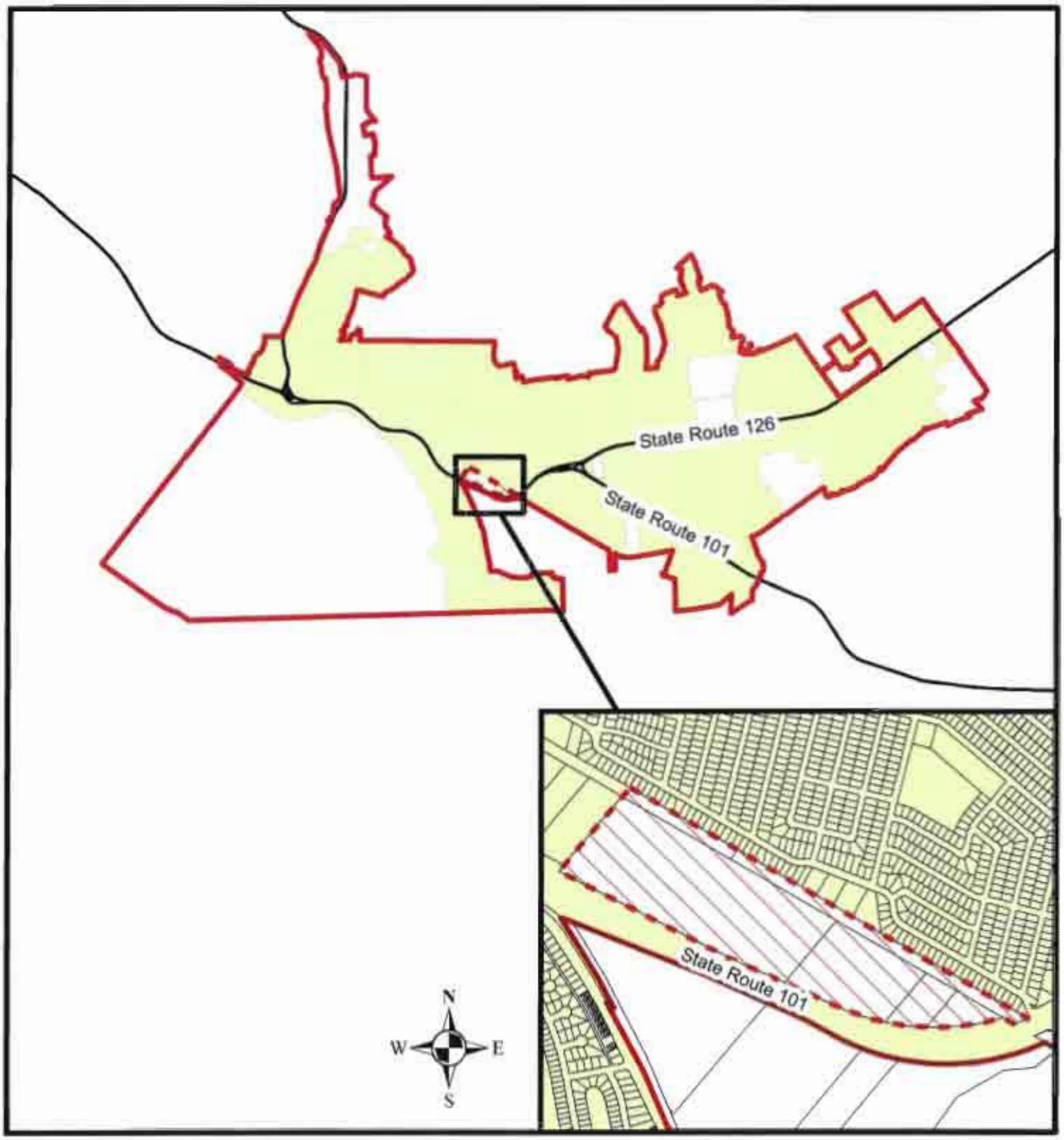
	AYE	NO	ABSTAIN	ABSENT
Commissioner Dandy	☐	☐	☐	☐
Commissioner Long	☐	☐	☐	☐
Commissioner Ford-McCaffrey	☐	☐	☐	☐
Commissioner Morehouse	☐	☐	☐	☐
Commissioner Parks	☐	☐	☐	☐
Commissioner Parvin	☐	☐	☐	☐
Commissioner Pringle	☐	☐	☐	☐
Alt. Commissioner Bennett	☐	☐	☐	☐
Alt. Commissioner Cunningham	☐	☐	☐	☐
Alt. Commissioner Freeman	☐	☐	☐	☐
Alt. Commissioner Smith	☐	☐	☐	☐

Dated:_____ _____

Chair, Ventura Local Agency Formation Commission

Attachments: Exhibit A

Copies: City of San Buenaventura
Ventura County Surveyor
Ventura County Geographic Information Systems Officer
Ventura County Planning Department



LAFCo 13-01S
City of San Buenaventura
Sphere of Influence Review/Update

Legend

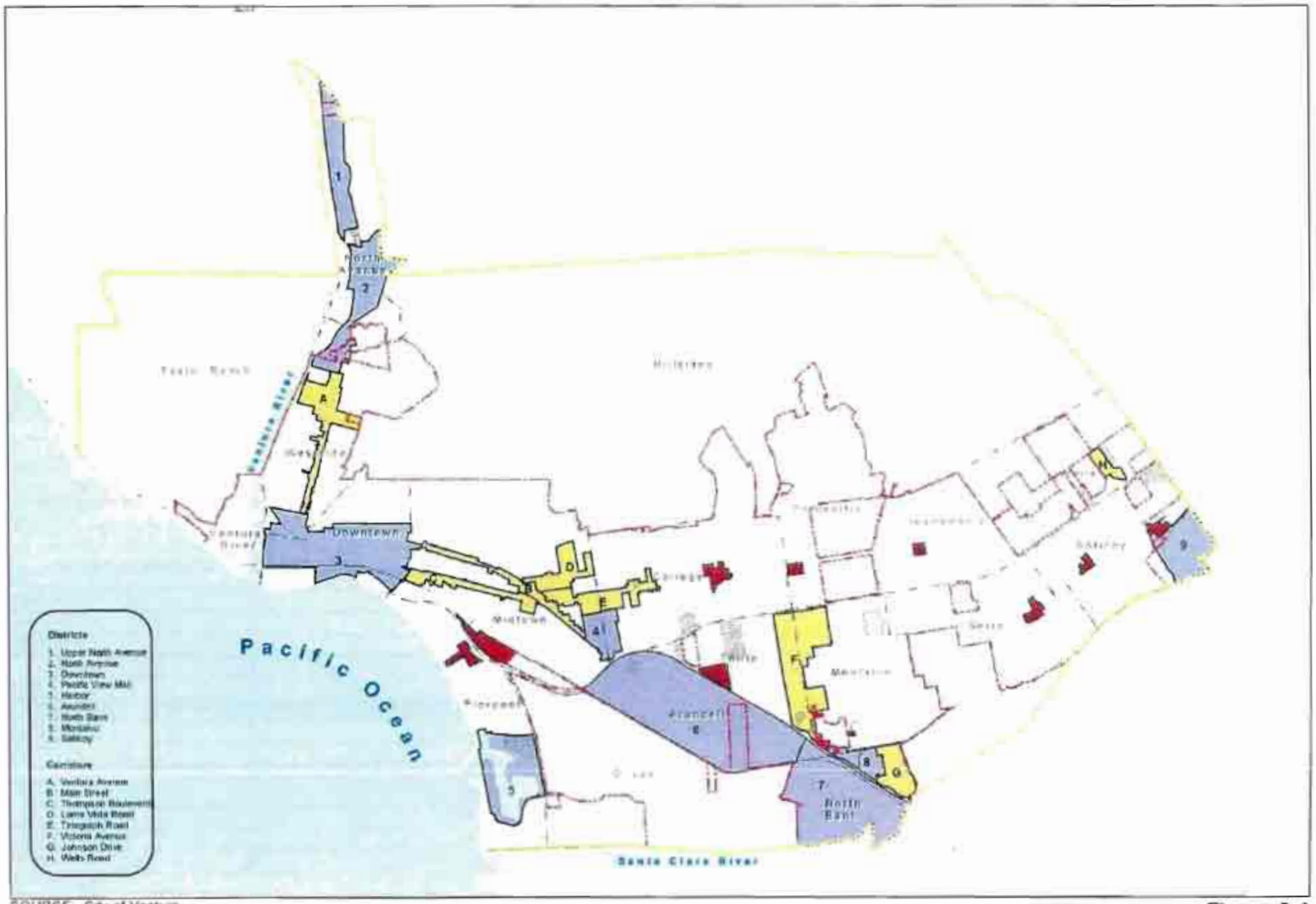
- Current Sphere of Influence
- Area to be Excluded from Sphere
- City of San Buenaventura

Table 3-1. Potential Development Based on Carrying Capacity of Land Area

Planning Designation	Allowed Density (du/acre)	Existing Development 2004					General Plan Capacity			
		Single Family Units	Multi Family Units	Comm./Ind. Sq. Ft.	Parcels	Acres	Vacant Parcels	Vacant Acres	Additional Potential[3] Units	Additional Potential[3] Sq. Ft.
Neighborhood Low	0-8	19,425	3,335	49,386	22,511	4,629	108	426	1,221	
Neighborhood Medium	9-20	1,163	8,965	149,513	4,414	1,061	32	116	4,859	
Neighborhood High	21-54	814	2,468	194,143	1,634	303	8	16	8,477	
Commerce[1]		257	490	4,995,248	1,366	808	95	108	7,892	22,328,276
Industry[2]		29	31	8,299,840	1,037	1,401	89	392	4,724	34,215,483
Public & Institutional		4	0	54,422	66	571				
Park & Open Space		6	0	15,491	264	11,693				
Agriculture		4	0	19,550	154	6,857				
Downtown Specific Plan	21-54	332	1,543	1,795,401	1,174	307	45	20	2,500	450,000
Harbor District		0	310	350,160	10	254	1	21	300	876,100
Total		**22,034**	**17,142**	**15,923,154**	**32,630**	**27,884**	**378**	**1099**	**29,910**	**57,869,859**

1. Commerce residential unit capacity is for property within a Corridor, District, or Neighborhood Center and assumes buildout to the maximum FAR and that 25% of floor area would be commercial (with the remainder residential).
2. Industry residential unit capacity is for property within a Corridor, District, or Neighborhood Center and assumes buildout to the maximum FAR and that 75% of floor area would be industrial (with the remainder residential).
3. "Additional Potential" assumes a historic buildout rate of 70% for both residential and non-residential.

Table 3-2. Predicted Development Intensity & Pattern	Residential Development (units)	Non-Residential Development (square feet)				
		Retail	Office	Industrial	Hotel	Total
DISTRICTS						
Upper North Avenue	100	10,000	50,000	150,000	-	210,000
North Avenue	50	10,000	50,000	250,000	-	310,000
Downtown Specific Plan	1,600	100,000	200,000	-	150,000	450,000
Pacific View Mall	25	25,000	-	-	-	25,000
Harbor	300	315,000	-	-	230,000	545,000
Arundell	200	25,000	300,000	1,000,000	-	1,325,000
North Bank	50	300,000	50,000	300,000	-	650,000
Montalvo	50	-	50,000	25,000	-	75,000
Saticoy	50	-	-	25,000	-	25,000
Subtotals (Districts)	**2,425**	**785,000**	**700,000**	**1,750,000**	**380,000**	**3,615,000**
CORRIDORS						
Ventura Avenue	800	40,000	100,000	50,000	-	190,000
Main Street	100	15,000	40,000	-	-	55,000
Thompson Boulevard	300	15,000	40,000	-	-	55,000
Loma Vista Road	25	15,000	40,000	-	-	55,000
Telegraph Road	250	15,000	40,000	-	-	55,000
Victoria Avenue	50	15,000	40,000	-	-	55,000
Johnson Drive	150	50,000	20,000	-	-	70,000
Wells Road	50	15,000	20,000	-	-	35,000
Subtotals (Corridors)	**1,725**	**180,000**	**340,000**	**50,000**	**0**	**570,000**
SPHERE OF INFLUENCE (SOI)/OTHER INFILL/NEIGHBORHOOD CENTERS						
101/126 Agriculture	200	-	-	-	-	-
Wells/Saticoy	1,050	-	-	-	-	-
Pierpont	100	30,000	-	-	-	30,000
Other Neighborhood Centers	100	-	-	-	-	-
Second Units	300	-	-	-	-	-
Underutilized	250	-	-	-	-	-
Vacant	450	165,000	50,000	-	-	215,000
Subtotals (Other Infill)	**2,450**	**195,000**	**50,000**	**0**	**0**	**245,000**
TOTAL INFILL	***6,600***	***1,160,000***	***1,090,000***	***1,800,000***	***380,000***	***4,430,000***
PLANNED AND PENDING DEVELOPMENTS						
Downtown	50	1,072	-	-	150,000	151,072
Ventura Avenue/Westside	238	7,086	-	27,000	-	34,086
Midtown	34	13,751	-	-	-	13,751
College (Telegraph/Loma Vista)	4	2,718	8,843	-	-	11,567
Telephone Road Corridor	256	-	54,785	-	-	54,785
Montalvo/Victoria	296	-	4,300	-	-	4,300
Saticoy/East End	840	7,950	5,600	-	-	13,550
Arundell	-	41,640	42,614	18,080	-	102,334
Olivas	-	7,160	7,066	390,053	-	404,279
Subtotals (Planned/Pending)	**1,718**	**81,377**	**123,214**	**435,133**	**150,000**	**789,724**
TOTAL (Infill+SOI/Other+Pending)	**8,318**	**1,241,377**	**1,213,214**	**2,235,133**	**530,000**	**5,219,724**



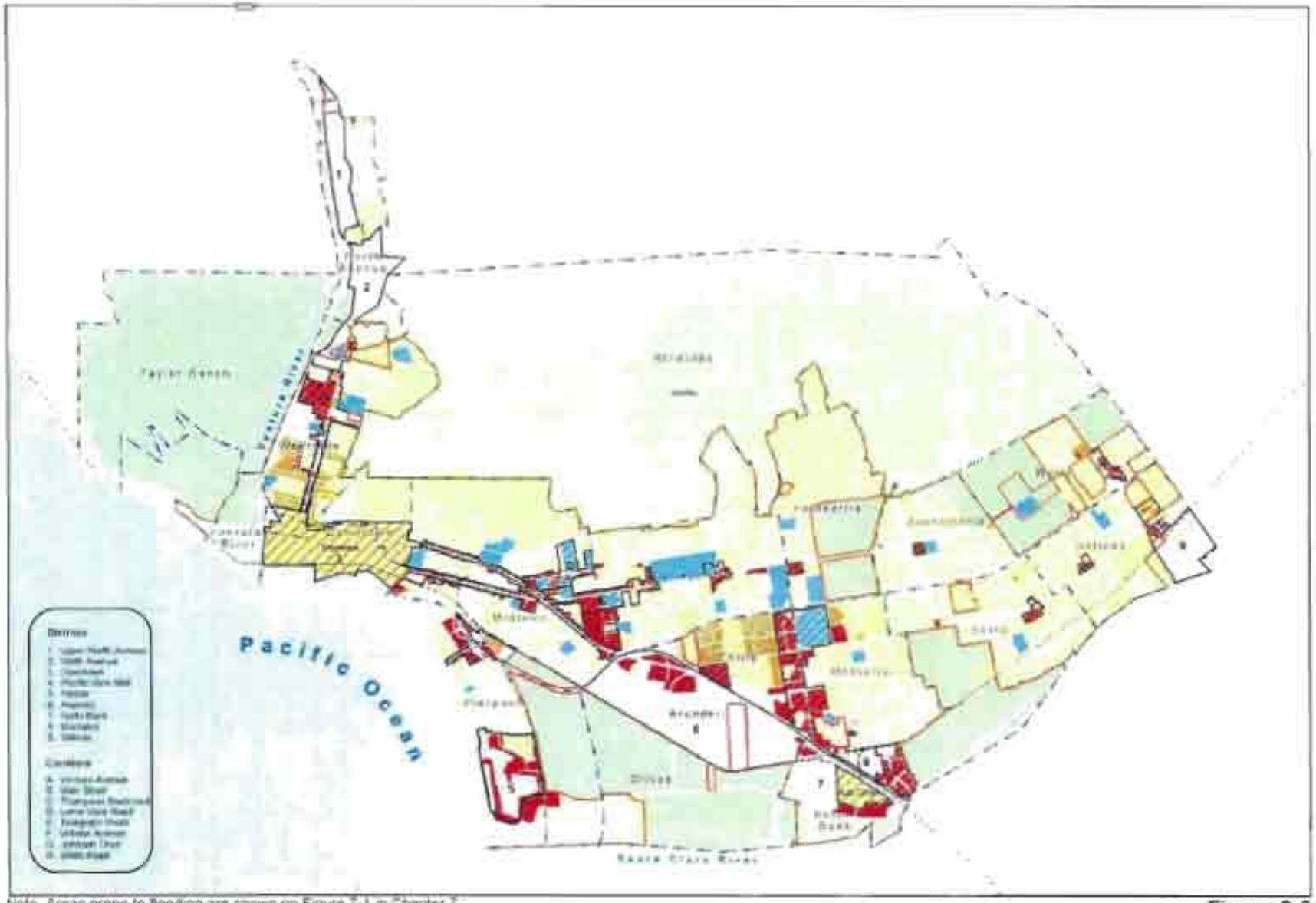
SOURCE: City of Ventura

Infill Sites

- Corridor
- Neighborhood Center (NC)
- District

- City Limits
- Planning Boundary
- Planning Neighborhoods

Figure 3-1
Infill Areas



Note: Areas prone to flooding are shown on Figure 7-1 in Chapter 7

Figure 3-5
GENERAL PLAN DIAGRAM

Neighborhood
- Low (up to 8 du/ac)
- Medium (9-20 du/ac)
- High (21-54 du/ac)

- Commerce
- Industry
- Public and Institutional
- Agriculture
- Parks and Open Space
- Specific Plan Area
- Corridors, Neighborhood Centers (NC)
- Districts
- City Limits
- Planning Communities
- California Coastal Zone Boundary

There are presently five water sources that provide water to the City water system.

- *Casitas Municipal Water District*
- *Ventura River Surface Water Intake, Subsurface Water and Wells (Foster Park)*
- *Mound Groundwater Basin*
- *Oxnard Plain Groundwater Basin (Fox Canyon Aquifer)*
- *Santa Paula Groundwater Basin*

Table 4.13-7 summarizes historic and projected water supply from these sources, as detailed in the 2000 City Urban Water Management Plan. The historic delivery values shown represent the capacity of available sources. The projected numbers in the table estimate available water supply levels under normal, non-drought conditions. Actual water supply levels in any given year may be significantly higher or lower than these averages.

Table 4.13-7
Historic and Projected Water Source Supply Availability
(Acre Feet)

Year	Surface Water		Groundwater				Total Water Supply
	Lake Casitas	Ventura River	Mound Basin	Oxnard Plain Basin	Santa Paula Basin	Saticoy Yard Well	
Historic							
1980	7,544	7,276	0	5,198	2,129	0	22,147
1985	9,099	5,493	2,360	6,172	46	0	23,170
1990	6,175	2,859	4,365	5,749	0	0	19,148
1995	1,622	9,042	2,169	2,603	2,594	0	18,030
1996	4,456	7,926	2,789	2,768	1,599	0	19,538
1997	7,089	7,052	213	3,452	2,025	0	19,831
1998	4,328	8,069	802	4,312	1,033	0	18,544
1999	7,061	6,419	3,955	1,621	1,669	0	20,725
2000	5,836	6,779	4,579	2,674	1,698	0	21,566
2001	6,292	5,727	4,030	905	2,006	0	18,960
2002	7,127	5,951	3,720	1,978	1,157	0	19,933
2003	4,874	6,722	5,546	2,898	316	0	20,356
Projected							
2005	8,000	6,700	4,200	4,400	3,000	0	26,300
2010	8,000	6,700	4,200	4,100	3,000	2,262	28,262
2015	8,000	6,700	4,200	4,100	3,000	2,262	28,262
2020	8,000	6,700	4,200	4,100	3,000	2,262	28,262

Source: City of Ventura Urban Water Management Plan, December 2000
City of Ventura 2004 Biennial Water Supply Report as amended, September 2004 (see Appendix F).

The City generally uses its water supplies in the following order: (1) Ventura River; (2) Lake Casitas; and (3) groundwater basins. Water is used in this order to maximize the amount of surface water that would otherwise be lost to runoff before using stored groundwater.

Table 4.13-8
Historic and Projected Water Production
(Acre Feet)

Year	Estimated Population Served	Per Capita Use (1)	Treated Water Production	Raw Water Production	Total Water Production
Historic					
1980	73,774	0.236	17,381	4,766	22,147
1990	94,856	0.177	16,831	2,317	19,148
1995	99,668	0.165	16,428	1,602	18,030
1996	100,482	0.180	18,038	1,500	19,538
1997	101,096	0.178	18,002	1,829	19,831
1998	101,610	0.165	16,775	1,769	18,544
1999	102,224	0.192	19,658	1,067	20,725
2000	103,238	0.198	20,437	1,129	21,566
2001	104,153	0.173	18,071	889	18,960
2002	105,267	0.180	18,965	968	19,933
2003	106,782	0.183	19,510	846	20,356
Projected					
2005	109,465	0.179	19,594	1,000	20,594
2010	115,774	0.179	20,724	1,000	21,724
2015	122,447	0.179	21,918	1,000	22,918
2020	129,504	0.179	23,181	1,000	24,181

Sources: City of Ventura Urban Water Management Plan, Dec. 2000
City of Ventura 2004 Biennial Water Supply Report as amended, September 2004 (see Appendix F).
(1) Per capita use excludes raw water and oil use.

Water Quality. The following terms are used to describe water quality:

- *Maximum Contaminant Level (MCL): The highest level of a contaminant allowed in drinking water. Primary MCLs are set as close to the Federal Public Health Goals or State Maximum Contaminant Level Goals as is economically and technologically feasible. Secondary MCLs are set to protect the odor, taste and appearance of drinking water.*
- *Primary Drinking Water Standard: MCLs for contaminants that affect health along with their monitoring and reporting requirements, and water treatment requirements.*
- *Maximum Contaminant Level Goal: The level of contaminant in drinking water below which there is no known or expected risk to the health; set by EPA.*
- *Public Health Goal: The level of a contaminant in drinking water below which there is no known or expected risk to health; set by the California EPA.*

Table 4.13-15
Projected Water Demand
Intensification / Reuse Only (Scenario 1)

	Residential		Non-Residential Development						Grand Totals
	Number of Units	Water (AFY)	Retail (sf)	Office (sf)	Industrial (sf)	Hotel (sf)	Total (sf)	Water (AFY)	Water (AFY)
Districts									
Upper North Avenue	100	50	10,000	50,000	150,000		210,000	70	120
North Avenue	50	25	10,000	50,000	250,000		310,000	105	130
Downtown	1,600	807	100,000	200,000		150,000	450,000	168	975
Pacific View Mall	25	13	25,000	0			25,000	7	20
Harbor	300	151	66,000			150,000	216,000	54	205
Arundell	200	101	25,000	300,000	1,000,000		1,325,000	444	545
North Bank	50	25	300,000	50,000	300,000		650,000	204	229
Montalvo	50	25		50,000	25,000		75,000	23	48
Saticoy	50	25	0		25,000		25,000	9	34
Subtotals (Districts)	**2,425**	**1,223**	**536,000**	**700,000**	**1,750,000**	**300,000**	**3,286,000**	**1,084**	**2,307**
Corridors									
Ventura Avenue	800	404	40,000	100,000	50,000		190,000	57	460
Main Street	100	50	15,000	40,000			55,000	15	66
Thompson Boulevard	300	151	15,000	40,000			55,000	15	167
Loma Vista Road	25	13	15,000	40,000			55,000	15	28
Telegraph Road	250	126	15,000	40,000			55,000	15	142
Victoria Avenue	50	25	15,000	40,000			55,000	15	41
Johnson Drive	150	76	50,000	20,000			70,000	20	95
Wells Road	50	25	15,000	20,000			35,000	10	35
Subtotals (Corridors)	**1,725**	**870**	**180,000**	**340,000**	**50,000**	**0**	**570,000**	**163**	**1,033**
SOI/Other Infill									
101/126 Agriculture	200	101					0	0	101
Wells/Saticoy	1,050	530					0	0	530
Pierpont	100	50	30,000				30,000	8	59
Other Neighborhood Centers	100	50						0	50
Second Units	300	151						0	151
Underutilized	250	126						0	126
Vacant	450	227	165,000	50,000			215,000	60	287
Subtotals (Other Infill)	**2,450**	**1,236**	**195,000**	**50,000**	**0**	**0**	**245,000**	**69**	**1,304**
Totals (Intensification/Reuse)	**6,600**	**3,329**	**911,000**	**1,090,000**	**1,800,000**	**300,000**	**4,101,000**	**1,316**	**4,645**
Planned and Pending Developments									
Downtown	50	25	1,072			150,000	151,072	84	110
Ventura Avenue/Westside	238	120	7,086		27,000		34,086	12	132
Midtown	34	17	13,751				13,751	4	21
College (Telegraph/Loma Vista)	4	2	2,718	8,849			11,567	3	5
Telephone Road Corridor	256	129		54,785			54,785	15	144
Montalvo/Victoria	296	149		4,300			4,300	1	151
Saticoy/East End	840	424	7,950	5,600			13,550	4	427
Arundell		0	41,640	42,614	18,080		102,334	30	30
Olivas		0	7,160	7,066	390,053		404,279	142	142
Subtotals (Planned/Pending	**1,718**	**867**	**81,377**	**123,214**	**435,133**	**150,000**	**789,724**	**295**	**1,162**
Totals (Intensification + Expansion + Pending)	**8,318**	**4,196**	**992,377**	**1,213,214**	**2,235,133**	**450,000**	**4,890,724**	**1,611**	**5,806**

2.3 Population

The City water service area is essentially an established community comprised primarily of residential areas with opportunities for infill development. Large commercial and industrial areas exist along Main Street, Harbor Boulevard, Telephone Road, Ventura Avenue, Telegraph Road and Victoria Avenue[2]. In 2005, the City of Ventura adopted the 2005 Ventura General Plan to redirect future growth toward 'Infill First' with an emphasis on encouraging more intense development of housing alongside commercial uses in the above mentioned commercial corridors, as well as Johnson Drive and Wells Road. The City's estimated population growth for the water service area is shown in Table 2-1. The population numbers reflect both the population within the City of Ventura limits as well as the population served by the public water system that is not within the City limits. Historical population data within the City is based entirely from the California Department of Finance Table E-4 Population Estimates for Cities, Counties, and the State with 2000 Benchmark. Historical population for the areas served by the water system that are outside of the City are based on the number of connections, multiplied by 2.57 persons per connection[3].

Future projections for areas within the City reflect a 0.88 percent annual growth rate based on the City's General Plan. Projections for areas served by the water system outside of the City are based on the historical annual growth rate of 0.1258 percent in the number of connections. Population estimates were extrapolated to fit 5 year increments. It is important to note that these figures are not intended to represent support for, nor reflect any commitment to, this level of growth. Rather, it is to provide a safe margin in planning for long-term water improvements that might be needed given the amount of growth that could be allowed under the City's 2005 updated General Plan as assessed in the certified EIR. Included for comparison is the EIR population projection for 2025 reflecting the two possible growth scenarios: (1) 1.14 percent annual population growth, which is equivalent to the annual growth rate in the City from 1984 to 2004; and (2) 0.88 percent annual population growth, which is equivalent to the annual growth from 1994 to 2004.

TABLE 2-1
POPULATION PROJECTIONS

	2010	2015	2020	2025	2030	2035
Projected Planning Area Population	113,478	118,416	123,575	128,963	134,592	140,472
General Plan EIR (0.88%)	-	-	-	126,153	-	-
General Plan EIR (1.14%)	-	-	-	133,160	-	-

Note: General Plan EIR only provides estimate for year 2025.

2.4 Existing and Target Per Capita Water Use

2.4.1 Base Daily Per Capita Water Use for SBX7-7 Reduction

As described in Senate Bill 7 of Special Extended Session 7 (SBX7-7), it is the intent of the California legislature to increase water use efficiency. The legislature has set a goal of a 20 percent per capita reduction in urban water use statewide by 2020. The requirements of

[2] City of San Buenaventura Water Master Plan, 2011.
[3] Based on City's General Plan Environmental Impact Report (EIR) dated 2005.

TABLE 2-5
PAST, CURRENT, AND PROJECTED WATER DEMANDS (AFY)

	Single-Family	Multi-Family	Commercial	Industrial	Institutional/ Governmental	Landscape	Petroleum Recovery Operations	Other	Total
2005	7,483	3,887	4,279	163	541	1,079	930	2,447	20,808
2010	7,006	3,678	3,384	64	495	1,044	368	1,312	17,351
2015	9,197	4,562	4,551	163	690	1,416	400	1,306	22,286
2020	9,615	4,761	4,749	170	720	1,478	400	1,363	23,256
2025	10,052	4,969	4,956	178	751	1,542	400	1,423	24,270
2030	10,508	5,185	5,173	185	784	1,610	400	1,485	25,330
2035	10,984	5,412	5,399	193	818	1,680	400	1,550	26,436

Note: 2005 and 2010 are actual demands. 2015 and beyond are projected.

TABLE 2-6
WATER SERVICE ACCOUNTS

	Single-Family	Multi-Family	Commercial	Industrial	Institutional/ Governmental	Landscape	Petroleum Recovery Operations	Other	Total
2005	22,834	2,269	2,537	15	193	222	2	2,966	31,038
2010	23,158	2,372	2,536	4	185	258	2	3,131	31,646
2015	25,627	2,545	2,733	7	200	279	2	3,375	34,769
2020	24,953	2,481	2,664	7	195	272	2	3,291	33,865
2025	26,095	2,590	2,781	7	204	283	2	3,434	35,396
2030	27,288	2,703	2,902	7	213	296	2	3,584	36,994
2035	28,534	2,821	3,029	8	222	309	2	3,741	38,665

Note: 2005 and 2010 are actual demands. 2015 and beyond are projected.

TABLE 3-1
SUMMARY OF WATER SUPPLY SOURCES

Water Supply Sources (AFY)	2010	2015	2020	2025	2030	2035
Existing Supplies						
Imported Wholesale Supplies						
Casitas Municipal Water District[a]	6,000	6,000	6,100	6,200	6,500	7,000
Supplier Produced Groundwater						
Mound Basin[b]	4,000	4,000	4,000	4,000	4,000	4,000
Oxnard Plain Basin[b]	4,100	4,100	4,100	4,100	4,100	4,100
Santa Paula Basin[b]	1,600	1,600	1,600	1,600	1,600	1,600
Supplier Produced Surface Water						
Ventura River (Foster Park)[b]	4,200	4,200	4,200	4,200	4,200	4,200
Recycled Water[c]	700	700	700	700	700	700
Transfers in	None	None	None	None	None	None
Exchanges in	None	None	None	None	None	None
Desalinated Water	None	None	None	None	None	None
Other	None	None	None	None	None	None
Total Existing Supplies	***20,600***	***20,600***	***20,700***	***20,800***	***21,100***	***21,600***
Planned Supplies						
Supplier Produced Groundwater						
Mound Basin (Well No. 2)[d]	0	0	0	0	0	0
Oxnard Plain Basin (Golf Course Well No. 7)[d]	0	0	0	0	0	0
Santa Paula Basin (Saticoy Well No. 3)[e]	0	1,400	1,400	1,400	1,400	1,400
Supplier Produced Surface Water						
Ventura River (Foster Park Wells Improvements)	0	0	2,500	2,500	2,500	2,500
Total Planned Supplies	***0***	***1,400***	***3,900***	***3,900***	***3,900***	***3,900***
Total Existing and Planned Supplies	***20,600***	***22,000***	***24,600***	***24,700***	***25,000***	***25,500***
FCGMA Groundwater Credit[f]	***30,000***	***22,000***	***22,000***	***22,000***	***22,000***	***22,000***

Notes:
(a) Estimated demand based on population growth within the Casitas service area served by Ventura Water .
(b) Average annual supply based on 2011 City of San Buenaventura Water Master Plan, Table V-14.
(c) Based on current and expected usage.
(d) Replacement wells for supply reliability.
(e) Well will allow full use of 1996 stipulated Judgment allocation.
(f) FCGMA Groundwater Credit is drought/reliability supply source; not a firm supply available for new development. 30,249 AF available for 2010 per Water Master Plan (See Oxnard Plain supply description, Section 3.3.1.2.) reduced to 22,000 AF by 2015 in the event of a drought or operational/production/treatment constraints from other supply sources.

3.2 Imported Supplies

The City has a contract Table A Amount of 10,000 AFY of State Water Project (SWP) water with DWR. However, there are no facilities to deliver this water to the City. The following describes the history of this allocation and the potential for future use of SWP supply.

In 1964, Ventura County Flood Control District contracted with the State of California for future delivery of up to 20,000 AFY of SWP water to Ventura County. In 1971, administration of the contract for SWP water was assigned to Casitas. The City executed an agreement in 1971 with Casitas and the Department of Water Resources (DWR) to allocate 10,000 AFY of the

B. EXISTING LAND USE

The City water service area is essentially a built-out community comprised primarily of residential areas. Large commercial and industrial areas exist along Main Street, Harbor Boulevard, Telephone Road, Ventura Avenue, Telegraph Road and Victoria Avenue. A large amount of land within the General Plan Boundary, over 11,500 acres, is dedicated to parks and open space.

Existing land use information was compiled from the 2005 General Plan. The various land use types and densities that are located within the City General Plan Boundary are listed in Table II-1.

Table II-1
Existing Land Use within City General Plan Boundary

Planning Designation	Allowed Density (du/acre)	Area (acres)
Neighborhood Low	0 – 8	4,629
Neighborhood Medium	9 – 20	1,061
Neighborhood High	21 – 54	303
Commerce/Mixed Use	N/A	808
Industry	N/A	1,401
Public and Institutional	N/A	571
Park and Open Space	N/A	11,693
Agriculture	N/A	6,857
Downtown Specific Plan	21 – 54	307
Harbor District	N/A	254
Total	-	**27,884**

Note: The difference in land use area stated in Table II-1 and Exhibit II-1 is due to the fact that Table II-1 does not include the area for vacant or additional potential parcels, however Exhibit II-1 does.

Refer to Exhibit II-1 at the end of this Section for the Land Use Map.

C. FUTURE LAND USE

The number of customers served from the City's water system is expected to increase due to planned future developments and changes in land use. Land use changes will impact the operation of the City's distribution system. Proper planning for these changes will enable the City to continue to meet demands, provide adequate fire protection and provide quality service to its customers.

Most of the land within the City's existing water service area is developed. Anticipated changes in land use will primarily occur through redevelopment of existing land and small developments

(in-fill projects) in the various vacant parcels scattered throughout the City. This section will be broken down to describe the anticipated near-term developments and redevelopments and the ultimate build-out of the City as identified by the 2005 General Plan.

1. Near-Term Developments and Redevelopments

The City's Community Development Department compiles proposed and current development projects throughout the entire City in a Pending Project Status Report. These projects are considered to be near-term because some level of planning has occurred and the projects are anticipated to be completed within the next 2-3 years (it should be noted that some of the projects identified below may have begun construction or have been completed at the time of finalization of this report). The majority of the projects are redevelopments of commercial land and new residential developments. Refer to Exhibit II-2 for the locations of the near-term projects as identified in the January 2006 Pending Project List and Appendix A for a list of the projects. See Table II-2 for a summary of the near-term land use.

Table II-2
Near-Term Land Use Summary

General Plan Land Use Category	Acreage	DU
Neighborhood Low (NL)	221	662
Neighborhood Medium (NM)	188	699
Neighborhood High (NH)	41	256
Commerce/Mixed Use (C)	78	459
Industry (I)	86	-
Public and Institutional (PI)	19	-
Parks and Open Space (POS)	440	-
Downtown Specific Plan (DTSP)	23	445
Total	**1,097**	**2,521**

A few of the larger near-term projects anticipated within the City water service area are listed in Table II-3.

Table II-3
Large Near-Term Development Project Summary

Project Name	Project Address	DU	Acreage	Land Use Category	Project Number
Parklands	Southwest corner of Wells Rd & Telegraph Rd	252	66.7	NM	RS-99
Parklands	Southwest corner of Wells Rd & Telegraph Rd	235	-	NL	RC-85
Harmony	South of Thille Rd @ Ringo St	182	15.8	NH	RC-61
Island View	NW Corner of Hill Rd and Moon Dr	120	26.9	NM	RS-87
The Grove	Copland Dr & Telephone Rd	75	25.6	NM	RS-98
Melody	Northwest corner of Telegraph Rd & Saratoga	74	15.7	NH	RC-64
Hails	Henderson Rd, West of Montgomery	172	40.1	NL	RS-92
Hails	Henderson Rd, West of Montgomery	60	-	NL	RC-70

2. Ultimate Build-out

The ultimate build-out is classified as projects expected to occur at some point in the future, but planning stages of the projects has yet to begin. These projects include the anticipated development of all vacant parcels within the City's potential water service area not included in the near-term development summary, as identified in the 2005 General Plan. The total area of vacant land that can be ultimately developed are summarized by Land Use Types in Table II-4. Further discussion of the demands generated by the build-out of all vacant lands is described in Section IV.

Table II-4
Existing Vacant Lands by Land Use (2005 General Plan Capacity)

Planning Designation	Allowed Density (du/acre)	Area (acres)
Neighborhood Low	0 – 8	426
Neighborhood Medium	9 – 20	116
Neighborhood High	21 – 54	16
Commerce	N/A	621
Industry	N/A	1,178
Public and Institutional	N/A	0
Park and Open Space	N/A	0
Agriculture	N/A	-
Downtown Specific Plan	21 – 54	30
Harbor District	N/A	41
Total	-	**2,428**

Table V-14
Summary of Current Water Supply

Water Supply Source	Historical Supply Projection (AFY)	Average Annual Supply (2000-2009) (AFY)	Present Operational Supply Constraint (AFY)
Casitas	4,960 – 8,000	6,200	6,200
Ventura River (Foster Park)	4,200 – 6,700	4,200	4,200
Mound Groundwater Basin	2,500 – 4,000	4,000	5,500 [1]
Oxnard Plain Groundwater Basin	4,100	4,100	6,775 [2]
Santa Paula Groundwater Basin	3,000	1,340	1,600 [3]
Total	**18,760 – 25,800**	**19,840**	**24,275**

[1] Assumes two wells operational, one well at 1,500 gpm and one at 2,000 gpm

[2] Assumes two wells operational at 2,100 gpm each.

[3] Assumes one well operational at 1,000 gpm.

B. POTENTIAL WATER SUPPLY

A water supply capacity evaluation is described later in this report (Section VIII). This section will briefly describe any planned or proposed projects which may affect the water supply sources for the City.

1. State Water Project

The City also has a 10,000 acre-foot per year allocation from the California State Water Project (SWP). The base contractual agreements concerning the City's annual entitlement to 10,000 acre-feet of SWP are: (1) the 1963 State Water Supply Contract of 20,000 acre-feet entitlement of SWP water between the Department of Water Resources (DWR) and Ventura County Watershed Protection District (VCWPD) known formerly as Ventura County Flood Control District (VCFCD); (2) the 1970 agreement between VCFCD and Casitas known formerly as the Ventura Municipal Water District that assigned the 20,000 acre-feet entitlement to Casitas; and (3) the 1971 agreements between Casitas and the City providing the City with an annual entitlement of 10,000 acre-feet and Casitas and United providing United with an annual entitlement of 5,000

VENTURA LOCAL AGENCY FORMATION COMMISSION

MUNICIPAL SERVICE REVIEWS

Nine Ventura County Cities

Cities of:

Camarillo
Fillmore
Moorpark
Ojai
Oxnard
San Buenaventura
Santa Paula
Simi Valley
Thousand Oaks

Prepared By

Ventura Local Agency Formation Commission
800 S. Victoria Avenue
Ventura, CA 93009-1850

Accepted November 14, 2012

2012 MUNICIPAL SERVICE REVIEWS

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INTRODUCTION

Local Agency Formation Commissions ("LAFCos"), which exist in each county in California, were formed for the purpose of administering state law and local policies relating to the establishment and revision of local government boundaries. As provided by what is now known as the Cortese-Knox-Hertzberg Local Government Reorganization Act of 2000 (California Government Code Section 56000 et seq.), LAFCos are responsible for achieving three primary objectives: encouraging the orderly formation and expansion of local government agencies; preserving agricultural land and open space resources; and discouraging urban sprawl. To accomplish their objectives, LAFCos are responsible for coordinating logical and timely changes in local government boundaries, conducting special studies that review ways to reorganize and streamline governmental structure and preparing a sphere of influence for each city and special district over which they have authority. A sphere of influence is a plan for the probable physical boundaries and service area of a local agency, as determined by LAFCo (Government Code §56076).

Beginning in 2001 each LAFCo was required to review and, as necessary, update the sphere of each city and special district on or before January 1, 2008, and every five years thereafter (Government Code §56425(g)). Prior to updating a sphere of influence, LAFCo is required to conduct a municipal service review (service review" or "MSR"). California Government Code §56430(a) provides that MSRs consist of written determinations relating to the following seven factors:

1. Growth and population projections for the affected area.
2. The location and characteristics of any disadvantaged unincorporated communities within or contiguous to the sphere of influence.
3. Present and planned capacity of public facilities, adequacy of public services, and infrastructure needs or deficiencies including needs or deficiencies related to sewers, municipal and industrial water, and structural fire protection in any disadvantaged, unincorporated communities within or contiguous to the sphere of influence.
4. Financial ability of agencies to provide services.
5. Status of, and opportunities for, shared facilities.
6. Accountability for community service needs, including governmental structure and operational efficiencies.
7. Any other matter related to effective or efficient service delivery, as required by Commission policy.

Municipal service reviews are:

- The written determinations adopted by a LAFCo for the services provided by cities and special districts.
- Not applicable to counties, except for special districts governed by a county board of supervisors.
- May include studies of private providers of public services, such as private water companies or public utilities regulated by the state Public Utilities Commission.
- Not investigations. While authorized to prepare studies relating to their role as boundary agencies, LAFCos have no investigative authority.

Between 2002 and 2007, the Ventura LAFCo completed 21 MSRs and 57 sphere of influence reviews/updates among 10 cities and 50 special districts. The first MSR for the cities was completed in 2007.

The MSRs contained in this report examine each of the cities in Ventura County except the City of Port Hueneme. The City of Port Hueneme is surrounded by the City of Oxnard on three sides and the Pacific Ocean on the fourth, and the City boundary and sphere of influence are co-terminus. As there is no further opportunity for the City to expand beyond its current boundary and sphere of influence, LAFCo has determined that no sphere of influence review or MSR is necessary.

The information used to prepare this service review report was obtained from several sources, including:

- 2012 MSR Questionnaire - Each city was requested to complete a questionnaire, which collected general information about the city (contact information, governing body, financial information, etc), as well service specific data.
- City Budgets – Information regarding services and funding levels was obtained from the adopted budgets of each city.
- General Plans – Each city's General Plan provided information regarding land use, populations, and service levels.
- City Documents – Various city documents were used to obtain supplementary information relating to service provision, including, but not limited to, 2010 urban water management plans, wastewater master plans, and water master plans.
- City Websites – Provided information primarily regarding parks and recreation, fire protection, and police services.
- City Staff – City staff provided information that was either not available or not clear in the above documents.

The 2007 MSR prepared for the cities utilized financial information obtained from *The Cities Annual Report* published annually by the State Controller. The Annual Report is a comprehensive listing of each agency's revenue and expenditures specific to municipal services. At the time that the 2012 MSRs were being prepared, the latest Cities Annual Report that was available was for fiscal year 2009-10. Thus, it did not provide any information for the current or previous two fiscal years and its use would not have adequately portrayed the current fiscal realities of each city.

This report contains nine city MSRs, one in each of the nine main sections. Each of the nine sections is divided into four subsections, which include:

- Profile – This subsection contains a summary profile of important information for each city, including contact information, the governing body, financial information, and staffing levels;
- Growth and Population Projections – This subsection provides past, current, and projected population for each city. As necessary, a discussion of future anticipated development is provided;
- Review of Municipal Services – This subsection contains a discussion of the municipal services that each city provides; and
- Written Determinations – This subsection contains the recommended determinations for each of the seven mandatory factors for each city.

The appendices include:

- Appendix A – This appendix provides comparison tables summarizing key information discussed in the MSRs, including each city's geographic area, population, services that are provided, and funding amount for specific services.
- Appendix B – This appendix provides a discussion on the challenges that each city faces to fund future street maintenance services.

The result of this report will be the adoption of determinations by LAFCo, via a separate resolution for each city addressing each of the seven mandatory factors, based on the recommendations in the Written Determinations subsection of each MSR. Everything else in this report should be considered as background information.

CITY OF SAN BUENAVENTURA
PROFILE

Contact Information	
City Hall:	501 Poli Street, Ventura, CA 93001
Mailing Address:	PO Box 99, Ventura, CA 93002
Phone Number:	(805) 654-7800
Web Site	www.cityofventura.net
E-mail	*firstinitiallastname*@ci.ventura.ca.us

Governance Information	
Date Incorporated	March 10, 1866
Organization	City Charter
Form of Government	Council - Manager
City Council	• Seven member city council; members elected at-large to staggered, four year terms of office; elections held in odd numbered years; Mayor elected by the city council to a two year term • The city council regularly meets on Monday each week, except during August and on holidays. The meetings begin at 6:00 p.m. City Council meetings are broadcast live on the City's government cable TV channel

Population & Area Information

	Population	Area (sq. mi.)
City	107,166 [1]	21.99
Sphere of Influence	Not available	35.44[2]

Services

Floodplain Management	Parks
Community Development	Police
Fire	Sewers (collection & treatment)[3]
Emergency Medical Services	Streets & Highways (inc. storm drains)
General Government	Street Lighting
Golf Courses	Street Trees & Landscaping
Libraries	Water
Parking Facilities	

[1] CA Dept. of Finance estimate Jan. 1, 2012
[2] Includes approximately 10.07 square miles of Pacific Ocean
[3] The Montalvo Community Services District provides these services for the Montalvo Community

Staffing – Full Time Equivalent Positions[1]

Departments	2008-09	2009-10	2010-11	2011-12	2012-13
- General Government					
City Attorney	7.00	7.60	7.10	7.10	7.30
City Manager/City Clerk	18.50	10.75	7.00	7.00	8.00
Finance and Technology	47.75	46.50	46.50	49.00	47.75
Human Resources	13.00	12.75	12.75	12.00	12.25
- Community Development[2]	33.50	28.90	46.75	46.90	46.90
- Parks, Recreation & Community Partnerships[3] (Community Services)	32.25	32.25	62.25	65.00	56.25
- Public Safety					
Fire[4]	112.00	103.75	74.00	74.00	83.00
Police	185.25	172.00	161.00	1610	165.00
- Public Works	226.50	217.60	177.50	177.50	83
- Ventura Water	0	0	0	0	98.60
Total	**675.75**	**632.10**	**594.85**	**599.5**	**608.05**

Public Agencies with Overlapping Jurisdiction

Casitas Municipal Water District
Fox Canyon Groundwater Management Agency
Montalvo Community Services District
Saticoy Sanitary District
South Coast Area Transit
United Water Conservation District
Ventura County Air Pollution Control District
Ventura County Transportation Commission
Ventura County Watershed Protection District
Ventura Port District
Ventura Regional Sanitation District
Ventura Unified School District

[1] Source: City of San Buenaventura staff, September 27, 2012
[2] The 2010-11 increased staffing is primarily due to relocation of the Building and Safety division from the Fire Department to the Community Development Department
[3] The 2011-12 increased staffing is primarily the result of department restructuring
[4] The 2010-11 reductions due to reduction of 9 sworn personnel and the reorganization which moved building and safety functions to Community Development

Summary Financial Information[1]

Revenues

	2009-10 Actual	2010-11 Actual	2011-12 Actual	2012-13 Adopted	2013-14 Adopted
General Fund					
General Government					
City Attorney	1,063,789	368,941	457,156	0	0
City Manager/City Clerk	37,440	34,126	3,593	1,100	1,100
Finance and Technology					
- Property tax	20,647,117	17,747,281	19,862,975	21,205,522	19,552,847
- Sales tax	14,598,479	13,749,457	14,231,683	14,359,979	15,197,873
- Utility users tax	9,019,830	8,719,233	8,774,362	8,963,885	8,674,953
- Franchise tax	3,713,057	2,984,316	3,278,468	4,089,964	4,346,250
- Transient lodging	3,707,592	3,477,798	3,431,094	3,500,743	3,500,743
- Transfers - other funds	2,315,080	3,208,128	1,108,790	1,843,613	1,619,310
- State motor vehicle license	8,480,754	8,194,617	8,342,441	7,841,913	7,945,913
- Other revenue	14,702,434	13,988,296	11,736,134	17,301,011	17,731,005
Human Resources	18,859	12,238	6,120	300	300
Community Development	1,065,929	909,352	1,533,323	1,933,684	1,229,585
Parks, Recreation, & Community Partnerships	2,218,786	2,219,923	2,692,310	2,549,919	2,572,919
Public Safety					
Fire	2,984,246	1,200,614	1,050,412	1,229,241	1,132,241
Police	4,101,850	2,401,356	2,038,697	2,115,300	2,115,300
Public Works	1,011,388	968,014	138,934	132,666	157,666
Total General Fund	**89,686,630**	**80,183,690**	**78,686,492**	**87,068,840**	**85,778,005**
Total Building & Safety Fund	--	**1,985,918**	**2,308,762**	**1,741,385**	**1,726,099**
Ventura Water[2]					
Wastewater	--	--	--	19,782,428	20,428.911
CIP - Wastewater	--	--	--	11,115,000	4,865,000
Water	--	--	--	23,586,955	25,345,631
CIP - Water	--	--	--	19,896,497	10,850,000

[1] City of San Buenaventura Adopted Budget for Fiscal Years 2012-13 & 2013-2014 and Adopted Budget for Fiscal Year 2011-12

[2] Ventura Water became operational in 2011

Expenditures

	2009-10 Actual	2010-11 Actual	2011-12 Actual	2012-13 Adopted	2013-14 Adopted
General Fund					
General Government					
City Attorney	2,202,140	1,304,185	1,331,314	1,711,112	1,622,315
City Council	240,580	210,876	195,057	231,421	299,091
City Manager/City Clerk	2,265,694	1,776,925	1,150,956	1,537,376	1,502,960
Finance and Technology	10,766,376	10,087,345	12,561,756	16,809,442	11,729,298
Human Resources	1,952,090	958,777	758,217	1,048,815	1,001,014
Community Develop.	4,601,367	3,629,692	5,030,789	5,461,141	5,247,886
Parks, Rec, & Comm. Partnerships	6,484,203	6,348,738	11,096,801	11,861,865	11,953,828
Public Safety					
Fire	19,648,534	15,715,345	14,421,806	15,308,562	15,947,264
Police	30,024,089	27,852,555	27,310,957	27,416,970	28,747,808
Public Works	13,938,077	12,449,124	6,034,469	7,405,073	7,726,541
Total General Fund	**89,921,010**	**79,029,377**	**79,892,122**	**88,791,777**	**85,778,005**
Total Building & Safety	--	**2,077,472**	**2,222,923**	**1,741,385**	**1,726,099**
Ventura Water[1]					
Wastewater	--	--	3,252,299	19,782,428	20,428,911
CIP - Wastewater	--	--	127,718	11,115,000	4,865,000
Water	--	--	4,312,605	23,586,955	25,345,631
CIP - Water	--	--	0	20,697,789	10,850,000

[1] Ventura Water became operational in 2011

GROWTH AND POPULATION PROJECTIONS

City Annual Growth Projections

According to the US Census, from 2000 to 2010, the City increased in population from 100,916 to 106,433. The California Department of Finance estimates the City's population to be 107,166 as of January 1, 2012. Thus, from 2000 to 2012, the City grew by an estimated 6,250 people, or 6.19 percent. This 6.19 percent growth rate over 12 years equates to an estimated average annual growth rate of 0.52 percent. The following table reflects the City's projected population in 5 year increments based on this estimated rate of growth. The table also reflects the annexation of the community of Montalvo to the City in 2012:

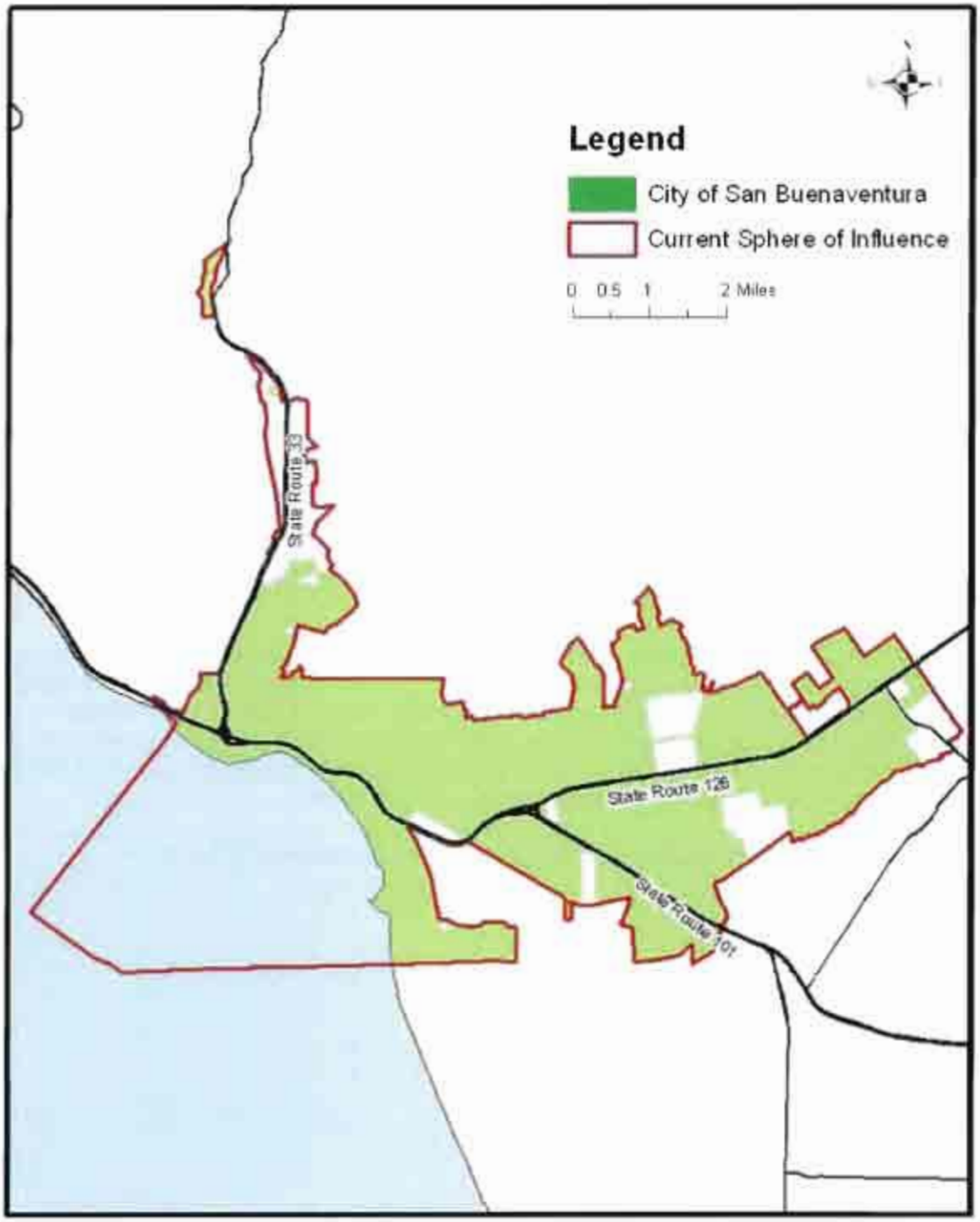
	2012	2015	2020	2025	2030
City Population	107,166	108,847	111,706	114,641	117,653
Montalvo	632	632	632	632	632
Total Population	**107,798**	**109,479**	**112,338**	**115,273**	**118,285**

The City updated its General Plan in 2005. The EIR prepared for the update included population projections based on an annual growth rate of 0.88 percent (average from 1994-2004) and a 2004 population of 104,952. The projections used in the General Plan would result in an estimated 2012 population of approximately 112,500, substantially higher than the current estimate by the Department of Finance. Thus, it appears that the anticipated growth rate projected in the General Plan EIR is overestimated based on the most recent population estimate from the California Department of Finance.

According to City Planning staff, the City has approved 2,434 residential units that have not yet been constructed. Using the average 2.57 person per household identified by the US Census, development of these units would add 6,255 people to the City. If the 685 residential units that are currently being considered for approval are, in fact, approved, it would add another 1,760 people. When the total population from these units is added to the current population, it results in a population of nearly 116,000.

The City's current boundary and sphere of influence are depicted in Figure 6.

Figure 6: City of San Buenaventura Sphere of Influence



REVIEW OF MUNICIPAL SERVICES

The following review of City services is based on provisions of state law requiring LAFCo to make determinations regarding the present and planned capacity of public facilities, the adequacy of public services, infrastructure needs and deficiencies and the City's financial ability to provide these services.

A. Fire Services

The City's Fire Department is an "all risk" department providing emergency medical response (paramedic), fire prevention, fire suppression, hazmat inspection/response, ocean rescue, and urban search and rescue throughout the City. Ambulance services are provided via a County contract with American Medical Response.

Fire Stations

The City operates 6 fire stations, each of which contains a fire engine company. In addition, a paramedic is assigned to each engine. Each station is located within a primary response area, or sector:

Sector 1 – Includes the west end of the City and western portion of downtown
Sector 2 – Includes eastern downtown, midtown and the harbor area
Sector 3 – Generally includes the northern-central area of the City
Sector 4 – Generally includes the southern central area of the City
Sector 5 – Generally includes the southeast portion of the City
Sector 6 – Includes the eastern portion of the City

According to responses to the MSR questionnaire, in addition to these primary response sectors, the Fire Department has entered into a contract with the County to provide initial response to the "North Ventura Avenue" area located outside City boundaries. Mutual aid agreements also provide for fire response to all areas located outside of the City. In addition, the City has entered into a reciprocity agreement with the City of Oxnard to provide emergency mutual aid.

Response Times

	Goal	Average Time	Percentage of Responses Meeting Goal
Non Emergency	No goal	2011: 6 min. 56 sec. 2012 (1st quarter): 6 min 32 sec	Not tracked
Emergency	Under 5 min. 90% of the time	2011: 5 min. 11 sec. 2012 (1st quarter): 4 min. 48 sec.	2010: 48% 2011: 48% 2012 (1st quarter): 58%

In 2010 and 2011, on average the City met its response time goal for less than half of all emergency calls. That percentage increased substantially at the beginning of 2012. The inability to meet the response time goal more than half the time in 2010 and 2011 appears to the be directly related to the City's closure of the fire station in Sector 4 in 2010 due to budgetary constraints. As a result of this closure, staffing levels fell to those of 1974 and

response times in the eastern half of the City met the City's goal only 16 percent of the time[1]. In mid 2011, the City was awarded a $2.3 million grant from the Department of Homeland Security to reopen the fire station. However, in order to receive the grant, the City had to contribute an additional $1.2 million. The City estimates that the $3.5 million would fund operation of the fire station for approximately three years ($1.2 million per year). The decreased level of service was a significant concern for the Ventura LAFCo during its consideration of a 2011 annexation proposal to the City (LAFCo 11-06 Parklands), so much so that LAFCo conditioned its approval on the City's acceptance of the $2.3 million grant. In late 2011 the City identified a source of funding for its share of the cost, received the grant, increased staff by 9 firefighter/medic positions, and reopened the fire station in January 2012.

Current Staffing Levels
The following Fire Department staffing levels are currently provided:

Administration	1 Fire Chief 1 Management Analyst 1 Secretary
Operations	1 Assistant Fire Chief 1 Battalion Chief - Training 3 Battalion Chiefs 1 EMS Coordinator 1 Secretary 21 Fire Captains 21 Fire Engineers 24 Firefighter/paramedics
Prevention	1 Fire Marshal 1 Secretary 2 Fire Prevention Specialists 1 Fire Prevention Technician 2 Hazmat Inspectors

The *Ventura Fire Department and Police Department Operational Details Report*, (ODR) dated February 15, 2012, was prepared to assist the City in understanding various operational aspects of the Fire Department. It included an analysis of the City's Fire Department staffing levels. According to the ODR, 25 Fire Captains, 25 Fire Engineers, and approximately 28 Firefighter/Paramedics are needed to sufficiently staff the City's six fire stations. In addition to responding to calls, this level of staffing allows for adequate time for incident documentation, apparatus and station maintenance, training, and various administrative tasks. It also minimizes the use of overtime to backfill minimum staffing slots due to personnel vacancies or personnel who are on various types of leave. The ODR recommends that either the Department be staffed with sufficient employees so that a capacity exists to frequently cover the absence of one shift worker without requiring overtime; or provide additional budgeted overtime to cover staff vacancies when needed. However, the ODR notes that excessive overtime can lead to staff "burnout".

[1] Ventura LAFCo 11-06 staff report, dated October 19, 2011

Costs
The adopted 2012-13 budget allocates $15,308,562 from the General Fund for fire services, an increase on nearly $900,000 from the last year's budget. The per capita cost for 2012-13 is approximately $142.

Future Staffing Levels

According to the City's response in the 2012 MSR questionnaire, the federal grant and required matching funds that enabled the Sector 4 fire station to reopen will fund operation of the fire station through November 2014. In order to avoid the substantial decrease in fire protection services in 2015 and beyond, the City will need to identify alterative long-term funding sources to keep all existing fire stations operational.

If the increased service demands anticipated from the over 8,000 estimated residents resulting from currently approved and proposed development projects are considered, the ODR staffing level recommendation would need to be further increased.

B. Library Services

The City of Ventura is served by two public libraries: the E.P. Foster Library, located downtown, and the Avenue Library, located on the west side of the City on Ventura Avenue. The libraries are administered and staffed by the Ventura County Library System.

Due to budget constraints, the H.P Wright Library, which provided services to the eastern portion of the City, was closed in November 2009. In May 2012 the City adopted a Library Strategic Plan, which identifies a 5-year plan during which current services/facilities are to be enhanced and a new library branch is to be constructed to serve the east side of the City by 2017.

Costs
According to the Library Strategic Plan, the amount of revenue received from property taxes is $17 per capita. The City provides an additional $90,000 per year and the County Library System provides an additional $350,000 in funding, bringing the per capita spending to almost $24. The national and state average per capita spending for library services is $48 and $33, respectively.

C. Police Services

The City's Police Department provides a wide variety of law enforcement services, including patrol, traffic enforcement, SWAT, school resource officers, investigations, and dispatch.

Current Staffing Levels

Administration	1 Chief 1 Assistant Chief 3 Secretaries 1 Civic Engagement Specialist
Field Operations	3 Commanders 8 Sergeants 8 Corporals 67 Police Officers

Investigations	1 Commander 2 Sergeants 22 Detectives 3 Police Services Officers 1 Crime Analyst
Dispatch	1 Sergeant 4 Corporals 12 Dispatchers 2 Police Service Officers
Records	1 Supervisor 10 Records Specialists 2 Dictation clerks
Professional Standards	1 Commander 2 Sergeants 1 Police Service Officers
Traffic	1 Sergeant 1 Corporal 4 Officers
Business Services	1 Business Services Officer 1 Payroll Specialist

In 2008, the City funded 134 sworn officer positions, for a ratio of 1 officer to approximately 794 residents (using 2010 population). Beginning In 2009, the number of officers funded by the City was reduced to 122, for a ratio of 1 officer per 878 residents. The City subsequently experienced a 24 percent increase in violent crime, as well as substantial increases in gang activity and other criminal behavior between 2010 and 2011. In fact, according to the City's website, in 2011 the City had the highest per capita violent crime rate in the County despite having one of the highest officers to resident ratios in the County.

For fiscal year 2012-13, the City has budgeted for an additional five sworn officers, for a total of 127 sworn officers, a ratio of 1 officer per 849 residents. An additional two officers are anticipated to be added next fiscal year.

Response Times

	Goal	Percentage of Responses Meeting Goal in 2011
Non Emergency	No goal	Not measured
Emergency	Under 5 min. 90% of the time for Priority 1 calls	62%

Operational Costs

For the current fiscal year, $28,510,749 was allocated for police services, of which $27,416,970 is to come from the General Fund. The total per capita cost for police services for the current fiscal year is $264.

Future Staffing Levels

In order to maintain the current ratio of 1 officer per 849 residents for approved and proposed residential development, an additional 9.5 sworn officers will be required. Without these additional officers the ratio of officer to resident would be 1 to 911, which is lower than the 2009 ratio that corresponded to a spike in violent crime. In order to maintain the current staffing ratio of one officer per 844 residents for the projected population in 2030, a total of 139 sworn officers will be required.

D. Recreation and Park Services

The City provides a wide variety of park facilities and recreational programs, services, and activities for City residents and nearby communities. Non-City residents who participate in recreational programs are charged an additional $5.00 for programs costing $25-$75 and $10 for programs costing more than $75.

Park Facilities
The City General Plan identifies three type of parks: 'Neighborhood Parks' are typically under 8 acres in size and primarily serve a specific residential area; 'Community Parks' provide specialized recreational opportunities for more than one neighborhood and can include formal sports fields, courts, and recreational buildings; 'Citywide Parks' provide recreational opportunities that draw a wide range of ages and interest groups throughout the City. The City also operates special use parks and linear parks.

The table on the following page is a list of all parks and facilities operated by the City.

	Acres	Play-ground	Basket-ball	Tennis Courts	Soft-ball	Sports Fields	Trails
Neighborhood Parks							
Barranca Vista	8.7	•					
Blanche Reynolds	3.4	•					
Cemetery Memorial	7.1						
Chumash	6.1	•					
Downtown Mini	0.4						
Hobert	7.1	•					
Juanamaria	5.0	•	•	•			
Junipero Serra	2.7						
Marion Cannon	5.0		•				
Mission	1.5						
Montalvo Hill	7.0	•	•				
Ocean Avenue	1.3	•	•				
Plaza	3.7	•					
Promenade	1.0						•
Thille	5.0	•	•				
Community Parks							
Fritz Huntzinger Sports*	18.3				•	•	
Ventura Community	100				•	•	•
Westpark	7.3	•	•			•	
Citywide Parks							
Arroyo Verde	129.3	•					•
Camino Real	38.2	•	•	•	•	•	•
Grant	107.3						
Harry A. Lyon	10.7		•	•	•	•	
Marina	15.3	•					
Special Use							
Albinger Archeological	0.9						
Eastwood	0.7						
Linear Parks	46.0						•
Olivas Adobe Historical	22.5						
Ortega Adobe	0.3						
Seaside Wilderness	24.0						•
Surfers Point at Seaside	3.4						

The City provides approximately 589 acres of developed park facilities. According to the City General Plan, the City parkland standard is to provide 10 acres per 1,000 residents. To meet this standard for a current population of approximately 108,000, 1,080 acres would need to be provided.

The City also operates the Ventura Avenue Adult Center at which seniors can receive various services or participate in classes and activities, as well as two recreation centers, and two golf courses.

Recreation Programs
Among the parks and recreation programs offered by, or in conjunction with, the City are:

- Youth and adult sports classes, clinics, camps and leagues including basketball, golf, soccer, softball, volleyball and fitness programs
- Aquatics programs and activities
- Special interest and life enrichment classes for youth, teens and adults
- Arts and crafts programs, dance, music, and other creative classes
- Various cultural events
- Senior services, including computer, recreational, social, health, and fitness programs

E. Solid Waste Services

Solid waste services are provided via franchise agreements with E.J. Harrison & Sons. The City funds a number of services related to solid waste, including managing contracts, customer service, waste reduction programs, and hazardous waste disposal.

F. Streets, Highways and Drainage

According to the City's 2012 MSR questionnaire responses, the City is a direct provider of street construction and maintenance and street lighting services. Street sweeping and landscape maintenance are provided via contract. The City estimates that it has 1,240 paved lane miles.

According to the transmittal letter for the City's proposed 2012-13 budget, the City "is failing to keep up with repair of streets, sidewalks, storm drains, alleys, parks, public buildings and facilities."

Street Maintenance
City's 2012-13 General Fund budget allocates $1,193,473 for pavement maintenance, or $962.48 per lane mile. The allocation for street pavement maintenance has dropped steadily from approximately $1.5 million in 2009. According to City staff, based on the latest data, in order for the City to maintain a good Pavement Condition Index (PCI) average of 75, a one-time investment of $27 million is needed and $9.6 million annually thereafter. Annual funding levels (including Gas Tax) are at $3.9 million for street resurfacing and preventive maintenance, which means the City would need an additional $5.7 million per year.

According to the adopted budget, Gas Tax revenues will provide approximately $16.3 million in capital improvements for streets, including street repaving, slurry seal, and bike lane improvements.

Street Lighting
A total of $2,076,338 is allocated for both street lighting and traffic signal maintenance. This includes $1,368,760 for Street light District 36, which provides for maintenance and operation for the Southern California Edison-owned street lights. Currently, the General Fund allocates $487,124 toward the maintenance of the City's Street light District 36.

Stormwater
The City provides stormwater and flood control services to comply with the Ventura Countywide Municipal Stormwater National Pollutant Discharge Elimination System (NPDES) permit. The City provides public outreach, illicit discharge response and abatement, public infrastructure maintenance, new development discharge controls, and construction site pollution controls. The 2012-13 budget allocates $738,990 toward this program, a per capita cost of $6.90. An additional $904,784 is allocated for stormwater utility maintenance.

Street Sweeping
Street sweeping services are provided via contract with a private provider. Residential streets are swept once per month. Commercial and industrial streets are swept twice per month. Downtown streets and major thoroughfares are swept three to five times per week.

G. Water Services

The City supplies potable water to all areas within the City. It also provides potable water to unincorporated areas outside the City, including North Ventura Avenue, Saticoy, and the Saticoy Country Club community. Customers outside the City pay a surcharge of $0.73 dollars per each 750 gallons of water.

Current Potable Water Demand and Supply
According to the City's 2010 Urban Water Management Plan (UWMP), water demand in 2010 was 17,351 acre feet per year, substantially lower than the 2005 demand of 20,808 acre feet. This reduction in demand is likely attributable to a variety of water conservation efforts during the drought, which ended in 2011 (indeed, the UWMP projects that water demand for 2015 will be 22,286 acre feet). For demand projection purposes, the UWMP assumes a daily per capita use of 168 gallons, which is the average demand from 2000-2009. Using a current population estimate of approximately 108,000, current demand within the City is estimated to be 20,324 acre feet per year. Overall demand would be expected to be higher when considering the 2,000-3,000 inhabitants and commercial/industrial uses in Saticoy and the North Ventura Avenue area. However, based on the City's water billing records for the City's water service area and an assumed 6.5 percent increase due to unaccounted for water uses, total demand in 2011-12 is estimated at 17,242 AF[1].

According to City staff[2] and the UWMP, the City's current water supply sources are as follows:

Casitas Municipal Water District	5,000 acre feet per year
Groundwater from City wells	9,700 acre feet per year
Surface water (Ventura River)	4,200 acre feet per year
Recycled water	700 acre feet per year
Total	19,600 acre feet per year

Thus, current water demand within the City service area appears to consume approximately 88 percent of the current total supply.

[1] Memo from Ventura Water Water Resource Manager, Susan Rungren, to LAFCo Executive Officer, Kim Uhlich, dated October 30, 2012
[2] Ibid

Future Potable Water Demand and Supply
The UWMP estimates that the population in the City's water service area will increase to 140,272 by 2035, resulting in a demand of 26,436 acre feet per year (AFY). However, state law requiring a per capita reduction in water demand by 2020 results in a target demand of 22,345 by 2035.

According to the UWMP, the City will have constructed an additional groundwater well by 2015 that will allow the City to increase pumping from the Santa Paula Groundwater Basin from the current 1,600 AFY to its full 3,000 AFY year allocation. The City also anticipates that, by 2020, it will complete improvements to wells drawing water near the Ventura River that will provide an additional 2,500 AFY. Based on these estimates, the City's anticipated water supplies by 2035 are as follows:

Casitas Municipal Water District	5,000 acre feet per year
City-pumped groundwater	11,100 acre feet per year
Surface water (Ventura River)	6,700 acre feet per year
Recycled water	700 acre feet per year
Total	23,500 acre feet per year

Anticipated water supply in five year increments through by 2035 is as follows:

City's Anticipated Water Supply (AFY)

2012	2015	2020	2025	2030	2035
19,600	21,000	23,500	23,500	23,500	23,500

According to the City Planning Division, there are 2,170 residential units that have been approved, but are not yet built, and 264 units currently under construction, for a total of 2,434 units. Using the 2.57 average persons per household identified by the 2010 Census, these 2,434 residential units will house approximately 6,255 people. At 168 gallons per capita per day, the anticipated water demand from these units would be 1,177 AFY, for a total demand of 18,419 AF. Thus, currently, 94 percent of the City's water supply has been allocated to existing and approved development. In addition, another 685 residential units are currently being considered for approval, which would result in an additional 331 AFY of demand for a total of 18,750 AFY, or 96 percent of current supply.

It should also be noted that during drought conditions, the UWMP estimates that supply from the Ventura River would be reduced by 700 AF during the second year of drought and 2,200 AF the third year. In addition, pursuant to a 1996 stipulated judgment, in multi-year drought conditions groundwater supply from the Santa Paula basin must be reduced from 3,000 AFY to 1,141 AFY, a reduction of 1,859 AF. Additional groundwater pumping could provide 1,500 AF. Therefore, according to the UWMP, during drought conditions, the City's water supply could be reduced by as much 2,559 AFY. It appears that during drought conditions, the City may not have adequate supplies to meet normal demand in upcoming years and measures would need to be put in place to reduce demand.

The City is exploring a number of measures to increase supply and/or reduce demand, including using additional reclaimed water from the Ventura Water Reclamation Facility, partnering with the Ojai Valley Sanitary District for use of reclaimed water, various conservation measures and public education, implementation of the City's Water Efficiency plan, continued implementation of the City's Reclaimed Water Policy, and the possible

development of a water rights ordinance. The effectiveness of these measures has yet to be determined and the timeframes for their implementation are unclear.

H. Wastewater Services

The City provides wastewater conveyance and treatment services to approximately 98 percent of the residences within in the City as well as McGrath State Beach Park and the communities along the coast north of the City within Ventura County Service Area No. 29. The City anticipates taking over wastewater treatment services from the Montalvo Community Service District in the near term and the Saticoy Sanitary District in the long term. The City's wastewater collection system consists of approximately 285 miles of gravity sewers ranging in size from 4 to 42 inches, approximately 5 miles of force mains, 11 wastewater lift stations, and the Ventura Water Reclamation Facility (WRF), a tertiary treatment plant. The collection system sewers convey flows generally from east to west and north to south, culminating at the Ventura Water Reclamation Facility for treatment.

Wastewater Demand, Treatment, and Conveyance
The City's 2010 Wastewater Treatment Master Plan evaluated the condition of the wastewater conveyance system. It identified a number of existing, short-term, and ultimate (General Plan build-out) system deficiencies in the collection system and the projected costs to correct them, as follows:

- Existing – 339 pipe segments totaling 86,500 feet ($36,400,000)
- Near term – 233 pipe segments totaling 61,760 feet ($16,400,000)
- Ultimate – 318 pipe segments totaling 81,800 feet ($21,500,000)

These deficiencies are located throughout the City and include both mainlines and large trunk lines.

According to the 2012 MSR questionnaire responses, the WRF has a treatment capacity of 12.1 million gallons of wastewater per day and currently treats an average of 8.63 million gallons per day. According to the City's 2010 Wastewater Treatment Master Plan, the City's treatment plant has a permit-rated capacity of 14.0 million gallons per day, however, many of the facilities at the treatment plant are operating beyond a typical design life and the conditions of the facilities were not assessed as part of the Master Plan. Additional assessments of these facilities will be necessary and depending on their condition, a comprehensive replacement program may need to be developed before the plant can be expanded to a 14.0 million gallon per day treatment capacity.

According to the Wastewater Master Plan, near-term development within the City and in areas outside the City but within the City's wastewater service area will increase the volume of wastewater flows to approximately 11.4 million gallons per day, or 94% of the current capacity of the treatment facility. Build-out of the current General Plan and demand within the anticipated service area is projected to generate 13.0 million gallons per day, exceeding the treatment plant's current capacity.

In 2011, the City entered into a long term settlement of pending legal challenges to the discharge of wastewater into the Santa Clara River estuary. It commits the City to invest in new facilities to divert 100 percent of the wastewater to "beneficial uses" in coming decades. Funding to accomplish this goal and provide for the necessary infrastructure will be derived from increased rates to customers.

WRITTEN DETERMINATIONS

A. Growth and population projections for the affected area

According to the US Census, from 2000 to 2010, the City increased in population from 100,916 to 106,433. The California Department of Finance estimates the City's population to be 107,166 as of January 1, 2012. Thus, from 2000 to 2012, the City grew by an estimated 6,250 people, or 6.19 percent. This 6.19 percent growth rate over 12 years equates to an estimated average annual growth rate of 0.52 percent. The following table reflects the City's projected population in 5-year increments based on this estimated rate of growth. The table also reflects the annexation of the community of Montalvo to the City in 2012:

	2012	2015	2020	2025	2030
City Population	107,166	108,847	111,706	114,641	117,653
Montalvo	632	632	632	632	632
Total Population	**107,798**	**109,479**	**112,338**	**115,273**	**118,285**

The City updated its General Plan in 2005. The EIR prepared for the update included population projections based on an annual growth rate of 0.88 percent (average from 1994-2004) and a 2004 population of 104,952. The projections used in the General Plan would result in an estimated 2012 population of approximately 112,500, substantially higher than the current estimate by the Department of Finance. Thus, it appears that the anticipated growth rate projected in the General Plan EIR is overestimated based on the most recent population estimate from the California Department of Finance.

According to City Planning staff, the City has approved 2,434 residential units that have not yet been constructed. Using the average 2.57 person per household identified by the US Census, development of these units would add 6,255 people to the City. If the 685 residential units that are currently being considered for approval are, in fact, approved, it would add another 1,760 people. When the total population from these units is added to the current population, it results in a population of nearly 116,000.

B. The location and characteristics of any disadvantaged unincorporated communities within or contiguous to the sphere of influence

As defined by Section 56033.5 of the Government Code, a "Disadvantaged Unincorporated Community" (DUC) is a community with an annual median household income that is less than 80 percent of the statewide annual median household income. The Ventura LAFCo has determined that the community of Saticoy, abutting the City to the southeast and located within the City's current sphere of influence, is a DUC. The following demographic information was obtained from the 2010 Census:

Population:	1,029
Median Household income:	$21,343
Poverty rate:	28.4%
Race:	87% Hispanic

Saticoy receives wastewater services from the Saticoy Sanitary District, an independent special district which serves only the community of Saticoy. Potable water services are

provided by the City and customers are subject to the City's water surcharge for service provided outside of City limits. City policy generally precludes new or expanded water services greater than a ¾-inch meter, thus, limiting the amount of multi-family, commercial, and industrial development/redevelopment that can occur within the community. Law enforcement services are provided by the County Sheriff's Office and fire protection services are provided primarily by City under a mutual aid agreement.

C. Present and planned capacity of public facilities, adequacy of public services, and infrastructure needs or deficiencies

Fire services:

- The City operates six fire stations which serve the City and nearby unincorporated communities.
- The closure of Fire Station 4 in 2010 resulted in substantial reductions in response times for emergency services to approximately the eastern half of the City. In 2011, the City obtained funding to reopen the fire station through most of 2014. However, the availability of funding for this station beyond 2014 is uncertain at this time.
- The current level of staffing does not appear to be sufficient to provide personnel adequate time to perform their duties and to maintain adequate emergency response staffing without incurring substantial overtime costs.

Library services:

- Library services are provided by two libraries, both of which are located on the west end of the City. The city has adopted a 5-year plan with the goal of improving services and constructing a new library to serve the east side of the City.
- Per capita library spending is below the national and state averages.

Police services:

- The City provides a high ratio of sworn officers to residents.
- Recent reductions in police staffing correlated to a significant increase in violent crime in the 2011. The City has budgeted for an additional five sworn police officers and plans for another two officers next fiscal year.
- In order to maintain the current ratio of sworn officers to residents for approved and proposed residential development, an additional 9.5 sworn officers will be required.

Recreation and parks services:

- The City provides a wide range of park facilities and recreation programs.
- The City's goal is to provide 10 acres of park space per 1,000 residents. To meet this goal for the current population, 1,080 acres would need to be provided.
- The City provides 589 acres of developed park facilities.

Solid waste services:

- The City has entered into franchise agreements with a refuse collection company for solid waste collection and disposal services. Customers are billed directly by the service provider for these services.
- The City funds a number of additional solid waste-related services to encourage recycling, hazardous waste collection, and community beautification and enhancement.

Streets and highways:

- The City provides street and landscaping maintenance and storm drain maintenance services. Street sweeping services are provided as part of the franchise agreements with solid waste providers. A large majority of street lighting in the City is owned and maintained by Southern California Edison and is funded by the City. The City does maintain street lights owned by the City.
- Maintenance of City streets is significantly underfunded and likely to result in continued deterioration of City streets.

Potable water:

- The City provides potable water to the City and to areas adjacent to the City.
- It appears that current demand within the City's water service areas is 88 percent of current total supply.
- It appears that the water demands from approved, but not built, development will increase demand to 94 percent of current supply.
- It appears that currently-proposed development would increase water demand to 96% of current supply.
- It appears that anticipated reductions in supply during drought conditions will result in current and future normal water demand exceeding supplies, requiring implementation of measures to reduce demand.

Wastewater:

- The City provides wastewater collection and treatment services to the City and to adjacent unincorporated areas.
- The City's collection system currently experiences capacity deficiencies. In addition, the City has identified short-term capacity deficiencies and deficiencies at buildout of the General Plan.
- The City's Treatment Plant has adequate capacity to accommodate current wastewater flows. Anticipated wastewater flows from buildout of the General Plan will exceed the current capacity of the City's treatment plant. Additional assessment must occur in order to demonstrate that expansion of the treatment facility is feasible.

D. Financial ability of agencies to provide services

- Long-term funding needed to keep all currently operating fire stations open beyond 2014 has not been identified.
- In order to maintain the current Police officer-to-resident staffing ratios for new and proposed development, an additional 9.5 sworn officers are required. It is unclear how these positions will be funded.
- The City has identified funding shortfalls of up to $5.7 million per year for maintenance services necessary to prevent further deterioration of City streets.
- The costs to address the current deficiencies identified in the City wastewater collection system are projected to exceed $36 million. The source of funding and the timing of the improvements have not been identified.
- Sewer system improvements needed to accommodate near term and ultimate future growth and development is projected to cost approximately $38 million. The source of funding and the timing of the improvements have not yet been identified. In addition, the cost to construct the infrastructure necessary to divert wastewater for "beneficial uses" per the City's legal settlement has not been identified.

E. Status of, and opportunities for, shared facilities

- No other obvious additional opportunities for shared facilities were noted.

F. Accountability for community service needs, including governmental structure and operational efficiencies

- The City is locally accountable through an elected legislative body, adherence to applicable government code sections, open and accessible meetings, dissemination of information, and encouragement of public participation.
- The City's website contains a significant amount of information on the current and previous City budgets, services and programs, City happenings and activities, public meetings, development activities, and City documents. Current and past City Council minutes and agendas are posted and agenda items are linked to staff reports.
- Meetings of the City Council are broadcast live on the City's cable channel. Archived videos of past meetings are available for viewing on the City's website.
- To achieve operational efficiencies for storm water quality purposes, the City is covered under the County's National Pollutant Discharge Elimination System permit.

G. Any other matter related to effective or efficient service delivery, as required by Commission policy

- No other matters were identified.

ATTACHMENT D: DEVELOPMENT ENTITLEMENT REPORT 2005-2012
(Approved, Under Construction and Built Projects)

	2005 Retail (sf)	2012 Retail (sf)	% Projected	2005 Office (sf)	2012 Office (sf)	% Projected	2005 Industrial (sf)	2012 Industrial	% Projected	2005 Hotel	2012 Hotel	% Projected	2005 Total Non-Residential	2012 Total Non-Residential	% Projected	2005 Residential Dwelling Units	2012 Residential Dwelling Units	% Projected
DISTRICTS																		
Upper North Avenue	10,000	0	0	50,000	0	0	150,000	0	0	0	0	0	210,000	0	0	100	0	0
North Avenue	10,000	0	0	50,000	0	0	250,000	0	0	0	0	0	310,000	0	0	50	0	0
Downtown Specific Plan	100,000	18,557	19	250,000	123,859	52	0	0	0	150,000	0	0	450,000	142,472	32	1,600	449	28
Pacific View Mall	25,000	16,981	68	0	7,434	743,400	0	0	0	0	0	0	25,000	24,415	98	25	0	0
Harbor	[illegible]	[illegible]	[illegible]	0	[illegible]	0	0	[illegible]	[illegible]	330,000	[illegible]	0	538,000	21,350	4	300	300	100
Arundell	25,000	11,625	47	300,000	2,320	1	1,000,000	55,087	5	0	0	0	1,325,000	69,035	5	200	0	0
North Bank	300,000	30,282	10	50,000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	650,000	421,311	65	50	0	0
Montalvo	0	0	0	50,000	0	0	25,000	0	0	0	0	0	75,000	0	0	50	0	0
Saticoy	0	0	0	0	0	0	25,000	0	0	0	0	0	25,000	0	0	50	0	0
Subtotals (Districts)	785,000	98,099	13	700,000	133,413	19	1,750,000	440,116	26	380,000	0	0	3,615,000	681,633	19	2,425	749	31
CORRIDORS																		
Ventura Avenue	40,000	7,029	18	100,000	7,300	7	50,000	0	0	0	0	0	190,000	14,329	8	800	240	30
Main Street	15,000	6,082	41	40,000	593	1	0	0	[illegible]	0	0	0	55,000	6,675	12	100	46	46
Thompson Boulevard	15,000	17,716	118	40,000	0	0	0	0	0	[illegible]	0	[illegible]	55,000	17,716	32	300	34	11
Loma Vista	15,000	5,100	34	40,000	341,660	854	0	0	0	0	0	0	55,000	346,760	630	25	0	0
Telegraph Road	15,000	0	0	40,000	0	0	0	0	0	0	0	0	55,000	0	0	250	0	0
Victoria Avenue	15,000	0	0	40,000	0	0	0	0	0	0	0	0	55,000	0	0	60	154	308
Johnson Drive	50,000	840	2	20,000	0	0	0	0	0	0	0	0	70,000	840	1	150	0	0
Wells Road	15,000	25,000	167	20,000	0	0	0	0	0	[illegible]	[illegible]	0	35,000	25,000	71	50	173	346
Subtotals (Corridors)	180,000	61,767	34	340,000	349,553	103	50,000	0	0	0	0	0	570,000	411,320	72	1,725	647	38
SPHERE OF INFLUENCE(SOI/OTHER INFILL/NEIGHBORHOOD CENTERS																		
101/126 Agriculture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200	0	0
Wells/Saticoy	0	0	0	0	0	0	0	0	[illegible]	0	0	0	0	0	0	1,050	694	66
Pierpont	30,000	20,230	67	0	0	[illegible]	0	0	0	0	0	0	30,000	0	0	100	138	138
Other Neighborhood Centers (includes Seaward/Allessandro+College/ Day+Gateway Plaza+Victoria Plaza+Bristol+Kimball/Telegraph+Petit/Telephone+Telephone/ Cachuma+Saticoy)	0	20,965	2,093,600	0	0	0	0	0	0	0	87,000	8,868,900	0	107,965		100	0	0
Second Units	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	300	55	18
Underutilized	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	250	0	0
Vacant	165,000	0	0	50,000	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	215,000	0	0	450	0	0
Subtotals (SOI/Other Infill/NC)	195,000	41,195	21	50,000	0	0	0	0	0	0	87,000	8,868,900	245,000	107,965	44	2,450	887	36

	2005 Retail (sf)	2012 Retail (sf)	% Projected	2005 Office (sf)	2012 Office (sf)	% Projected	2005 Industrial (sf)	2012 Industrial	% Projected	2005 Hotel	2012 Hotel	% Projected	2005 Total Non-Residential	2012 Total Non-Residential	% Projected	2005 Residential Dwelling Units	2012 Residential Dwelling Units	% Projected
Planning Communities (Not included within District/Corridor/Center-above)																		
Downtown	1,072	0	0	0	0	0	0	0	0	150,000	0	0	151,072	0	0	50	0	0
Ventura Ave/Westside	7,086	0	0	0	0	0	27,000	0	0	0	0	0	34,086	0	0	238	0	0
Midtown	13,751	0	0	0	0	0	0	0	0	0	0	0	13,751	0	0	34	3	9
Colleges (Telegraph/Loma Vista)	2,719	0	0	8,843	1,761	20	0	0	0	0	0	0	11,561	1,761	15	4	14	350
Telephone Road Corridor	0	0	0	54,785	0	0	0	0	0	0	0	0	54,785	0	0	256	0	0
Montalvo/Victoria	0	0	0	4,300	0	0	0	0	0	0	0	0	4,300	0	0	296	0	0
Saticoy/East End	7,950	56,102	706	5,600	0	0	0	0	0	0	0	0	13,550	56,102	414	840	220	26
Arundell	41,640	0	0	42,614	0	0	18,080	0	0	0	0	0	102,334	0	0	0	0	0
Ollvas	7,160	0	0	7,066	0	0	390,053	0	0	0	0	0	404,279	0	0	0	0	0
Pierpont	0	912	91,200	0	0	0	0	0	0	0	0	0	0	912	91,200	0	0	0
Serra	0	0	0	0	1,000	100,000	0	0	0	0	0	0	0	1,000	100,000	0	232	23,200
Thille	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120	12,000
Wells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Westside	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	163	16,300
Subtotal (Planning Communities)	81,377	57,014	70	123,208	2,761	2	435,133	0	0	150,000	0	0	789,718	59,775	8	1,718	752	44
TOTAL	1,241,377	258,974	21	1,213,208	486,733	40	2,235,133	449,116	20	530,000	87,000	16	5,219,718	1,280,823	25	8,318	3,035	36

Gustorf, Kevin

From: Rungren, Susan <srungren@venturawater.net>
Sent: Tuesday, January 08, 2013 2:45 PM
To: Gustorf, Kevin
Cc: Rungren, Susan
Subject: Fwd: Ventura utility section

fyi

Susan Rungren
Principal Engineer
Ventura Water
(805) 652-4523

From: "Chandra Chandrashaker" <cchandrashaker@ci.ventura.ca.us>
To: "Susan Rungren" <srungren@ci.ventura.ca.us>, "Betsy Cooper" <bcooper@ci.ventura.ca.us>
Cc: "Lucho Rodriguez" <lrodriguez@ci.ventura.ca.us>
Sent: Tuesday, January 8, 2013 2:36:25 PM
Subject: Fwd: Ventura utility section

Susan,

Here are the water demand factors for non-residential uses identified in the GP EIR. Chandra

---

From: "Joe Power" <JPower@rinconconsultants.com>
To: "Chandra Chandrashaker (cchandrashaker@ci.ventura.ca.us)" <cchandrashaker@ci.ventura.ca.us>
Sent: Tuesday, January 8, 2013 9:53:48 AM
Subject: FW: Ventura utility section

Chandra:

Below are the water demand factors from the General Plan EIR. The same factors were used citywide.

Joe

From: Mike Swan [mailto:mswan@psomas.com]
Sent: Tuesday, January 08, 2013 9:43 AM
To: Joe Power
Subject: RE: Ventura utility section

Joe –

I was not able to find the exact final table included in the document you sent but I did find some preliminary water demand projection worksheets that included the demand factors and I tested them in the tables you provided and they worked. So here are the demand factors used:

Residential 450 gpd/du

Retail	250 gpd/ksf
Office	250 gpd/ksf
Industrial	315 gpd/ksf
Hotel	500 gpd/ksf

ksf = thousand square feet

We had some other demand projections that were acreage-based but these should work with the tables you referenced.

Call if you have any questions.

Michael D. Swan, PE
PSOMAS | *Balancing the Natural and Built Environment*
Senior Project Manager
Water & Wastewater Infrastructure
5 Hutton Centre Drive, Suite 200
Santa Ana, CA 92707 714 751-7373
Direct 714 481 7679

From: Joe Power [mailto:JPower@rinconconsultants.com]
Sent: Monday, January 07, 2013 3:41 PM
To: Mike Swan
Subject: Ventura utility section

Hi Mike:

Those tables are 4.13-15 through 4.13-20 in the attached document. Thanks.

Joe Power
Principal

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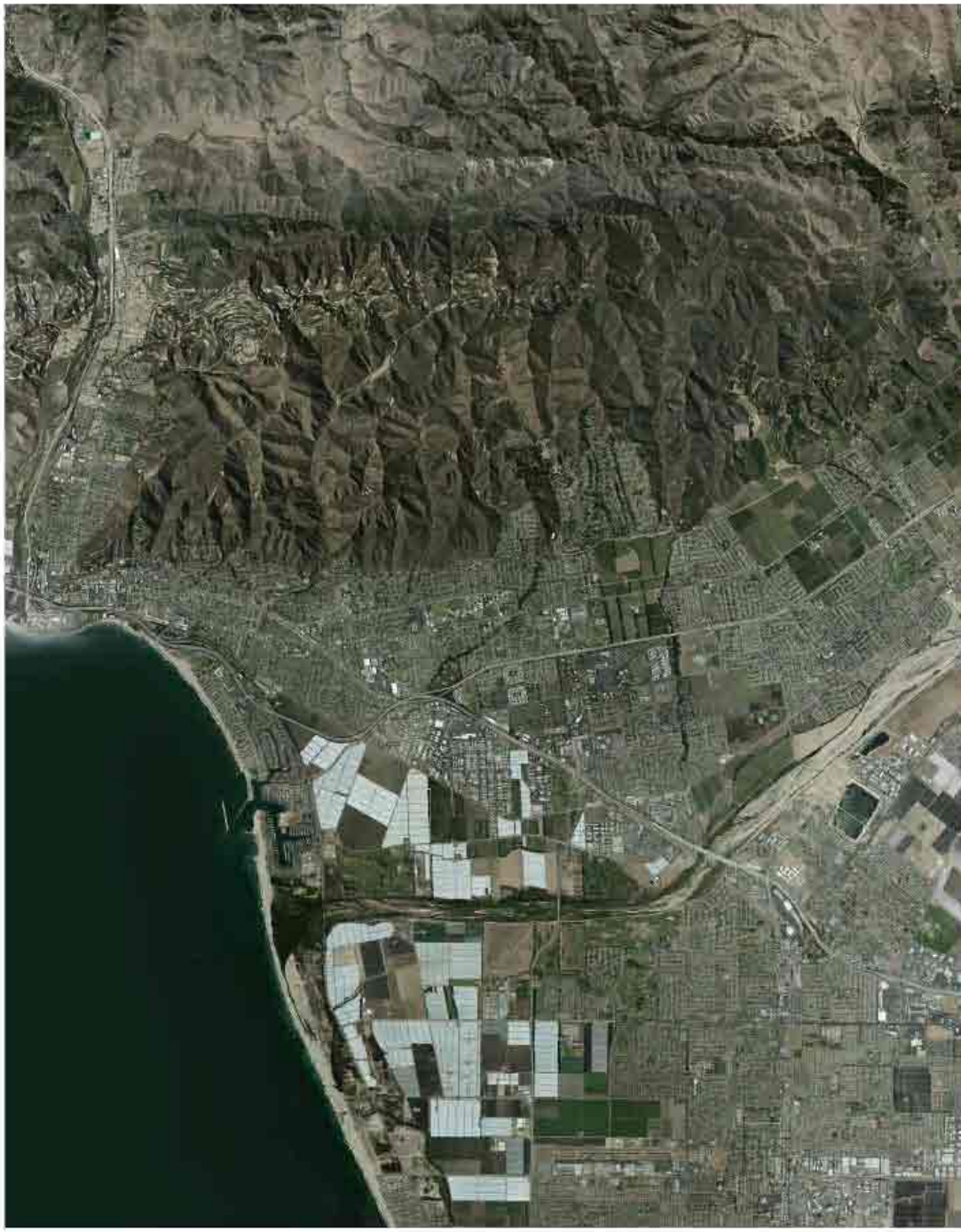

DYNAMICS OF WATER USE AND RESPONSES TO HERBIVORY IN THE INVASIVE REED, *Arundo donax* (L.)

A Thesis

by

DAVID AMI WATTS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Rangeland Ecology and Management

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MASTER OF SCIENCE

Approved by:

Chair of Committee,	Georgianne Moore
Committee Members,	David Briske
	Harry Cralle
Head of Department,	Steven Whisenant

May 2009

Major Subject: Rangeland Ecology and Management

ABSTRACT

Dynamics of Water Use and Responses to Herbivory in the

Invasive Reed, *Arundo donax* (L.). (May 2009)

David Ami Watts, B.S., University of California, Los Angeles

Chair of Advisory Committee: Dr. Georgianne W. Moore

The first objective of this study was to investigate the role of an invasive grass species, *Arundo donax* (L.), on the hydrologic cycle. At a site on the Rio Grande in South Texas, we measured the gas exchange of carbon dioxide and water vapor at the leaf scale and structural characteristics, such as leaf area and shoot density, at the stand scale. In order to assess the effect of water availability, this study was conducted along transects perpendicular to the edge of the river along a potential moisture gradient. The second objective was to quantify the effect of two herbivores, an armored scale, *Rhizaspidiotus donacis* (Leonardi), and a stem-galling wasp, *Tetramesa romana* (Walker),on the photosynthetic and transpiration rates of *A. donax*. Leaf gas exchange measurements were made to determine the direction and magnitude of the effect on physiological processes and by what mechanisms any effects arose.

Stands of *A. donax* used approximately 9.1 ± 1.1 mm of water per day. This rate of water use was at the high end of the spectrum for plants. The major controls on stand scale transpiration were evaporative demand, leaf area index, and water availability. During two summer seasons, stand scale transpiration varied greatly, following the

pattern of variability in precipitation, suggesting that recent rainfall constituted a significant proportion of the water taken up by this species.

Herbivory by a stem-galling wasp and a sap-feeding scale, both separately and together, reduced the rates of leaf scale physiological processes in *A. donax*. The efficacy of the wasp was density dependent, and this herbivore reduced the carboxylation rate of Rubisco. The effect of the scale took approximately five months to manifest, which coincided with generation time. Scale reduced photosynthesis by decreasing the maximum rate of electron transport. When the two insects were both present, the effect of their herbivory seemed to be additive. These results will assist the responsible management agencies in evaluating the propriety of using one or both of the insect herbivores as biological control agents.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Georgianne Moore, and my committee members, Dr. David Briske and Dr. Harry Cralle for their guidance and support throughout the course of this endeavor. Thanks to Kira Zhaurova and Laura Martin for their help in the field, and thanks to Dr. John Goolsby, Ann Vacek, and Dr. Patrick Moran for all their assistance within and without the quarantined greenhouse.

I also give thanks to my friends and colleagues at Texas A&M University, and in the Department of Ecosystem Science and Management in particular. Thanks, as well, go to the Texas Water Resources Institute, including the Rio Grande Basin Initiative, the United States Geological Survey, and the United States Department of Agriculture's Agricultural Research Service.

Finally, I must thank my family for always being wonderfully supportive.

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CHAPTER I

INTRODUCTION

Semi-arid regions are inherently water-limited. The importance of the relationships between the biological and hydrological constituents of these landscapes has recently been discussed (Wilcox and Newman 2005; Newman *et al.* 2006). The emerging field of ecohydrology has focused attention on two distinct but interacting components – the upland rangeland areas and the riparian corridors. Of special importance within semi-arid rangelands are causes and effects of the protracted expansion of woody plants (Archer 1989; Archer 1994; Archer *et al.* 2001; Ansley *et al.* 1995; Huxman *et al.* 2005; Potts *et al.* 2006; Schlesinger *et al.* 1990; Van Auken 2000), and management strategies beneficial to both the landscapes and the people who inhabit them (Wilcox 2002).

Ecohydrological research on the riparian zones of semi-arid regions has largely focused on the role of woody plants in the water cycle (Busch *et al.* 1992; Wagner and Bretschko 2003; Clinton *et al.* 2002; Tabacchi *et al.* 2000; Williams *et al.* 2006; Levine and Stromberg 2001; Scott *et al.* 2000; Stromberg 1998; Stromberg 2001). For example, invasion by saltcedar species, *Tamarix* spp., attracts particular interest in the quantity of water used by this invader and adjacent native species at multiple spatial and temporal

---

This thesis follows the style of *Journal of Ecology*.

scales (Cleverly *et al.* 2002; Cleverly *et al.* 2006; Dahm *et al.* 2002; Glenn and Nagler 2005; Horton *et al.* 2001; Moore *et al.* 2008; Nagler *et al.* 2008; Nagler *et al.* 2003; Sala *et al.* 1996; Smith *et al.* 1996).

Non-woody vegetation, including grasses, can also play an important role in the dynamics of riparian ecosystems (Naiman and Decamps 1997). Grasses that invade ecosystems well outside their historical range damage these ecosystems measurably (D'Antonio and Vitousek 1992; Milton 2004). Such invaders are often labeled 'transformer species' (Pyšek *et al.* 2004). Because little is known about the interactions between non-woody vegetation and the water cycle in the riparian zones of semi-arid areas, the invasion by *Arundo donax* (L.) is worth studying. This species has already been labeled a 'transformer' (Spencer *et al.* 2005), exhibiting strong negative impacts on biodiversity (Guthrie 2007; Kisner 2004; Herrera and Dudley 2003) and ecosystem function (Quinn and Holt 2008; Quinn *et al.* 2007; Rieger and Kreager 1989; Scott 1994).

In the lower Rio Grande watershed in southern Texas, water resources are made scare by drought and human demand (Usborne 2001). Since this region supports large areas of irrigated agriculture and sizeable urban populations, water resources are decidedly important. *A. donax* is thought to cover approximately 40,000 hectares along the Rio Grande and its tributaries, irrigation canals, ditches, and resacas (oxbow lakes) (Yang, pers. comm.), and efforts are currently underway to use recently established remote-sensing methods to quantify the distribution and total areal coverage of this

species throughout the lower portion of the Rio Grande/Rio Bravo watershed (Everitt *et al.* 2004; Everitt *et al.* 2008; Everitt *et al.* 2005).

Basic data on the rates and quantities of water used by *A. donax* are necessary but completely lacking at any spatial or temporal scale. One of the few estimates of water use rates of *A. donax*, at over 1700 mm year^{-1}, was not peer-reviewed and was based on the assumption that this species transpires the same quantity of water as rice (Iverson 1998). This figure exceeds reported values evapotranspiration measured in riparian woodland systems in the southwestern United States by 18-40% (Cleverly *et al.* 2002; Devitt *et al.* 1998). Therefore, the first step in this study was to understand how *A. donax* uses water resources at different spatial and temporal scales under highly variable field conditions. Leaf scale transpiration and leaf area index were measured at three different canopy heights across four plots that increase with lateral distance from the river's edge. Because a potential management method for this invader is biological control, the second step of this study was to quantify the effect of insect herbivores (which are potential biological control agents) on the rates of physiological processes in the host plant. The two selected agents were a stem-galling wasp, *Tetramesa romana* (Walker) and an armored scale, *Rhizaspidiotus donacis* (Leonardi). I examined their effects on transpiration and photosynthetic rates as well as the mechanism behind these effects. This research was conducted to provide critical feedback to the agencies responsible for their approval and eventual release.

CHAPTER II

WATER USE DYNAMICS OF *Arundo donax* FROM LEAF TO STAND

INTRODUCTION

The conservative use of water resources from both rivers and aquifers is vital for the maintenance of natural, agricultural, and municipal systems, and as these latter two sectors consume large shares of these resources, natural systems can be left in deficit. This is especially evident in drier periods, as exemplified by dramatic events such as when Rio Grande flows do not reach the Gulf of Mexico (Usborne 2001). Water-limited river systems, common in the western United States , are particularly susceptible to drought pressures (Cleverly *et al.* 1997), and have added biotic pressures from riparian invasive species (Dukes and Mooney 2004) that may be capable of significantly altering the structure and function of ecosystems (D'Antonio and Vitousek 1992; Hobbs and Mooney 1998; D'Antonio *et al.* 1999).

Much recent attention has been paid to the role of invasive semiarid woody plants in the water cycle, as exemplified by focus of research on saltcedar (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia* L.) (Cleverly *et al.* 2006; Dahm *et al.* 2002; Nagler *et al.* 2003), because some invasive species compete for water resources aggressively (Wilcox and Thurow 2006). To many restorationists and land stewards, the removal of invasive species will increase streamflow, and this notion is epitomized by flagship efforts like South Africa's Working for Water Programme (Marais and Wannenburgh 2008; Cullis *et al.* 2007; Gorgens and van Wilgen 2004). However, the

water regained by these types of projects are not easily predictable in semiarid and arid landscapes (Wilcox 2002; Huxman *et al.* 2005). Predicted differences do not always live up to expectations. For example, evapotranspiration (ET) in *Tamarix* stands on the Lower Colorado River was estimated to be only 1% of mean yearly streamflow (Nagler *et al.* 2008). Also, reducing water loss through one pathway, such as transpiration, does not necessarily equate to increases in streamflow if there are offsets through other pathways, such as increased soil evaporation (Wilcox and Thurow 2006). Moreover, depending on the rates of water use employed in economic models, expectations of potential water gain through the removal of invasive species can be unrealistically high (Owens and Moore 2007).

The hydrology, geomorphology, and ecology of riparian ecosystems are interdependent. For example, riparian vegetation can provide channel stability at small spatiotemporal scales but lead to instability at larger, longer-term spatiotemporal scales (Rowntree and Dollar 1999). Additionally, woody debris in streams can trap sediment, dissipate energy, and create habitats (Naiman and Decamps 1997). Tabacchi et al. (2000) reviewed the ways in which vegetation influences runoff and hydraulic processes, water cycling, and water quality. From the opposite perspective, plant species and diversity are partly a result of the distribution of hydrological and geomorphological processes and forms (Bendix and Hupp 2000; Amoros and Bornette 2002). These complex feedbacks can be altered by changes in community structure brought about as a result of invasions (Tickner *et al.* 2001). Invasive plant species can not only alter the dynamics between vegetation and geomorphology in riparian systems (Rowntree 1991), but they can also

have negative effects on hydrology if increases in leaf transpiration rate, leaf area, and/or access to previously unused sources of moisture lead to reductions in soil moisture content (Walker and Smith 1997). Although interactions between various water sources and riparian forests have been studied (Clinton *et al.* 2002; Wagner and Bretschko 2003), little is known about the interactions between non-woody vegetation and the saturated or vadose zones of riparian corridors. The impacts of invasive grasses on water resources in particular have been understudied (Milton 2004), in large part due to highly problematic woody invaders (Richardson and van Wilgen 2004).

Giant reed (*Arundo donax* (L.)) is found in the 25 southernmost states (Bell 1997), and is known to have been in the southwestern United States since at least the early 19th century (Hoshovsky 1993; Dudley 2000). As with many riparian plants (Tabacchi *et al.* 2000), basic information on the rates and quantities of water used by *A. donax* is lacking. One of the few reports of water use rates in *A. donax* comes from non-peer-reviewed literature, where it reportedly consumes over 1700 mm/yr (5.62 ft/yr) based on the assumption that this species transpires the same quantity of water as rice (Iverson 1998). This figure exceeds reported evapotranspiration values measured in riparian woodland systems in the southwestern United States by 18 to 40%, including dense, multi-story canopies (Cleverly *et al.* 2002; Dahm *et al.* 2002; Devitt *et al.* 1998).

A. donax is currently targeted for control in some of its introduced range (Milton 2004). *A. donax* covers approximately 40,000 hectares in the Rio Grande basin (Yang, pers. comm.), and efforts are currently underway to use recently established remote-sensing methods (Everitt *et al.* 2004; Everitt *et al.* 2005) to quantify the distribution and

total areal coverage of this species throughout the lower portion of the watershed. A necessary first step in understanding how this invasion affects the water cycle is quantifying variation in the water use of *A. donax* stands.

Water supply fluctuations increase variability in transpiration, even in riparian ecosystems (Williams *et al.* 2006). For example, soil moisture in a temperate riparian zone was spatially heterogeneous in both lateral gradients away from the edge of open water and vertical gradients away from the saturated zone (Dall'O' *et al.* 2001). The first objective of this study was to examine transpiration variance, both spatially and temporally, by examining stand structure, leaf gas exchange, and water use efficiency along potential gradients perpendicular to the Rio Grande. We predicted that leaf area and leaf level transpiration were highest near the active river channel and declines with distance away from the river, although soil fertility may also be a factor. We also anticipated some seasonality in the above spatial trends driven by water availability gradients. We expected that a more pronounced lateral trend with distance would occur during warm seasons with high evaporative demand. For the same reason, within-stand spatial variance was expected to be more pronounced during drought. Non-phreatophytic riparian vegetation responded largely to either recent rainfall or water from deeper in the soil profile without using much or even any groundwater, depending on the type of vegetation (Scott *et al.* 2000; Dawson and Ehleringer 1991). Thus, as soil moisture in riparian zones varied interannually and seasonally due to fluctuation in precipitation (Joris and Feyen 2003; Scott *et al.* 2004), transpiration rates of riparian vegetation were accordingly dynamic (Williams *et al.* 2006). Our second objective was to use a bottom-

up approach to scaling to estimate stand level transpiration (Baldocchi *et al.* 1991) based on observed spatial and temporal variance. Thus, this study represents a critical first step (Baldocchi *et al.* 1996) in characterizing the dynamics of how *A. donax* impacts water resources.

MATERIALS AND METHODS

This study was conducted along the Rio Grande river (26°01′53″ N, 97°43′41″ W, 15 m a.s.l.) in Cameron County, Texas. Mean annual precipitation is 715 mm and monthly average temperatures range from 9 to 21 °C in January and 23 to 35 °C in September and August (Anonymous 2008). Soils at the site are characterized as loam or clay loam, which are a part of the Rio Grande-Matamoros association (Williams *et al.* 1977). This area consists of a historic gently sloping floodplain 4.0 to 6.0 km wide, where flooding still occasionally occurs as a result of rainfall, although dams and levees have altered the historic flood regime (Lonard and Judd 2002). Common native trees of the Lower Rio Grande include honey mesquite (*Prosopis glandulosa* Torr.), sugar hackberry (*Celtis laevigata* Willd.), cedar elm (*Ulmus crassifolia* Nutt.), and anacua (*Ehretia anacua* (Terán & Berl.) I.M. Johnst.), while the dominant shrub was granjeno (*Celtis pallida* (Klotzsch) Liebm.) (Lonard and Judd 2002). The most common ground cover species are the exotic Guinea grass (*Panicum maximum* (Jacq.) R. Webster) and buffel grass (*Pennisetum ciliare* (L.) Link) (Lonard and Judd 2002). During the 20th century, 91 to 99% of native woodland and riparian vegetation was cleared due to the expansion of agriculture and urban development (Jahrsdoerfer and Lesie 1988; Tremblay *et al.* 2005).

Three transects were established perpendicular to and immediately adjacent to the Rio Grande within a large monoculture of *A. donax* in order to investigate within-stand dynamics. Very few other plant species were present at the site except a sparse ground cover layer consisting largely of *P. ciliare*. The following conditions were used to locate transects: maximal lateral stand width perpendicular to the river, sufficient slope to allow for a potential gradient in plant available water from river edge to upper bank, and uniform connectedness of the stand of *A. donax*. Transects were set up with a minimum of 15 m separation, and were between 12 and 20 m in length. At least 1 m of *A. donax* extended beyond the ends of the each transect in all directions to minimize edge effects that might reduce competition for resources (Spencer *et al.* 2005).

Four 1 m by 1 m plots were spaced evenly within each transect according to total transect length. The relative proximity of these four plots to the active channel (hereafter referred to as 'distance from the river') was used to investigate differences in stand structure, leaf gas exchange, and water use efficiency. Within each plot, four ramets (individual stems within a single clonal stand) were selected from within the subset of all ramets that both reached the top of the sunlit canopy and retained the apical meristem (Peterson and Chesson 2002). Moreover, ramets were chosen that did not appear to emerge from the same rhizome, whenever possible (Decruyenaere and Holt 2005). Leaf gas exchange of the four chosen ramets per plot was measured throughout the study.

In order to assess stand structure and document phenological trends in allometric properties, ten additional transects were allocated for one-time destructive sampling as follows. These transects were located parallel to those previously discussed and

harvested at approximately two month intervals from July 2007 through March 2008, and again in July 2008. As before, transects were divided into four 1.0 m^2 plots spaced at even intervals. They were then further divided into three vertical sections: the upper (L_U), middle (L_M), and lower (L_L) portions of the canopy. These vertical sections were partitioned equally, relative to the height of the tallest ramets in and around each transect. In the plots, the density of all ramets was recorded, as were the diameter and height of each ramet. Total leaf area within 0.25 m^2 subplots was quantified using a leaf area meter for five of the transects. All ramets were then oven-dried at 60° C for a minimum of 24 hours and continued drying until they were a constant mass. Leaf area index (LAI) for each 1.0 m^2 plot was then estimated by the relationship between ramet leaf area (L_r, cm^2) and biomass (BM, grams) and distance from the river (D, m) in the 0.25 m^2 subplots ($L_r = \exp(4.293+0.853 \ln(BM) - 0.010D)$, $R^2 = 0.912$, $N = 90$, $P \leq 0.05$) derived from a multiple regression model of leaf area. For one transect from this site, specific leaf area (SLA) was determined by weighing leaf material separately from stem material for 5 random ramets from each plot.

Leaf based gas exchange measurements were taken on 23 days from 27 June, 2007 through 22 July, 2008 using a leaf gas exchange system with a red and blue light source and CO_2 injector. All but five sampling days entailed midday measurements to capture peak rates of physiological processes. On the remaining five days, diurnal changes in gas exchange were measured on all ramets within a single transect every 2 h between 07:00 and 19:00 CST. Measurement dates from 2007 were 27 June, 23, 24, and 31 July, and 22 and 25 November. Measurement dates from 2008 were 20 and 22

January, 29 February, 5 and 7 March, 13, 15, 18, 20, 21, 25, 29, and 31 May, 1, 3, 4, and 5 June, and 22 July. Gas exchange measurements were conducted on clear days whenever possible, though the prevailing weather conditions were partly cloudy, and small isolated showers were common. Light level was always set to match ambient conditions measured at the beginning of each measurement cycle (adjusted every 2 hours on days of diurnal samplings), and CO_2 concentration was set to maintain 370 µmol/mol in the sample chamber. Only the second fully-emerged leaf from each ramet was sampled in order to control for leaf age.

To further document spatial variation in soil and plant water status with distance to the river, predawn and midday leaf water potentials (Ψ_{pd} and Ψ_{md}, respectively) were measured on a total of 10 days throughout the sampling period using a pressure chamber. On each day, 12 to 16 Ψ_{pd} measurements were completed before astronomic sunrise, and an equivalent number of Ψ_{md} measurements (or more) were taken on the same day between 11:00 and 14:00 h. To corroborate soil water status trends with distance to the river, we also looked for spatial trends in soil moisture at a single point in time. On two days in the middle of the growing season (4 and 5 June, 2008), volumetric water content of the top 20 cm of soil was measured for each plot in each of the four cardinal directions within 1.0 m from the center point of the plot using a soil moisture probe. Soil samples were collected on these same dates from 0 to 10 and 10 to 20 cm between 1.0 and 2.0 m distance laterally from the center point of each plot to reduce the likelihood that rhizomes within the plot would sustain damage (Dong and Alaten 1999). These samples were analyzed for soil texture, pH, electrical conductivity, cation exchange,

base saturation, and total C and N content by the Forest Science Laboratory at Texas A&M University. Such soil descriptors and fertility measures were used to verify that any observed physiological trends within the stand were unlikely caused by factors other than gradients of soil water access.

In order to have a longer, time-integrated view of leaf water use efficiency, which is the ratio of photosynthetic carbon gain per unit water transpired, the same leaf tissues from the second fully-emerged leaf from each ramet that was used for diurnal measurements of gas exchange were collected on 3 to 5 June to analyze stable carbon isotope ratios ($\delta^{13}C$) (Farquhar *et al.* 1989; Dawson *et al.* 2002; Ehleringer *et al.* 1993). Concurrent examinations of leaf C and N content were conducted to ensure that leaf nutrient status did not covary with $\delta^{13}C$ (Handley and Raven 1992). Samples were dried at 60° C for at least 24 hours until they were a constant mass and were then finely ground to an even texture by a combination of a custom-made roller grinder and a ball mill. Homogeneous 2 mg aliquots were analyzed by the Stable Isotope Biogeochemistry Laboratory in the Department of Ecosystem Science and Management at Texas A&M University.

Leaf transpiration rates (E_ℓ), were averaged for each ramet for a single set of midday measurements. To elucidate temporal differences in stand structure and leaf gas exchange with season and drought, data were divided into three temporal groups: summer 2007 (June to July), winter 2007/2008 (November to February), and summer 2008 (May to July). Daily weather data, including potential evapotranspiration (PET) and precipitation, were obtained from the nearest weather station, the Texas AgriLife

Research Weslaco Center (26° 9'52" N, 97°57'25" W). To compare between growing seasons, mean daily precipitation was calculated from one week prior to the first sampling date of each summer through the final measurement date. In order to look for the effect of distance from the river on LAI, a one-way ANOVA with Fisher's LSD as pairwise comparisons was used on plot means of LAI for all transects. Seasonal ramet means of E_ℓ were used in a separate two-way ANOVA, along with Fisher's LSD as pairwise comparisons to evaluate plot-level effects of distance to river as well as differences between transects. In order to test for effects of distance to river on the other leaf based data, one-way ANOVA was also used for ramet based averages of %C, %N, and $\delta^{13}C$. To assess whether soil and plant water status differed within the distance treatment, a one-way ANOVA was run on each of Ψ_{pd} and Ψ_{md}. In order to determine whether the distance treatment also affected soil fertility properties, one-way ANOVAs were conducted on each of gravimetric water content (GWC), % N, % C, P, and cation exchange capacity. All statistical analyses were conducted using SPSS. Note, the original experimental design was set up to use repeated measures analysis of variance (ANOVA), but because the site was unexpectedly mowed in late July or early August by the Texas Commission on Environmental Quality after several days worth of leaf gas exchange measurements, this was no longer possible.

Because the same ramets were used for gas exchange in the winter season and the following summer (2008), including season in the preceding analyses was not possible because it would violate the assumption of independence in ANOVA. Instead, Student's t-tests were used to compare the gas exchange and precipitation data from

summer 2007 and summer 2008. Gas exchange data for this comparison consisted of summer-long mean values for each ramet. Separately, a paired t-test was used to compare gas exchange data from winter 2007/2008 to summer 2008.

Bottom-Up Approach to Estimate Stand Transpiration

An empirical model was constructed to estimate total daily stand level transpiration as follows:

$$E_{stand} = (E_U \times L_U) + (E_M \times L_M) + (E_L \times L_L) \quad [1]$$

Diurnal estimates for each day were based on peak midday values and the shape of the curves from days in which gas exchange was conducted for an entire diurnal cycle. Second order polynomial curves provided a good fit to the diurnal measurements. It was assumed that transpiration was zero at night and increased linearly from dawn until the first morning measurement at 07:00 h and that it declined linearly to zero from the last evening measurement at 19:00 h until twilight. The model partitioned the measured transpiration into the three vertical canopy layers using measured data in the upper canopy (E_U) and estimated data in the middle (E_M) and lower (E_L) canopy layers based on the measured light penetration in those sections of the canopy and the corresponding transpiration values taken from light response curves conducted on shaded leaves (Niinemets *et al.* 1999; Niinemets 2007). This method is the most conservative method in this type of scaling (Dang *et al.* 1997). Instantaneous gas exchange values, in mmol $H_20/m^2/s^1$, were integrated for each day then multiplied by the molar mass of water and divided by density of water at 25 °C to convert to mm/day. This was done for each plot and canopy layer, and the three transpiration values were then multiplied by the LAI of

each of the three vertical sections, L_U, L_M, and L_L. In order to derive total daily transpiration per unit ground area (E_{stand}), expressed in mm/day, the three stratified layers were summed (Equation 1).

RESULTS AND DISCUSSION

Within-Stand Dynamics

The *A. donax* stand we studied is notably productive for a graminoid (Sharma *et al.* 1998; Papazoglou *et al.* 2005; Perdue 1958; Angelini *et al.* 2005). The mean LAI of *A. donax* in our study site was 4.1, and this is corroborated by measurements of LAI in a stand at another site 300 km upstream, where mean LAI was 4.5 (data not shown). These values of LAI are higher than those found in stands of *Tamarix ramosissima* (Ledeb.), another common invasive species on the Rio Grande, that range from 2.5 to 3.6 (Dahm *et al.* 2002). LAI values from 2007 were used in the scaling model to determine E_{stand} in both 2007 and 2008, but an independent measure of LAI in July 2008 verifies that LAI equaled or exceeded that of July 2007 (data not shown). *P. australis*, with very similar ecological and morphological characteristics to *A. donax*, has been reported to have LAI values of up to 8.9 in the peak of the growing season in wetlands of semi-arid southeastern Spain (Moro *et al.* 2004); however, *P. australis* growing at our study location was very sparse and limited to a band 1 m wide nearest the river (Pers. obs.).

The *P. australis* stand in Spain (Moro *et al.* 2004) exhibited a stronger seasonal trend than we observed at our site, wherein LAI increased gradually throughout the growing season and ranged from 3.3 in March 2008 to 5.5 in January 2008. Most *A. donax* leaves apparently do not senesce and abscise until late winter. The winter's

coldest period occurred from January 2 to January 26, 2008, after which there was a strong reduction in leaf area (Figure 1). We did not observe the onset of leaf production due to lack of frequent sampling during early spring and summer. The rate of growth in *A. donax* should vary yearly in a similar fashion.

Ramets of *A. donax* growing very near to the river are capable of supporting a higher LAI than those at a greater distance from the active channel and topographically upslope. This pattern was observed in the majority of individual transects measured. Mean LAI for all sample dates varied with distance to the river channel (Table 1). Replicated plots nearest the channel (1 and 2) had the highest LAI and were 79% and 53% greater than plots farther away from the channel (3 and 4), respectively. Interestingly, the section of the stand of *A. donax* with the lowest LAI was not the plots furthest from the river's edge (Plot 4), but rather one plot closer (Plot 3).

An apparent edge effect in LAI further strengthens the argument that some combination of greater light availability and reduced intraspecific competition occurs in stands of *A. donax* at the most laterally distant edge allows for compensation in ramet growth despite the potential limitation of water resources (Urbanc-Bercic and Gaberščik 1997). The edges of stands are also likely subject to greater advection (Speck 2003; Speck and Spatz 2004). Moreover, it has been shown that increased dispersal of offspring leads to greater competitive ability in clonal plants (Lenssen *et al.* 2005). For *A. donax*, the ramets that are the greatest lateral distance from the river channel may experience a reduction in intraspecific competition, and thus have a slight increase in metrics of yield like LAI.

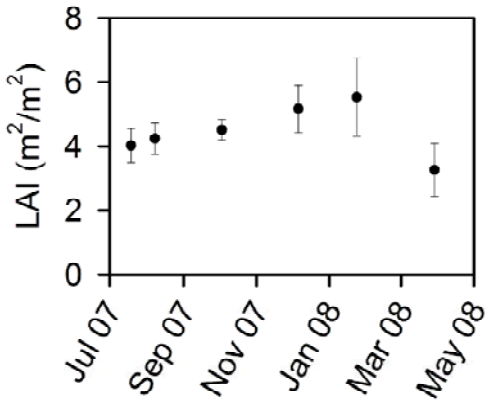

Figure 1. Mean leaf area index (LAI) estimates in m^2/m^2 throughout the study period. Standard error bars are indicated (N = 4 in all cases except October 2007, where N = 8).

Table 1. Comparisons between plots in a stand of *A. donax*. Shown are characteristics of stand structure [leaf area index (LAI, m^2/m^2) and specific leaf area (SLA, m^2/kg)], leaf water stress [pre-dawn (Ψ_{pd}) and midday (Ψ_{md}) water potential (kPa)], leaf chemistry [nitrogen (N, %), and carbon (C, %)], and soil properties [gravimetric water content (GWC, %), nitrogen (N, %), carbon (C, %), phosphorus (P, ppm), and cation exchange capacity (CEC, meq/100 g)]. All data are reported as mean (SE). Of all the listed variables, only LAI differed between plots, as indicated by letters from pairwise comparisons (Fisher's LSD) ($P \leq 0.05$).

	Stand structure		Leaf water status		Leaf chemistry		Soil properties				
Plot	LAI	SLA	Ψ_{pd}	Ψ_{md}	[N]	[C]	GWC	[N]	[C]	[P]	CEC
1	6.06 (1.13) a	12.25 (0.83)	-0.63 (.06)	-2.05 (.11)	2.32 (.05)	42.02 (.34)	24.50 (2.38)	0.15 (.04)	3.63 (.52)	17.90 (6.99)	18.23 (2.15)
2	4.63 (0.32) ab	9.45 (1.86)	-0.78 (.09)	-2.27 (.09)	2.24 (.06)	42.02 (.37)	25.24 (1.52)	0.13 (.02)	3.36 (.30)	12.57 (5.52)	16.91 (1.16)
3	3.38 (0.36) b	13.47 (0.62)	-0.90 (.10)	-2.50 (.16)	2.34 (.11)	42.44 (.28)	25.96 (0.87)	0.13 (.02)	3.39 (.18)	11.64 (4.39)	16.55 (0.39)
4	3.95 (0.68) b	12.45 (1.69)	-0.79 (.10)	-2.24 (.12)	2.37 (.12)	43.06 (.30)	25.44 (1.48)	0.16 (.03)	3.84 (.46)	11.40 (4.47)	17.48 (1.15)

Populations of *A. donax* frequently extend almost to the water's edge, but these areas were not sampled because of a drop-off extending approximately 3 m from the river to our first plots on top of the terrace (≈ 2 m vertically above the water level during normal flow). Both LAI and E_l would very likely be even higher in ramets below the terrace. Because *A. donax* appears to prefer habitats with mild slopes (≤ 2%) (Dudley 2000), the low floodplain slopes of many reaches along the Rio Grande are well suited for its survival.

Mean E_l also varied with distance to the river in summer 2007 and summer 2008, and followed the same trend as with LAI, having the highest values near the channel. The lowest values were in the plots farthest from the river in summer 2007, while in summer 2008, the lowest values of E_l were in the third, rather than fourth plots (Figure 2). During the cool winter season, E_l did not differ between parts of the stand either laterally or longitudinally (Figure 2). In the summer of 2007, mean E_l in Plot 1 was 15% and 20% greater than in Plots 2 and 4, respectively. Mean E_l in Plot 3 exceeded Plot 4 by 15%. In the summer of 2008, E_l was 68% higher in Plot 1 than in Plot 3. In the summer of 2008, E_l was highest in the plot closest to the river; however, the pattern that emerged during this growing season was different from the previous year in that the plot furthest from the river did not have the lowest E_l. Instead, the pattern here mirrored that of LAI, where Plot 3 had the lowest E_l. In both summer seasons, but not in the winter, the transects also differed from each other. For example, in summer 2008, transect 5 consistently had the lowest E_l (Figure 2). There was no interaction between plot and transect in either summer season, indicating that plots responded to distance from the

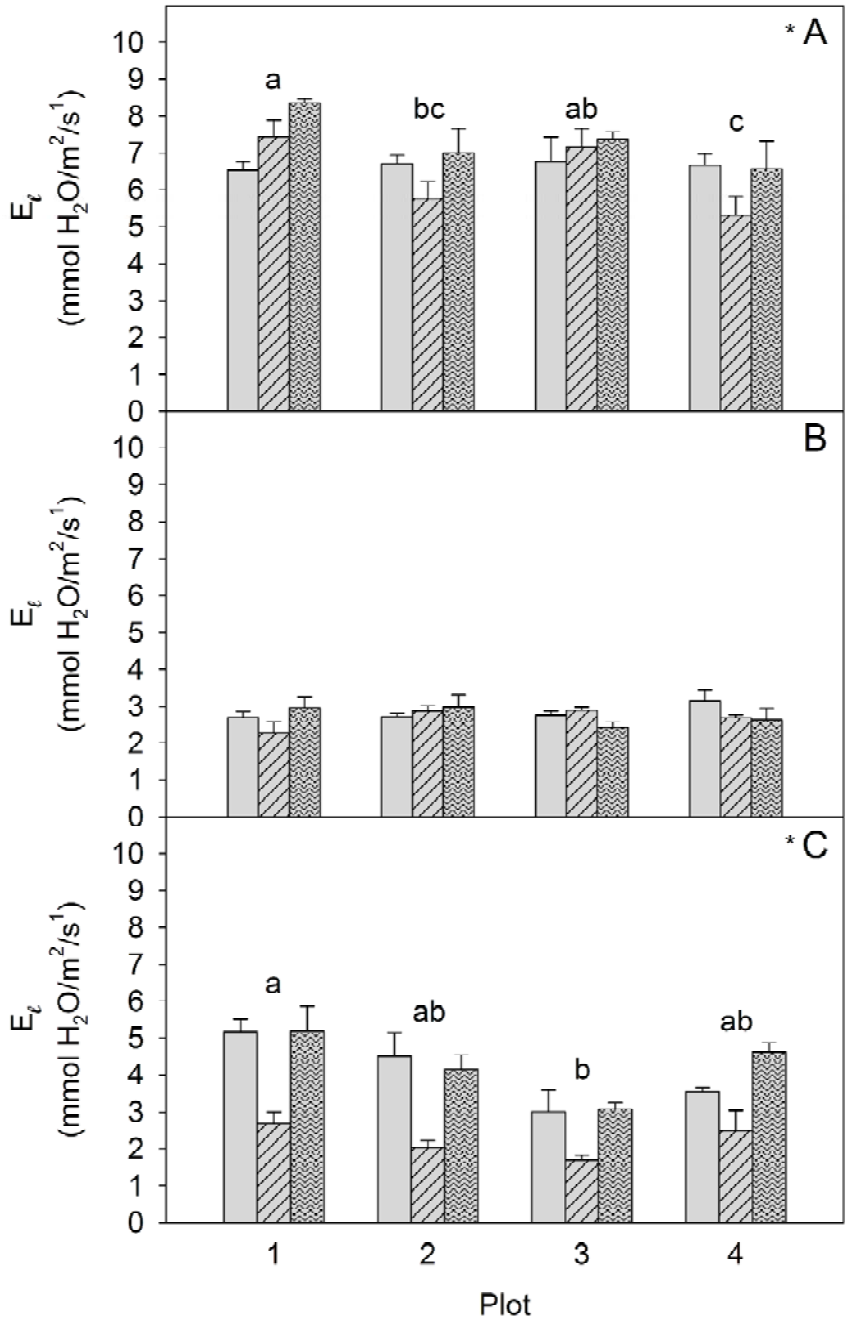

Figure 2. Leaf scale transpiration for each sampling period. Shown are mean leaf scale transpiration (E_l) and standard error bars (N = 4) for: (A) summer 2007 (N = 4 days); (B) winter 2007/2008 (N = 7 days); and (C) summer 2008 (N = 12 days). Bar patterns indicate the three randomly selected transects. Asterisks denote differences between transects ($P \leq 0.05$) within a season. Letters denote differences between plots from pairwise comparisons (Fisher's LSD) ($P \leq 0.05$) within a season.

river consistently in all transects. The two summers differed greatly in precipitation with 6.37 mm/day and 2.42 mm/day from 2007 and 2008, respectively.E_l was higher in the wetter summer of 2007 than the drier summer of 2008 (*t*-statistic = 7.958, $P < 0.000001$, d.f. = 19.003), and E_l was higher in the drier summer than in winter 2007/2008 (*t*-statistic = 2.224, $P < 0.05$, d.f. = 11).

The lack of spatial heterogeneity in E_ℓ during the winter season was likely due to reduced evaporative demand (Franks *et al.* 2007). Furthermore, the magnitude of the difference in E_ℓ between the highest and lowest plots was greater during the relatively dry summer of 2008 than the very wet summer of 2007, signifying that proximity to the river is even more important when there is less precipitation during the growing season. This likely means that *A. donax* does not use groundwater as its sole water source, but rather uses soil moisture from the vadose zone, and this lends credence to the conclusion that *A. donax* is not actually an obligate wetland plant. *A. donax* lacks adaptations for gas transfer to the root zone to tolerate the anoxic conditions found in frequently saturated soils (Brix *et al.* 1992). Also, the SLA of *A. donax* was 11.93 m^2/kg and did not differ between plots. This SLA estimate is roughly equivalent to the lowest values reported by Mommer et al (2006), who demonstrated that higher SLA correlates with plants that occur in wetter habitats. Thus, *A. donax* does not appear to have specialized adaptations to the wettest parts of riparian zones, and its occasional classification as a freshwater macrophyte warrants further scrutiny.

Water supply fluctuations within the stand were likely a driving factor for the observed spatial and temporal dynamics. Our results provide evidence of moisture

gradients within the stand, depending on the measurement method. We found the most pronounced differences with distance to the river during periods of high moisture stress. Stable carbon isotope ratios ($\delta^{13}C$) of leaves collected during the dry summer of 2008 provide a more time-integrated perspective of plant-water relations and water use efficiency (or carbon gained per unit water lost). Results indicated that these leaves experienced a gradient of water availability over their lifespan until they were removed from the shoots. The values of $\delta^{13}C$ became less negative with increasing relative distance from the river channel's edge (Table 1, Figure 3), which suggests that water use efficiency was higher at greater distances away from the river. Plot 1 had the most negative $\delta^{13}C$ values and was lower than Plots 3 and 4 by 0.54‰ and 0.76‰, respectively (Figure 3). Plot 4 had the least negative values. Although every effort was made to select leaves of the same age, the wide scatter of $\delta^{13}C$ values within each plot is likely the result of a combination of varying leaf age and light environment (Sandquist *et al.* 1993). Small differences in leaf age in such a rapidly growing species may alter leaf carbon assimilation rates and thus affect isotope ratios.

Integrated water use efficiency, as measured by $\delta^{13}C$, varied with distance to the river. Instantaneous assessments of leaf water status were not affected by distance to the river in either predawn or midday measurements (Table 1). Soil moisture content in the top 20 cm also was unaffected by distance (Table 1). Although our data on both plant water status and soil moisture content showed no lateral distance trends, Ψ_{pd} did differ on 29 February, 1 June, and 22 July 2008, each amidst a dry down period (at least 14 days with < 4 mm precipitation). The unique circumstances of conducting research on

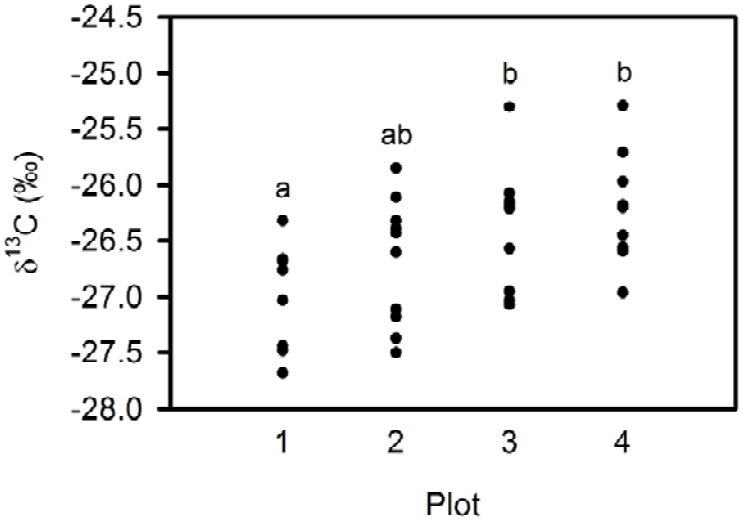

Figure 3. The relative water use efficiency of young leaves of giant reed as measured by carbon isotope discrimination, $\delta^{13}C$. Plot 1 is closest to the river channel; plot 4 is at the greatest distance. Letters indicate significance of pairwise comparisons (Fisher's LSD) between plot means ($P \leq 0.05$).

an international boundary prevented more frequent collection of Ψ_{pd} data. Moreover, the trends in both Ψ_{pd} and Ψ_{md}, mirrored the pattern in E_ℓ from summer 2008, in that plants were least water stressed (i.e. least negative Ψ_{pd} and Ψ_{md}) adjacent to the channel, while in most cases plants in plot 3 were most stressed (i.e. most negative Ψ_{pd} and Ψ_{md}). Also, Ψ_{pd} may not be highly indicative of soil Ψ in wet environments (Donovan *et al.* 2001). Drought conditions, at least in the top 20 cm, were not apparent during the narrow timeframe when soil moisture was quantified, but soil moisture can vary greatly over small spatial scales (Peterson and Chesson 2002). *A. donax* has functional rhizomes at depths as great as 1 m (Boose and Holt 1999), so fine roots may extend even lower in the soil profile, giving this species access to soil moisture at depth (Kemp *et al.* 1997) in systems where doing so provides a benefit (Kleinhenz and Midmore 2001).

Soil fertility, and plant responses to it, can vary over small spatial (Robertson *et al.* 1988; Jackson and Caldwell 1993) and temporal (Jackson *et al.* 1990) scales, and inherently affects leaf nutrient status. Our results for both leaf N and several measures of soil fertility indicate no difference with distance to the river channel, further emphasizing that the differences in both LAI and E_ℓ may indicate that water was the limiting resource. There was no significant relationship between relative distance from the river and either % C or % N in leaves (Table 1). There was no relationship between leaf N content and $\delta^{13}C$ (adjusted $R^2 < 0.001$, not shown), indicating that the variation in $\delta^{13}C$ values is reflective of differences in water use efficiency rather than leaf chemistry. In determining measures of fertility for the top 20 cm of soil, none of cation exchange or soil N, C, or P content varied with distance to the river (Table 1). Moreover, *A. donax* is

known to be quite effective at taking up nutrients (Abissy and Mandi 1999; Mavrogianopoulos *et al.* 2002; Cosentino *et al.* 2006; Manios *et al.* 2002; Srivastava *et al.* 2008) but does not appear to be nutrient limited at this site. If there were differences in plant available N, a reflection in *A. donax* growth or gas exchange would be evident because it is known to respond to N enrichment (Abissy and Mandi 1999).

Stand Transpiration

The observed spatial and temporal variation in LAI and E_ℓ described above were incorporated into a scaling model for stand transpiration (E_{stand}) which resulted in an overall estimate of 9.1 ± 1.1 mm/day, averaged over all 23 sample dates (Figure 4). An example of the measured and modeled diurnal transpiration patterns is given in Figure 5. The derived diurnal trend in E_ℓ resembles that of the driving variables for transpiration: humidity, and temperature, and light (Figure 5). Large differences in E_{stand} were evident within short time periods (Figure 4), and were likely a result of physiological responses to varying weather conditions (Herbst and Kappen 1999; Lissner *et al.* 1999). For example, in six sampling days between 29 May and 5 June, 2008, E_{stand} varied from 4.7 mm to 10.9 mm. Differences between the peak growing season and a much less active winter season are also clear (Figure 4). The model estimated that mean daily E_{stand} was 17.8 mm in the summer of 2007, 4.8 mm during following winter, and 8.8 mm during the summer of 2008.

These E_{stand} values are on the high end of the range of reported values in the literature on evapotranspiration in riparian ecosystems. For example, E_{stand} based on eddy-covariance from a site dominated by *T. ramosissima* reached up to 7 mm/day

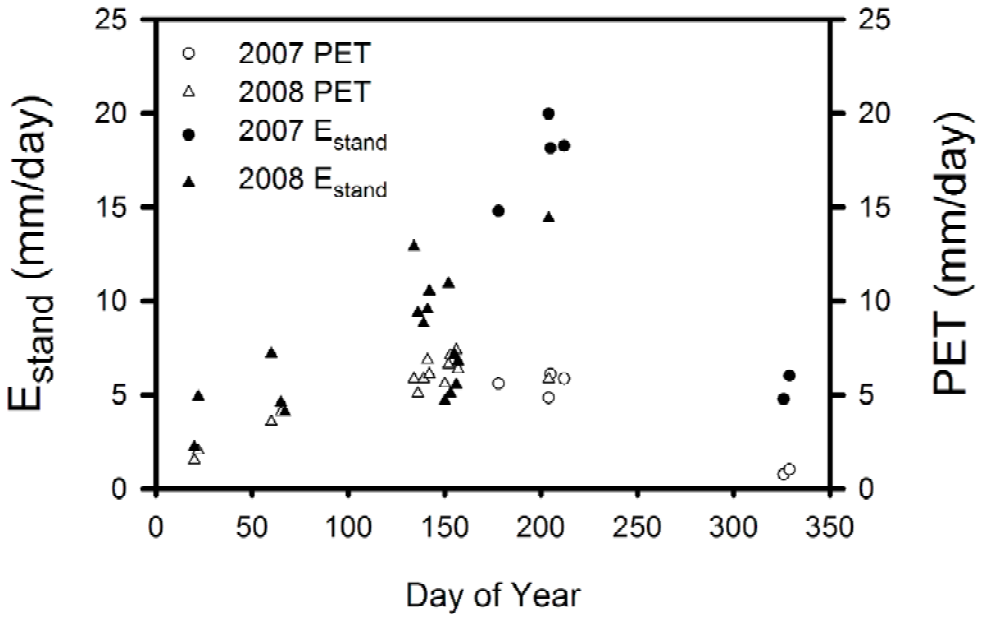

Figure 4. Total daily stand scale transpiration (E_{stand}) and daily potential evapotranspiration (PET) for all modeled sampling days in 2007 and 2008.

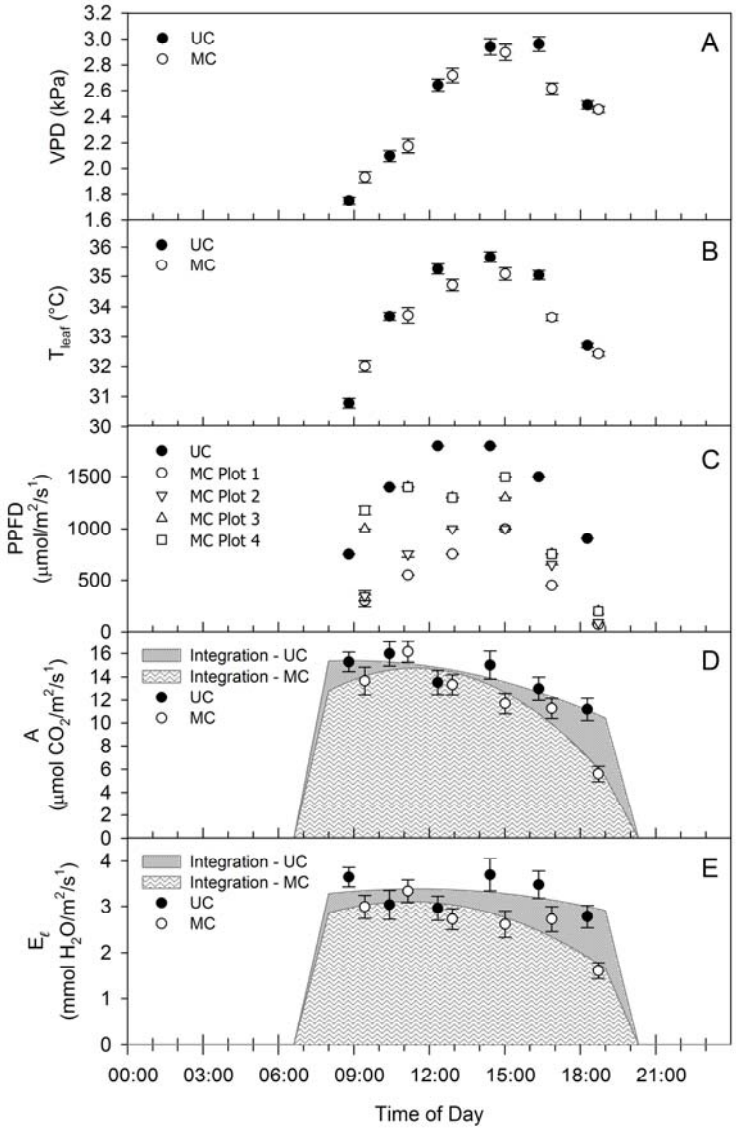

Figure 5. Diurnal observations from 3 June, 2008. Shown are: (A) Vapor pressure deficit (VPD); (B) Leaf temperature (T_{leaf}); (C) Photosynthetic photon flux density (PPFD); (D) Carbon assimilation rate (A); and (E) Transpiration rate (E) collected at approximately two hour intervals throughout the daylight hours. Closed symbols indicate leaves from the upper canopy (UC) layer; open symbols indicate leaves from the middle canopy (MC) layer. Means and standard error bars are given for each point (N = 16 ramets). For open symbols in graph (C), circles, downward-pointing triangles, upward-pointing triangles, and squares represent Plots 1, 2, 3, and 4, respectively. In graphs (D) and (E), shaded and lined regions are the integrated predicted values on this day for the upper and middle canopy layers, respectively, using the diurnal model described in the Materials and Methods section.

(Cleverly *et al.* 2002). In a similar study, E_{stand} from sites dominated by mixtures of native and invasive woody species reached peak values of approximately 9 mm/day (Dahm *et al.* 2002). E_{stand} in a pond lined by *Phragmites australis* (Cav.) Trin. ex Steud. in Nebraska, USA was estimated at 4 mm/day in a stand that had a maximum LAI of 2.6 (Burba *et al.* 1999). E_{stand} in *P. australis* in Germany is estimated at 10 to 16 mm/day in stands with summertime LAI of about 5 (Herbst and Kappen 1999). *P. australis* in semi-arid Spain has been shown to have average midsummer E_{stand} values of about 23 mm/day in a stand with simultaneous LAI values of 8.9 (Moro *et al.* 2004). Keeping transpiration rates constant, this would equate to approximately 9.6 mm/day if LAI were equivalent to that of *A. donax* in this study. Additionally, the ratio of E_{stand} to potential evapotranspiration (PET) for reed systems can range from 0.75 to 3.4, and one of the strongest controlling factors in these systems is the horizontal advective component that supplies additional energy to drive evaporative demand (Burba *et al.* 1999; Devitt *et al.* 1998; Moro *et al.* 2004; Herbst and Kappen 1999; Peacock and Hess 2004; Fermor *et al.* 2001). Our data show that *A. donax* had E_{stand}/PET ratios ranging from 1.4 in the summer of 2008 to 3.7 in the summer of 2007. Soil evaporation is unlikely a significant contributor to total evapotranspiration (Goulden *et al.* 2007), largely because of the substantial mulch layer and the general lack of exposed soil (Pers. obs.).

Our E_{stand} estimates may be representative of *A. donax* stands throughout the Rio Grande Valley, but a regional study is needed to determine larger-scale water use patterns. The climate of our study region is subtropical with evaporative demand that is very high in the summer and winters that are quite mild. *A. donax* is also well

established and highly invasive in more temperate regions. Different reaches along the banks of waterways experience differing moisture conditions which exerts strong controls on E_{stand}. The observed heterogeneity of the stand structure and transpiration rate of *A. donax* further underlines the importance of recognizing spatial variation at the population scale (Levin 1992). Furthermore, riparian vegetation water use varies with stand size. Consequently, our results may not be representative of all stands of *A. donax*, particularly because stands vary in density, height, and extent. Advection may have elevated transpiration at our site because of its high edge-to-interior ratio. Nevertheless, the estimation of approximately 1700 mm/year made by Iverson (1998) may be a reasonable value for stand scale water use in stands of *A. donax* similar in structure to the stand in this study.

To have precise scaling from leaf to stand, our model utilizes detailed horizontal and vertical measurements and replicated on-site measures of LAI (Spencer *et al.* 2006) that are reliable for highly diverse locations (Spencer *et al.* 2008). Leaf age, however, was not taken into consideration in this study, although it has been shown to have little to no effect on leaf physiology in a tussock grass, *Stipa tenacissima* (L.) (Haase *et al.* 1999). It is possible for leaf gas exchange to overestimate E_{stand}, as is known to occur in *S. tenacissima* by 71% (Ramirez *et al.* 2006). Leaf age accounted for over a third of that difference (Ramirez *et al.* 2006), but the basal sprouting growth form of *S. tenacissima* creates a complex vertical light environment that was not considered in their scaling model. Our model proportionately reduced E_{ℓ} in middle and lower canopy layers according to observed reductions in light.

We accounted for shading and carefully controlled the light environment during gas exchange measurements to best isolate effects of moisture gradients. Ambient light was recorded in full sun and the cuvette set at this constant value at the start of a measurement cycle, which possibly exposed leaves to higher than ambient light conditions on partly or mostly cloudy days. This could only cause overestimation of E_{stand} if it stimulated artificial stomatal opening, which is unlikely since carbon assimilation in *A. donax* peaks at light levels well below the range of values observed under cloudy conditions (Pers. obs.).

We can better understand impacts of exotic species such as *A. donax* on ecosystems by examining the underlying mechanisms of invasion (Levine *et al.* 2003). *A. donax* is a clonal species that can maintain functionality and survive when resources are scarce; however, it actively spreads, through both rhizomes and stems, when and where resources are plentiful (Decruyenaere and Holt 2005; Boland 2006; Decruyenaere and Holt 2001). Because of the mechanism of spread, *A. donax* may maintain connections between parent and offspring rhizomes, through which resources could be shared in order to increase fitness of the overall stand (Peterson and Chesson 2002). This mechanism could allow portions of *A. donax* stands that are in low quality habitats to maintain a competitive advantage over native species. Resources could be translocated from resource rich sections of the stand to low quality areas without having a detrimental effect on the stand's overall fitness (Jónsdóttir and Watson 1997). Future research is needed to better understand how the clonal growth form of *A. donax* influences its ability to utilize resources and how this may contrast with non-clonal native species.

Additionally, the partitioning of the water sources used by *A. donax* into soil water from recent precipitation, groundwater, and streamflow through the use of hydrogen and oxygen isotope analyses (Busch *et al.* 1992; Lamontagne *et al.* 2005; Yakir *et al.* 1990) would further elucidate the impact of this species on water resources. Finally, *in situ* comparisons of water use between *A. donax* and potential replacement vegetation, especially native species that would be considered in restoration efforts, would provide knowledge that would allow for regionally-based management decisions.

CHAPTER III

ECOPHYSIOLOGICAL RESPONSES OF *Arundo donax* TO HERBIVORY

INTRODUCTION

Invasive species are frequently capable of significantly altering the structure and function of ecosystems (Vitousek 1990; D'Antonio and Vitousek 1992), and these invaders can sometimes be characterized as 'transformer' species, which substantially modify their environments (Pyšek *et al.* 2004). Such modification can come in several forms. Invasive species alter the historic patterns of disturbance, such as fire regime or erosional processes. Invasive species excessively use critical resources, like light or water, in competition with native species. Furthermore, invasive species modify or redistribute important resources, such as nutrients or halides (Pyšek *et al.* 2004; Richardson *et al.* 2000).

Arundo donax (L.) (Giant reed) has been present in parts of the southwestern United States since at least the early 19th century (Dudley 2000; Hoshovsky 1993), and is currently found throughout the southern half of the continental United States from California to Maryland as well as on the Hawai'ian archipelago (Bell 1997). *A. donax* is already considered a strong example of a transforming invader (Spencer *et al.* 2005). This species has modified ecosystem processes to such an extent that some riparian zones in California's watersheds are now regulated largely by fire, rather than the historic control process of flooding (Scott 1994). *A. donax* burns easily at nearly all times of the year (Scott 1994), yet generally occupies a location in the landscape, the

riparian zone, that would ordinarily be relatively sheltered from wildfires. Its presence increases both fire frequency and intensity (Bell 1997), which in turn favors its regeneration (Frandsen 1997). Other forms of disturbance, such as mechanical clearing or large flood events, can similarly lead to further expansion of this species (Rieger and Kreager 1989). Research examining the integrity of watersheds considers abundant occurrences of *A. donax* to be associated with disturbed and degraded systems, even in its naturalized range (Ferreira *et al.* 2005).

Because of its rapid growth rate (Dudley 2000; Perdue 1958) and ready ability to resprout (Else 1996), *A. donax* is capable of forming dense, monotypic stands within a relatively short time period (Coffman 2007; Perdue 1958; Rieger and Kreager 1989; Bell 1997), thus reducing the biodiversity of the riparian zone. Losses in the abundance and richness of both the avian (Kisner 2004) and aerial invertebrate (Herrera and Dudley 2003) communities have been positively correlated with *A. donax* coverage. One possible reason for this may be the reduction in structural complexity as riparian ecosystems shift from multi-story communities to systems dominated by a largely uniform canopy of *A. donax*, resulting in a reduction in the overall nesting habitat available to birds (Frandsen 1997).

Mechanisms for this reduction in the biodiversity of communities in riparian zones invaded by *A. donax*, other than the simplification of habitat structure, are not yet clearly understood. It has been suggested that *A. donax* tissue is not easily digested by generalist herbivores (MilesTunsuwanChittawongKokpol *et al.* 1993; MilesTunsuwanChittawongHedin *et al.* 1993; Spencer *et al.* 2005). As a result of the

reduced biodiversity of the arthropod community in areas of the riparian zone dominated by *A. donax*, there is a lesser likelihood that generalist herbivores will have a significant impact on the growth and spread of *A. donax*. Mature *A. donax* has a mean carbon to nitrogen (C:N) ratio of 22.1, which is considered to be too high to be particularly favorable to generalist herbivores (Spencer *et al.* 2007). Young shoots may be the most favorable to many herbivores, but the rapid growth rate of this species presents only a small window of palatability. Also, there are no closely related native species that may put at risk by exotic herbivores (Lambert *et al.* 2007). Given the low incidence of generalist herbivores and the nearly complete absence of co-evolved specialist herbivores, *A. donax* seem like a good candidate for biological control, since introduced specialists would have access to a large resource with little pre-existing competition.

However, Peterson et al. (2005) note that assessment of the efficacy of biological control agents, in terms of having a injurious effect on the target plant species, is an important aspect in the decision making process, and that evaluation of the change in plant physiology in response to herbivory is an effective tool in determining the value of introducing additional species to a given ecosystem. Moreover, it is important to understand the mechanism by which different potential biological control agents affect plant physiology, since simply removing photosynthetic material does not ensure that the photosynthetic rate (A) of active leaf tissue decreases. Studies have shown, however, stem-boring arthropods can cause a reduction in A in *Linaria dalmatica* (L.) Mill. (Peterson *et al.* 2005). One potential mechanism for this may be the disruption of the flow of carbohydrates belowground (Jeanneret and Schroeder 1992). The stress of

weevil herbivory seems to mimic water stress in *L. dalmatica* because it elicits a similar response (Saner *et al.* 1994). It is logical that root-mining and water stress have similar effects on plants because they both reduce the amount of water that a plant can take up, albeit through different mechanisms (Gange and Brown 1989).

Studies on a wide variety of other plant species also demonstrate the efficacy of herbivores in negatively impacting the physiology of their hosts. Cherry (*Prunus serotina* (Ehrh.)) and sumac (*Rhus glabra* (L.)) leaves galled by a mite had rates of A reduced by 24-52%, and even undamaged, neighboring cherry leaves experienced 24% reductions in A (Larson 1998). Galls in an aster, *Parthenium hysterophorus* (L.), induced by a moth used as a biological control agent showed declines in A, transpiration (E_l), stomatal conductance (g_s), and xylem water potential (Ψ) (Florentine *et al.* 2005). The mechanism is thought to be reduced water movement due to the disruptions in conductive tissue through a combination of damage and blockage of the phloem and associated components of the parenchyma by gall tissue (Raman and Dhileepan 1999). Both fungal infection and wasp galls in leaves of a suite of understory hardwood species have been shown to reduce the efficiency of photosystem II (Φ_{PSII}), a fundamental component process of photosynthesis, by over 25% (Aldea *et al.* 2006). Interestingly, this same study found that fungal infection raised leaf temperatures in areas surrounding damage, which was thought to be a result of reduced g_s, while wasp galls depressed leaf temperatures near sites of damage, which was thought to be due to an increase in g_s (Aldea *et al.* 2006). Another invasive species, *Hydrilla verticillata* (L. f.) Royle suffered 30-40% reductions in A with light (10-30%) damage and up to a 60% reduction in A

with heavy (70-90%) damage by the leaf-mining fly *Hydrellia pakistanae* (Deonier.) (Doyle *et al.* 2002).

Interestingly, similar research has also uncovered the opposite phenomenon, whereby the physiological processes within leaf tissues remain unchanged or even increase. A and E_l remained unchanged in both apple (*Pyrus malus* (L.) Mill.) and crabapple (*Pyrus coronaria* (L.) Mill.) leaves subjected to herbivory by the moth *Hyalophora cecropia* (L.) (Peterson *et al.* 1996). These plants simply had reduced leaf areas rather than adjusting rates of physiological processes, either upward or downward (Peterson *et al.* 1996). Fay et al. (1993) found that in well-watered rosinweed species, leaf gas exchange was unaffected by wasp galls, but galled drought-stressed individuals increased leaf A, g_s, and Ψ. In a later study, galled rosinweed (*Silphium integrifolium* (Michx.)) in a common garden experiment suffered initial reductions in leaf area and plant height, but the production of axillary meristems led to a recovery in the number of inflorescences and an even greater leaf area (Fay *et al.* 1996). However, rosinweed was incapable of reproducing this herbivory tolerant axillary growth under competitive field conditions (Fay *et al.* 1996). The willow, *Salix eriocarpa* (Fr. & Sav.) showed similar compensatory axillary growth when subjected to herbivory by a stem-galling midge (Nakamura *et al.* 2003). This same willow species also increased basal diameter in response to galls, which increased shoot survival rates and ultimately led to increased bud production (Nakamura and Ohgushi 2007).

Transpiration has also been shown to remain constant or even increase, on a unit leaf area basis, in plants subjected to herbivory. Damage to major veins by leaf

perforation significantly increased g_s and E_l in birch (*Betula pendula* Roth) and alder (*Alnus* spp.) (Oleksyn *et al.* 1998), and such damage is noteworthy because of the fundamental role major veins play in the transport of water through leaves (Sack *et al.* 2003). Interestingly, in soybean, *Glysine max* (L.) Merr., leaf-mass consumption as well as simulated herbivory temporarily increased water loss as a linear function of the amount of cut edge per unit leaf but did not simultaneously affect leaf A (Macedo *et al.* 2003; Peterson and Higley 1996). Rates of leaf E_l remained at normal levels in the intact parts of the leaves (Peterson and Higley 1996), and in some cases leaf E_l was reduced below rates in unaffected leaves within a period of approximately 16 h (Macedo *et al.* 2003). In another study, soybean leaves experienced an approximately 40% reduction in E_l in the first week after herbivory compared to undamaged leaves, although A and g_s remained unchanged, and the suggested cause is water lost through the edges of damaged areas as well as through small breaks in the cuticle (Aldea *et al.* 2005). It is important that research on the physiological response of plants consider the possibility of compensation through an increase in A or, of greater concern in this study, potential increases in E_l. This is especially true for research that will help understand how various modes of herbivory elicit different physiological and morphological responses by plants (Peterson *et al.* 2005; Karban and Myers 1989; Spence *et al.* 2007; Aldea *et al.* 2005).

One of the foremost methods for managing *A. donax* is likely to be biological control. This study is unique in quantifying the effect of insect herbivores that are potential biological control agents on the rates of physiological processes in the host plant in advance of their approval and release in order to further inform the decision-

making process. The main objective was to elucidate what effect these potential biological control agents may have on the leaf scale physiology of *A. donax*. A stem-galling wasp, *Tetramesa romana* (Walker) and an armored scale, *Rhizaspidiotus donacis* (Leonardi), were examined in terms of their efficacy in reducing leaf scale rates of A and E_l. The feeding method of *T. romana* is to form a gall within the meristem, generally near the apex, that acts as a sink for photosynthates, while that of *R. donacis* is to congregate at the base of leaf sheaths and at nodes along the stem and drink sap directly from the phloem (Gullan and Cranston 1994). The effect of the wasps was examined at two different population densities, while the effect of the scale was investigated at two different times in their developmental cycle. We expected that the wasp population density would play a strong role in the magnitude of any potential reduction in A and E_l, and we also anticipated that the greatest effect of the scale population on leaf physiological processes would come as adult females were nearing a reproductive cycle that would demand greater resource consumption. A final experiment examined the effect of the herbivores on leaf scale physiology when *T. romana* and *R. donacis* were used in combination. We expected that the combination of two herbivores with very different consumption strategies would lead to the highest magnitude reductions in A and E_l of *A. donax* leaves.

This study was completed during the biological control assessment process in order to provide feedback about physiological impacts of these particular exotic herbivores. This study also documents to the agencies responsible the degree of damage to fundamental physiological processes in *A. donax* that may be expected from the use of

biological control in management of this invasive plant. Our secondary objective was to further understand the mechanisms by which these insects impact *A. donax* through investigation of their effects on g_s and intercellular CO_2 concentration (C_i) and through the examination of photosynthesis CO_2 (A/C_i) response curves. The shapes of these curves reveals potential decreases in carboxylation capacity or electron transport rate (Lambers *et al.* 1998; Larcher 2003), and thus illuminate impairment in the basic components of the photosynthetic machinery by the two herbivores (Ni *et al.* 2008; Schroder *et al.* 2005).

MATERIALS AND METHODS

This study was conducted as a series of greenhouse experiments set up in a quarantined facility located within Moore Air Base, operated by USDA-APHIS (Animal and Plant Health Inspection Service) in Hidalgo County, TX (26° 23’ 39”N/98° 20’ 7”W). Because of the quarantined nature of this effort, the initial experiments were established using the wasp, *T. romana*, and the scale, *R. donacis*, alone and in separate greenhouses. Within each of these two greenhouses, pots containing shoots of *A. donax* were allocated to separate cages for this experiment. Because of the mobility of *T. romana*, two identical cages, one each for the control and herbivory treatments, were established and lined with mesh that prevented individual wasps from either entering or leaving the cages. By contrast, mobility was not a concern for *R. donacis*, so rhizomes for each of the treatments were established in large pots that were not segregated from the rest of the greenhouse. To ensure that no individuals of *A. donax* were resource limited, all pots were filled with a fertilized, uniform potting soil and were watered twice

daily. Furthermore, both greenhouses were supplied with artificial lighting (≥500 µmol m^{-2} s^{-1}) to provide at least 12 hours of light per day when day length was short. With the use of climate control, the greenhouse with *T. romana* was kept between 22 and 33 °C, and the *R. donacis* greenhouse was kept between 18 and 35 °C.

There were a total of two trials for *R. donacis*, one long-term (24 weeks) and one short-term (14 weeks). The long-term trial held 7 control shoots and 7 treatment shoots with an exposure level of approximately 500-700 first-instar crawler scale released onto each shoot, and the trial was conducted from 26 February to 16 August, 2007. The short-term trial consisted of 3 control shoots and 3 treatment shoots with an exposure level of a known minimum of 500 first-instar crawler scale released onto each shoot, and the trial was run from 24 November, 2007 to 3 March, 2008. Before the second trial was completed, one of the control shoots was broken during handling and was therefore not used. Leaf gas exchange survey data and CO_2 response curves were collected, and the parameters of interest were primarily carbon assimilation (A) and leaf transpiration (E_l), and secondarily stomatal conductance (g_s) and intercellular CO_2 concentration (C_i). Further details on sampling methodology and instrumentation used are provided below.

There were also a total of two experiments conducted to test the effect of *T. romana* on leaf physiology an initial low herbivore density experiment followed by a high herbivore density experiment. Within the greenhouse containing *T. romana*, during the low density treatment experiment, two identical cages, one per treatment, housed 6 potted plants each. The control and treatment cages each experienced similar environmental conditions. Three 6-week low density trials were run from May to June,

June to August, and October to November, 2007, consisting of a total of 12 shoots of *A. donax*, each at least 1 m tall, that were grown from rhizomes of a standardized weight in a uniform mixture of potting soil. The shoots were paired by size, with each pair being randomly divided between the two treatments, using height as a proxy for biomass (Spencer *et al.* 2006).

Approximately 20-25 adult female *T. romana* were released into the treatment cage at the start of each low density trial. This density level mimiced the densities of adventive *T. romana* populations in stands of *A. donax* in its invasive range (Moran, pers. comm.). This density was well below the minimum release rate that is the goal of the biological control program and does not reflect population densities in the wasp's native range. Because the generation time of *T. romana* is approximately 4 weeks (~25 days as larvae, 7 days as pupae) (Moran and Goolsby 2009), leaf gas exchange survey data as well as CO_2 response curves were collected as near to 4 weeks from the onset of each trial as possible using the methodology and instrumentation described below. During the final low density trial, two ramets from the control group were broken at the main stem before gas exchange measurements could be conducted and were therefore excluded from the study.

The high density experiment was conducted as a part of a single long-term trial that maintained a *T. romana* only treatment. Roughly one third of the *T. romana* greenhouse was blocked off with the same fine black mesh used in cage construction, and this space was further divided to separate treatment and control sections. Seven potted plants of *A. donax* were added to each section. *T. romana* were released in high

density into the treatment section, with an initial minimum of 60 wasps. Seven wasps per ramet per week were added, including additional wasps for ramets that appeared in the course of the trial. This treatment was considered high density because it approximates the level of the intended future mass releases of *T. romana* at established sites of *A. donax*, and it is assumed that the target *T. romana* population densities exceed the density of natural populations anywhere in the native and naturalized range of *A. donax* (Goolsby, pers. comm.). In addition to the high density *T. romana* only trial, a simultaneous trial added another treatment – combined herbivory by *R. donacis* in addition to the high densities of *T. romana*. This trial consisted of 7 additional pots, each starting out with a single shoot, and was also located within the same *T. romana* treatment section of the greenhouse. These pots were not separated from the wasp only high density treatment because of the negligible mobility of *R. donacis*, even in the first-instar crawling stage. A minimum of 500 first-instar *R. donacis* crawlers were released on the internodes of each of these ramets at the onset of the trial. Leaf gas exchange survey data and CO_2 response curves were recorded after 10 weeks and 26 weeks of exposure to herbivory to give the trial enough time to experience at least two generations of *T. romana* and one generation of *R. donacis*, respectively.

All leaf gas exchange data were collected using a LI-6400 open-pathway system with 6400-02B LED Light Source and 6400-01 CO_2 Injector. For each shoot, only the second fully expanded leaf was used for measurements in order to control for the effect of leaf age (Hikosaka 2005). All measurements were conducted between 10:30 and 14:30 CST, with photosynthetic photon flux density (PPFD) fixed at 1500 μmol m^{-2} s^{-1}

and CO_2 concentration at 370 μmol mol^{-1}. Leaves were given a minimum of 5 minutes to adjust to the conditions in the cuvette. Leaf gas exchange measurements were repeated on at least two, and usually three, consecutive days in order to obtain an average value per shoot. Calculations of the physiological parameters A, E_l, g_s, and C_i were as described by von Caemmerer and Farquhar (1981) and adjusted for sampled leaf area.

In order to understand through what mechanism the two herbivores, separately and in combination, impacted leaf scale physiology, we examined the shapes of A/C_i response curves for any changes in the Rubisco-limited carboxylation capacity or electron transport rate (Lambers *et al.* 1998). These measurements were taken once per leaf for each plant in each treatment. A/C_i response curves were generated at intervals of 50 μmol mol^{-1} from 50 to 400 μmol mol^{-1} and intervals of 100 μmol mol^{-1} from 400 to 800 μmol mol^{-1}. In order to model maximum carboxylation rate of Rubisco (V_{cmax}) and maximum rate of electron transport (J_{max}), values for necessary parameters were taken from Sharkey et al. (2007). The activation energy (E_a) of *A. donax* was assumed to be 60 kJ mol^{-1}, a value expected for a C-3 plant from a warm environment (Sage 2002).

SPSS 14.0 was used to analyze the data established as a randomized block design in which data were blocked by initial plant height. In order to compare between treatments, data were screened for outliers and checked for normality, then one-tailed Student's t-tests were used at a significance level of $\alpha = 0.05$. When the Levene's test for equality of variances failed ($P < 0.05$), data were compared assuming unequal variances. One-tailed tests were deemed appropriate due to the hypothesis that in all cases physiological processes will be reduced due to the method of herbivory by each of the

two insects (Larson 1998; Meyer and Whitlow 1992; Peterson 2001; Peterson *et al.* 2005; Raghu and Dhileepan 2005; Raghu *et al.* 2006), and doing so enabled us to minimize Type II errors. Separate Student's t-tests were conducted for the *R. donacis* experiment (pooled for both trials due to low sample size), the low and high density *T. romana* trials, and the 10-week and 26-week combined *R. donacis*/ *T. romana* trials. Additionally, component slopes of the A/Ci response curves corresponding to Rubisco-limited carboxylation capacity or electron transport rate were compared to elucidate the mechanistic differences between the way different injury guilds elicit responses in *A. donax* (Macedo *et al.* 2005; Peterson *et al.* 2005).

RESULTS AND DISCUSSION

R. donacis effectively reduced leaf gas exchange rates in *A. donax*. Mean E_l was 40% lower in leaves of plants with *R. donacis* than in control plants after several months of exposure to the herbivore (Table 2). Furthermore, mean g_s was 46% lower in plants subject to herbivory (Table 2). These strong reductions in water use were anticipated because of the nature of the method of feeding by *R. donacis*. As plants lose sap to scale herbivory, leaves are more likely to wilt or distort (Gullan and Cranston 1994), which may explain reductions in E_l and g_s . Since scale insects feed directly on nutrients in fluids from the phloem, they can act as a sink for photosynthates that would otherwise be directed towards plant growth, maintenance, or storage (Risebrow and Dixon 1987), but contrary to our expectation, we found only weak evidence of a reduction in A_l (Table 2).

Mean A_l in leaves of plants with *R. donacis* was over 32% lower than mean A_l in control leaves (Table 2); however, this reduction in treated plants was only marginally

Table 2. The efficacy of two herbivores, separately and in combination, in reducing crucial parameters of leaf scale physiology. Shown are: photosynthesis (A), transpiration (E_l), stomatal conductance (g_s), and intercellular CO_2 concentration (C_i). Mean ± standard error shown. Asterisks represent significance values of one-tailed Student's t-tests: * denotes $P < 0.05$; ** denotes $P < 0.01$; *** denotes $P < 0.001$. Single dash denotes not significant.

Agent	Experiment	A					E_l					g_s					C_i				
		C		T		Sig.	C		T		Sig.	C		T		Sig.	C		T		Sig.
		Mean	S.E.	Mean	S.E.		Mean	S.E.	Mean	S.E.		Mean	S.E.	Mean	S.E.		Mean	S.E.	Mean	S.E.	
R. donacis	—	10.21	1.58	6.92	1.12	—	3.44	0.41	2.08	0.21	**	0.22	0.03	0.12	0.01	**	278.1	9.1	267.0	7.9	—
T. romana	Low density	12.21	1.34	11.66	1.38	—	3.47	0.29	3.24	0.26	—	0.22	0.03	0.16	0.02	*	253.4	8.3	230.9	7.4	*
	High density	10.39	0.91	8.39	0.51	*	3.94	0.46	2.87	0.22	*	0.17	0.03	0.12	0.01	*	246.3	8.0	231.1	6.1	—
T. romana /	10 weeks	10.39	0.91	8.52	0.61	—	3.94	0.46	4.22	0.43	—	0.17	0.03	0.18	0.02	—	246.3	8.0	261.0	8.9	—
R. donacis	26 weeks	9.71	0.80	3.19	0.39	***	3.11	0.37	1.80	0.49	*	0.14	0.02	0.09	0.03	—	243.8	5.7	303.9	11.3	***

significant (t = 1.719, $d.f.$ = 17, P < 0.052). This is likely a result of the large variance between leaves in the same treatment. The standard error was 15.5% and 16.2% of the mean for the control and scale treatments, respectively. Meyer and Whitlow (1992) also reported no effect of a phloem-feeding insect on rates of A_l in goldenrod, *Solidago altissima* (L.), normalized by leaf weight. The aphid used in Meyer and Whitlow's study actually had no measurable effect on any investigated parameter, including E_l, g_s, and C_i, though it should be noted the duration for which plants were exposed to herbivory was limited to 12 days (1992).

Because *R. donacis* had not yet reproduced at the time of the measurement in the short-term trial (Moran and Goolsby 2009), we investigated whether this affected our results. When those short-term data were excluded from the analysis, A_l differed between treatments (t = 2.279 , $d.f.$ = 12, P < 0.025). *A. donax* leaf responses to herbivory by *R. donacis* were apparently sensitive to time of exposure, which is consistent with previously reported results for a tropical scale (Schaffer and Mason 1990). *R. donacis* may not be capable of negatively impacting physiological processes until after they produce offspring, which occurred between the 14-week and 24-week trials. It has already been shown elsewhere that as scale reach sexual maturity or some other significant stage in their life history, their demand for resources increases (Rees and Crawley 1989; Boggs 1992). *R. donacis* females do not produce offspring until at least 120 days when they are removed from the plant artificially and the next generation is not found on the plant until over 160 days when females are allowed to remain on the shoots (Moran and Goolsby 2009). The earlier instars may not take up many resources,

and only when later life stages are reached does the collective herbivory of many individuals begin to adversely affect physiological processes in 'downstream' leaves that would otherwise have utilized the consumed resources.

The A_l/C_i response curve yields further evidence for the negative effects of 24 weeks of herbivory by *R. donacis* on leaf scale physiological processes. J_{max} was drastically reduced by *R. donacis* (Table 3, Figure 6), so the presence of this herbivore clearly lowered the overall maximum rate of photosynthesis when CO_2 availability was not a limiting factor. V_{cmax} was also reduced, but the magnitude of the decrease was much smaller, indicating that there may be some limited effect of *R. donacis* on the efficacy of Rubisco in *A. donax*. *R. donacis* may have been a sink for photosynthates that otherwise would have been directed toward root growth, leading to a potential reduction in nutrient uptake (Li *et al.* 2006). Because J_{max} is an estimate of the maximal rate of electron transport by proteins in the photosynthetic apparatus (von Caemmerer and Farquhar 1981), a reduction in J_{max} could indicate that less nitrogen was being allocated to those crucial proteins (Hikosaka and Terashima 1996; Hikosaka 2004).

Herbivory by low densities of the galling wasp *T. romana* did not reduce the rates of either of the basic physiological processes of A_l or E_l in leaves of *A. donax* (Table 2). C_i and g_s were reduced by 9% and 26%, respectively (Table 2). The decrease in C_i without a significant reduction A_l may be due to some compensation on the part of *A. donax* if leaves were able to more effectively utilize the available CO_2 in the intercellular airspaces. This situation would only plausibly arise if stomata were closed more in leaves of plants with galls, which the reduction in g_s suggests. It was unexpected

Table 3. The efficacy of two insect herbivores, separately and in combination, in reducing the carboxylation rate of Rubisco (V_{cmax}) and the rate of electron transport (J_{max}). Mean and percent difference shown. C and T represent Control and Treatment, respectively.

Agent	V_{cmax}			J_{max}		
	C	T	% diff.	C	T	% diff.
R. donacis	59.9	49.1	-18.0	78.7	30.9	-60.7
T. romana	63.3	67.7	7.0	90.7	97.0	6.9
T. romana /*R. donacis*	38.7	12.6	-67.5	48.5	24.5	-49.4

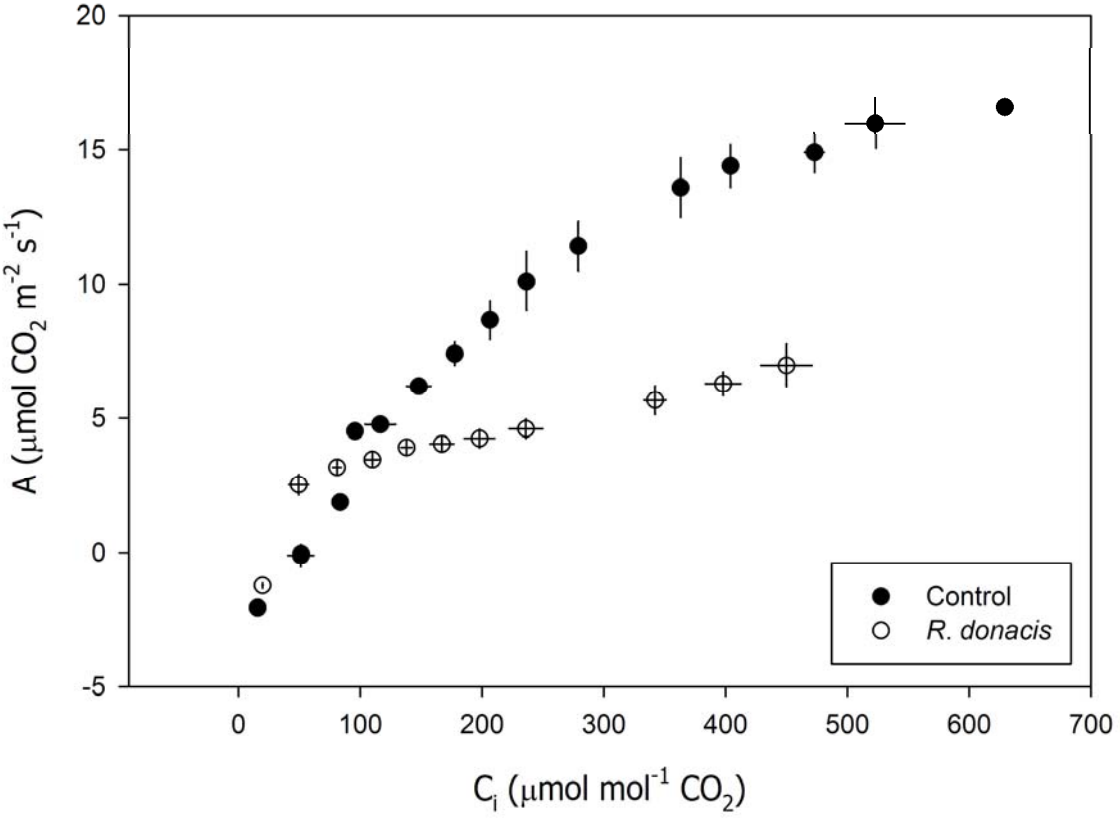

Figure 6. CO_2 response of leaves of *A. donax* to 24 weeks of exposure to herbivory from the armored scale, *R. donacis*. Mean values ± standard error are given. Photosynthetic photon flux density was 1500 μmol m^{-2} s^{-1}.

though, that such a strong reduction in g_s would not lead to a similar reduction in E_l. It may be the case that changes occurred below the detectable limit, especially since g_s is largely derived from E_l (von Caemmerer and Farquhar 1981). Leaf temperature and atmospheric pressure also factor into the calculation of g_s, so these variables were also compared between treatments, but no differences were found (data not shown). This is likely an indication that the E_l data had large enough variances to preclude statistical differentiation between treatments. Nonetheless, the ability of *A. donax* to balance the fundamental physiological processes of A_l and E_l did not seem to be perturbed by herbivory by *T. romana* at low density. Additionally, the A_l/C_i response curves for the low density treatment of *T. romana* demonstrated that there was little effect on *A. donax* physiology. Neither V_{cmax} nor J_{max} were much different in the plants experiencing herbivory (Table 3, Figure 7).

By contrast, when *T. romana* was present in high density, the response of *A. donax* to herbivory was quite distinct. A_l, E_l, and g_s were all lower in shoots that experienced herbivory, while C_i was not different between the two treatments (Table 2). In the high density treatment, A_l, E_l, and g_s were 19%, 27%, and 32% lower compared with control plants. The observation that both A_l and E_l are markedly lower in galled shoots in the high density treatment, in contrast with the low density experiment, clearly indicates that the effect of herbivory on *A. donax* by *T. romana* is density dependent. This phenomenon has been documented for galls by cynipid wasps on leaves (Bagatto *et al.* 1996; Dorchin *et al.* 2006), but to our knowledge, this is this first time this type of relationship has been documented for stem-galling wasps.

After 10 weeks of exposure to both *R. donacis* and high density *T. romana*, only A_l was marginally affected by this treatment ($t = 1.751$, $d.f. = 13$, $P < 0.052$). A_l in leaves from plants with herbivores was 18% lower than control leaves (Table 2), while none of E_l, C_i, or g_s were different between the two treatments. This is in contrast with the experiment of herbivory by *T. romana* alone while still in high density, in which, within 10 weeks, clear differences in these physiological parameters were evident (Table 2). Because these trials occurred simultaneously and within the same enclosure space, both the *T. romana* high density trials (with and without *R. donacis*) experienced similar levels of herbivory, which implies that leaves of *A. donax* exhibit a compensatory response when the shoot experiences multiple forms of herbivory. Another plausible explanation is that adult *T. romana* avoided shoots with *R. donacis* present in order to reduce interspecific competition, and that as time passed, there was a cumulative effect on leaf physiology that led to the difference between these treatments in leaf scale physiology after 10 weeks.

Apparently, compensation, if any, only lasts for a limited time, because 26 weeks after the two herbivores were released onto *A. donax*, very strong differences between the treatments had become manifest. A_l and E_l were lower in leaves of attacked shoots than in leaves of shoots without herbivores by 67% and 42%, respectively (Table 2). Conversely, C_i was greater in the herbivory treatment by approximately 25%, but g_s was not different between treatments (Table 2). This may be an indication that leaves of galled shoots are susceptible to increased water loss through parts of the leaf other than the stomata. Such strong reductions in A_l suggests that, as has been previously discussed

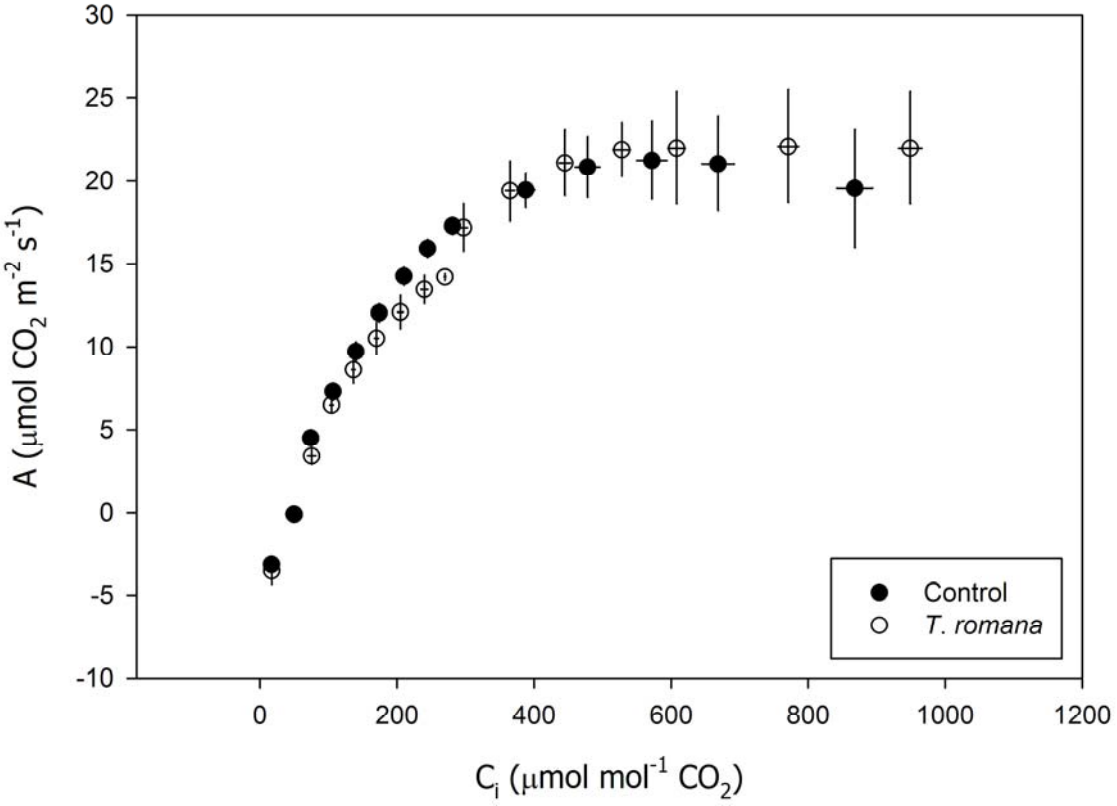

Figure 7. CO_2 response of leaves of *A. donax* to herbivory from low densities of the stem-galling wasp, *T. romana*. Mean values ± standard error are given. Photosynthetic photon flux density was 1500 μmol m^{-2} s^{-1}.

in the *R. donacis* only trials, as the scale reach the later stages of development and into the second generation, demand for photosynthates increased. These leaves do not appear to have lost stomatal control, as g_s remained unchanged, but the reduction in carbon assimilation is corroborated by the much higher CO_2 concentration in intercellular air spaces. This likely indicates that the photosynthetic machinery in the leaves subjected to prolonged herbivory by both insects is less capable of utilizing available carbon (Meyer and Whitlow 1992).

The A_l/C_i response of *A. donax* after 26 weeks of exposure to the two herbivores also points to a large cumulative impact, each likely acting in a different capacity. For example, a similar reduction in J_{max} to the presence of *R. donacis* alone was observed, suggesting this species negatively affects the process of electron transport (Table 3, Figure 8). Conversely, the much greater reduction in V_{cmax} with the additional presence of high densities of *T. romana* suggests that the carboxylation capacity of Rubisco was reduced largely as a result of the presence of a large number of galls (Table 3, Figure 8). Plants are already known to reduce both V_{cmax} and J_{max} in the presence of herbivores (Schroder *et al.* 2005), so this outcome was anticipated. The presence of two herbivores in large numbers may also induce *A. donax* into the production of plant secondary metabolites that would act as a further sink for energy gained from photosynthesis (Karban and Myers 1989), although their study did not explicitly address this question. However, this study is among the first to document that two insect herbivores differentially affect the physiology of their host species (Peterson *et al.* 2005). Because neither of these two insects feed by leaf consumption, understanding of the mechanisms

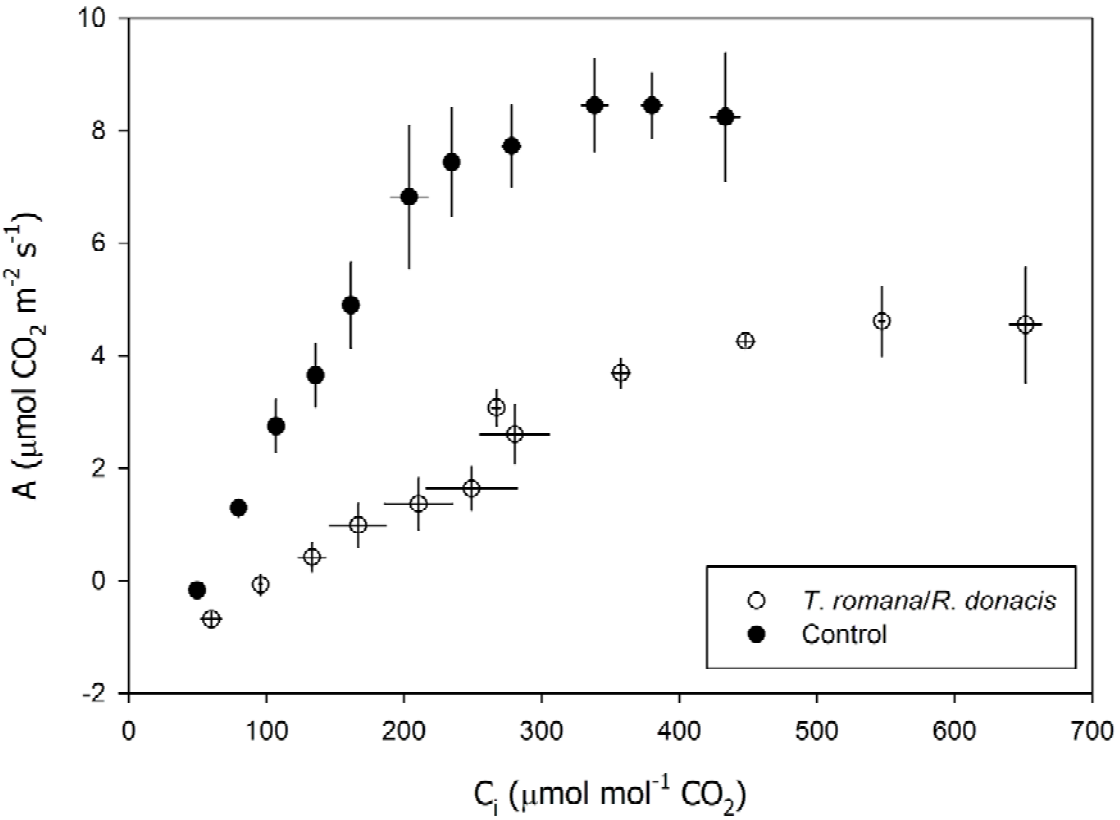

Figure 8. CO_2 response of leaves of *A. donax* to 26 weeks of herbivory from *R. donacis* and high densities of *T. romana*. Mean values ± standard error are given. Photosynthetic photon flux density was 1500 μmol m^{-2} s^{-1}.

by which they impact leaf scale processes is particularly lacking (Karban and Baldwin 1997).

From what little research has been done on combined herbivory by two or more phytophagous insects with differing foraging methods, we have learned that effects are not always directly additive (Meyer and Whitlow 1992). Results led to the evolution of the concept of the injury guild, which is simply the grouping of herbivores by the type of damage inflicted on plants rather than by taxonomic association, and examples include leaf mining, leaf mass consumption, and stem boring (Peterson 2001). It is well established that plants respond differently to these various forms of herbivory (Gavloski and Lamb 2000; Trumble *et al.* 1993). The data from these trials suggests that stem-galling negatively impacts the ability of *A. donax* to optimize the relationship between carbon gain and water loss, but that the addition of a sap-feeding insect may stimulate some temporary compensation by the plant. The trials of *R. donacis*, alone and combined with *T. romana*, have shown that it takes a comparatively long time for sap-feeding insects to impact physiological processes. However, once this temporal threshold is crossed, there do seem to be additive effects from both injury guild representatives on characteristics of leaf gas exchange, as the trial with the most deleterious impacts on *A. donax* was with both herbivores present. One possible explanation for this time lag may be that *A. donax* resorts to using stored carbon resources in its attempts to continue to produce young tissue (Boose and Holt 1999; Decruyenaere and Holt 2001), but once these resources become exhausted, the vigor of individual plants then begins to decline strongly.

In conclusion, the results of our greenhouse study clearly demonstrate that the stem-galling wasp *T. romana* is effective at inhibiting leaf-scale physiological processes of *A. donax* when present in high densities and that the armored scale *R. donacis* is also effective in reducing the rates of A_l and E_l given enough time. Moreover, these two insect herbivores seem to impact *A. donax* leaf physiology differentially, as *T. romana* appears to reduce the carboxylation capacity of Rubisco, while *R. donacis* measurably lowers the rate of electron transport.

CHAPTER IV

CONCLUSIONS

A model was developed to estimate stand scale water use in the invasive species *Arundo donax* (L.) in the lower Rio Grande basin. This study was the first attempt at quantifying water use in this species at any spatial or temporal scale. This model was based on using directly measured rates of transpiration to yield stand scale rates of transpiration by incorporating within-stand variability. Spatial heterogeneity was incorporated into the model through the measurement of vertical variation in parameters like leaf area index and light availability over four plots of increasing lateral distance from the edge of the water source. This model showed that mean stand scale transpiration for *A. donax* is approximately 9.1 mm per day, indicating that this species is at the high end of water use. By comparison, the highest values stand scale transpiration in the genus *Carex* is 8.8 mm per day (Busch 2001), while peak stand scale transpiration in *P. australis* was approximately 23 mm per day (Moro *et al.* 2004). *A. donax* is estimated to produce about 20 Mg per hectare per year on natural stands in sites in India and the United States (Sharma *et al.* 1998; Spencer *et al.* 2006), which is roughly 50% lower than yields of cropped C-3 plants (Nobel 1991).

The magnitude to which *A. donax* affects in-stream water resources remains somewhat unclear. Stand scale water use was much greater following periods of appreciable rainfall, suggesting that this species is not a true phreatophyte. Future work on tracing the source of the water used through the use of isotope analyses may elucidate

to what degree *A. donax* uses water derived from streamflow or from soil moisture resources maintained by precipitation (Dawson 1993; Dawson and Ehleringer 1991; Lamontagne *et al.* 2005; Yakir *et al.* 1990). Furthermore, additional investigations into the potential for physiological integration, whereby connected ramets could simultaneously share resources like water, photosynthates, and nutrients (de Kroon *et al.* 1998), using tracers, such as isotopes or dyes (de Kroon *et al.* 1996; Liu *et al.* 2007; Zhang *et al.* 2003) in common garden experiments or field studies, could elucidate the mechanism by which *A. donax* is capable of such high rates of stand scale transpiration.

Additionally, this study quantified the efficacy of two potential biological control agents, a stem-galling wasp, *Tetramesa romana* (Walker), and an armored scale, *Rhizaspidiotus donacis* (Leonardi), in negatively impacting the leaf scale physiological processes of *A. donax*. *T. romana* was shown to be effective in reducing rates of key characteristics, such as photosynthesis and transpiration, when present in high density. *R. donacis* was effective at reducing these aspects of leaf physiology given enough time (24 weeks), and this coincided with the time necessary for a full reproduction cycle. The result of having the two herbivores feeding on *A. donax* concurrently was a seemingly additive effect on leaf scale physiology, but only after 26 weeks. CO_2 response curves indicated that *R. donacis* affected the rate of electron transport while *T. romana* impacted the carboxylation rate of Rubisco.

Theoretically, these physiological data could potentially be used in economic models, in conjunction with morphometric data, to estimate the value of potential water savings based on scenarios of reductions in water use by *A. donax*. There is, however,

much uncertainty about the degree to which the magnitude of the effects of these herbivores holds at larger spatial and longer temporal scales. Moreover, further work on any mediation of the negative impact of one herbivore through the addition of a second herbivore may provide greater insight into the mechanisms behind plant responses to herbivory and whether this is partly a cause of the injury guild of the herbivores. Based on the results from this study, if the insect populations are maintained at a high enough density and given sufficient time to impact crucial physiological properties, the biological control of *A. donax* will likely enervate established stands of this highly invasive species.

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