SCCWRP Technical Report 0662

HISTORICAL ECOLOGY
of the lower Santa Clara River, Ventura River, and Oxnard Plain:
an analysis of terrestrial, riverine, and coastal habitats

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HISTORICAL ECOLOGY PROGRAM
CONTRIBUTION NO. 641 • AUGUST 2011

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Report and GIS layers are available on SFEI's website, at www.sfei.org/projects/VenturaHE.

Front cover, from left to right: Detail of cross section (by Jen Natali); 19th century Ventura River (Unknown ca. 1890, courtesy of the Museum of Ventura County); modern Santa Clara River (courtesy of Gretchen Coffman); diseño map (U.S. District Court ca. 1840c, courtesy of The Bancroft Library, UC Berkeley)

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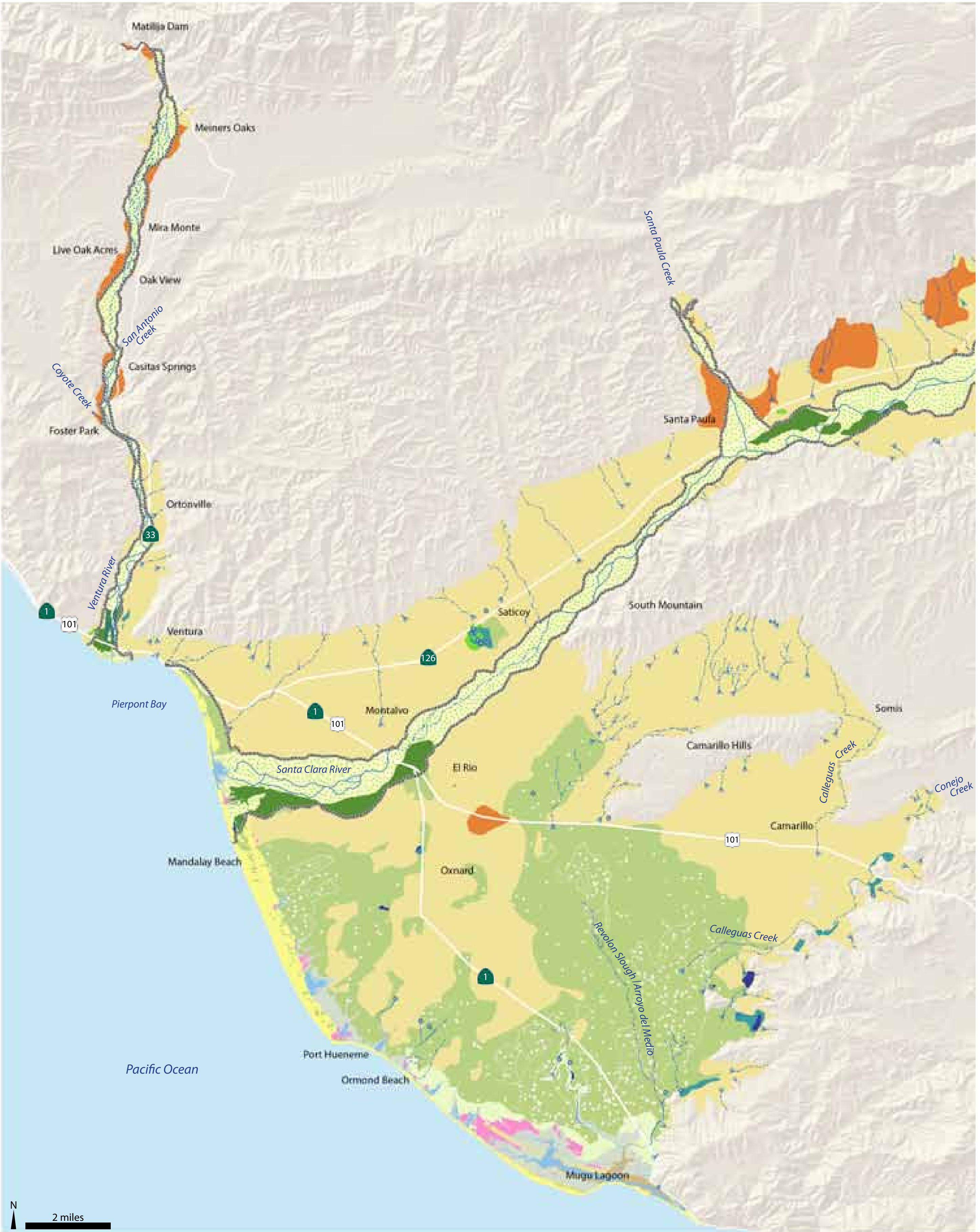
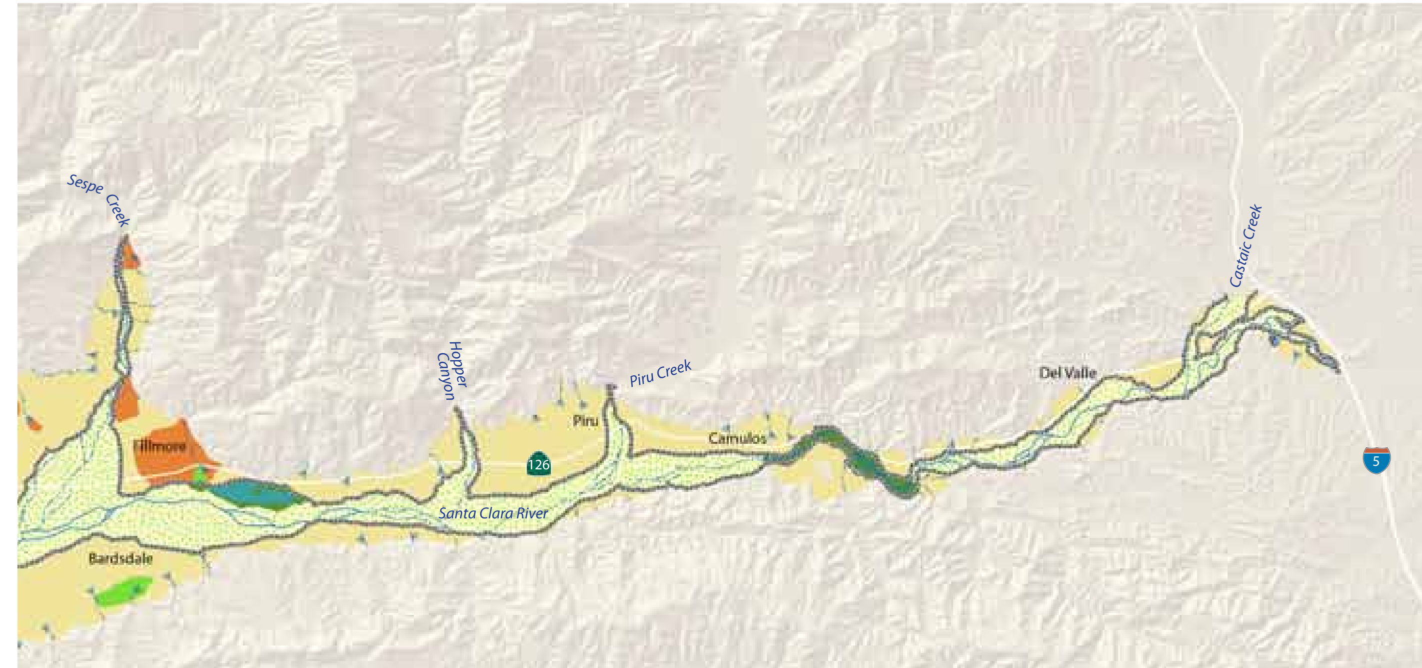




HISTORICAL CONDITIONS, EARLY 1800s

Coastal and Estuarine Habitats

- Ocean
- Beach/Dune
- Lagoon
- Tidal Flat
- Salt/Brackish Marsh and Tidal Marsh
- Salt Flat/Seasonal Pond/ Marsh Panne
- High Marsh Transition Zone

Palustrine and Terrestrial Habitat

- Perennial Freshwater Pond
- Valley Freshwater Marsh
- Willow Thicket
- Wet Meadow
- Alkali Meadow
- Alkali Meadow/Flat
- Oaks and Sycamores
- Grassland/Coastal Sage Scrub

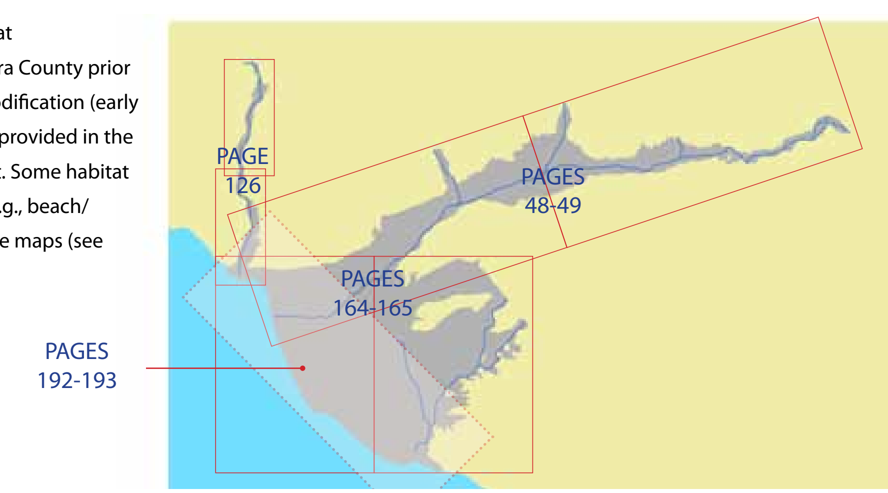
Characteristic Riparian Habitat

- Willow-Cottonwood Forested Wetland
- Other In-Channel Riparian

Hydrology

- Intermittent or Ephemeral
- Perennial
- Distributary
- Outer River Bank
- Spring

This map reconstructs the habitat characteristics of lowland Ventura County prior to significant Euro-American modification (early 1800s). More detailed views are provided in the map sections shown to the right. Some habitat classifications combined here (e.g., beach/dune) are separated in finer-scale maps (see pages at right).



The State Coastal Conservancy is proud to have funded this study of historical coastal wetlands, rivers, and other habitats of Ventura County. The project was led by the San Francisco Estuary Institute, the leading authority in the analysis of California coastal historical ecology. In this study, they have teamed with a number of experts on Southern California rivers and coastal wetlands, including Stillwater Sciences, Southern California Coastal Water Research Project, California State University Northridge, and other institutions.

This study uses history – namely, the interpretation and integration of historical documents with environmental sciences – to provide a new perspective on how the Ventura County landscape has changed since the early 19th century. Synthesizing over two centuries of local documents, this report and accompanying GIS layers significantly improve our understanding of the natural forces that have shaped the local landscape. The study provides guidelines and inspiration for improvement of the environmental health of this region, which is the goal of the Coastal Conservancy and the governmental agencies and conservation organizations who are our valued partners in Ventura County.

The work of the Coastal Conservancy is to protect, restore, and make accessible the lands and waters of the California coast. SFEI's study will assist us and our partners in several ways. First, it shows us what elements of Ventura County's natural heritage have been lost, and suggests where those might be recovered. Secondly, the study helps us understand the physical and ecological processes still influencing systems today, enabling us design more effective, cost-efficient projects. In fact, the study identifies a number of opportunities to take advantage of intact natural processes to make more self-sustaining projects. Finally, and perhaps most importantly, we hope this new information will involve the Ventura community in considering the natural history of their region and its potential for the future. What underlies the built environment of this area? Through this research, we can now discover and uncover what came before European settlement of Ventura County. Though it will never be the same again, much of this until-now forgotten landscape can be restored, along with the sights and sounds of the species that have long depended on it. These lessons from history can help us make our landscape healthier and more resilient in the coming decades.

This study is dedicated to the people of Ventura County, supporters and sustainers of our work together, so that they can better love and understand the place where they live.

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CONTENTS

REGIONAL SUMMARY

Great changes have swept through Ventura County over the past 250 years. Willows and live oaks have been cut down, and eucalyptus and other non-native street trees have been planted. Wetlands have been drained and cultivated. Creeks have been straightened and connected to larger streams. Rivers have been hydrologically and ecologically altered by levees, flow diversions, and timber cutting, and have lost floodplain area to farms and cities.

Despite these changes, lowland Ventura County retains substantial high quality ecological resources, particularly in comparison to other, more urbanized, areas of coastal southern California. The two major rivers in the region—the Ventura and the Santa Clara—possess significant restoration potential. The Santa Clara River has remained unchannelized and relatively unregulated by dams, and as a result has retained much of its former reach-scale flow variability, geomorphic process, and riparian heterogeneity. The Ventura River, due in part to relatively limited urban development and floodplain encroachment, has also retained substantial portions of its former hydrologic and ecological patterns, despite the presence of Matilija and Casitas dams. Current management activities, such as the proposed removal of the dam and the Parkway projects ongoing on both rivers, recognize and take advantage of this potential.

This report documents the historical ecological and hydrological patterns and dynamics of the Ventura River valley, the lower Santa Clara River valley, the Oxnard Plain, and the Ventura County shoreline. To do so, we integrated hundreds of historical cartographic, textual, and visual accounts to create a heterogeneous but substantial dataset describing hydrologic, geomorphic, and riparian characteristics back to 1769—the date of the first non-native, land-based exploration of the region. These data were synthesized to provide detailed analysis of landscape-level pattern and process in the region prior to substantial Euro-American modifications, and to better understand the impacts of modifications over the past two and a half centuries. The goal of this process is to provide scientists and managers in Ventura County with detailed, readily accessible information about the region's historical ecological landscape, with particular focus on historical habitat patterns and riverine processes. (The report does not address the historical fauna of Ventura County in detail.)

Our findings reveal an ecologically diverse landscape, with vegetation and drainage patterns reflective of both underlying, long-term physical drivers and temporally and spatially dynamic processes. Valley floor habitats were relatively dry overall, with extensive open grasslands and scrublands predominating in the Santa Clara River valley, lower Ventura River valley, and large portions of the Oxnard Plain. Live oaks and sycamores colonized terraces in the Ventura River valley, in addition to many alluvial fan surfaces north of the Santa Clara River. With few exceptions (notably, Saticoy Springs), non-riparian wetlands were concentrated on the Oxnard Plain. This included coastal brackish and saline wetlands, freshwater ponds and marshes along the eastern foothills in the Calleguas Creek watershed, and (comprising the great majority of the total) the seasonal alkaline wetlands of the Oxnard Plain.

Wetland distribution on the plain has been largely shaped by the migration of the Santa Clara River over geologic time: the river deposited sediments that formed higher and drier zones above the alkaline lowland, which were colonized by grassland and scrub. This migration also created a pattern of coastal lagoon systems along the shoreline, leaving a legacy of perched and closed lagoons marking former river mouths (and separated from the ocean by dunes whose sediment was largely supplied by the river). At least three types of coastal estuarine systems are represented on the Ventura shoreline: seasonally or intermittently closing freshwater-brackish estuaries associated with the Santa Clara and Ventura river mouths, dune-dammed non-tidal lagoons associated with now-abandoned Santa Clara River mouths, and the large, more open wetland system at Mugu. These features formed a near-continuous sequence of coastal wetlands from Mugu Lagoon all the way to the Ventura River mouth: the eastern edge of the Ventura River floodplain was separated from the northwestern edge of the Santa Clara River floodplain (today's Ventura Marina area) by less than one mile.

Then as now, the Santa Clara River dominated the region; even its delta (the Oxnard Plain) was referred to as the lower Santa Clara River valley in the 19th century. Geologic and climatic parameters influenced the river's form and flow, creating a stream with reach-scale variability in channel morphology and the presence of summer surface water. In turn, these elements were linked to heterogeneous riparian patterns along the river, with nodes of broad willow-cottonwood riparian forest and in-channel wetlands separated by reaches characterized by scrub and patchy forest. As a result, riparian forest did not form a continuous corridor along the river, instead occurring in discrete patches corresponding to variations in groundwater-surface water interactions.

Like the Santa Clara, the Ventura River occupied a broad river corridor, with reach-scale variability in hydrology, morphology, and riparian patterns. The Ventura River also maintained large willow-cottonwood forests at its mouth, in addition to a dense riparian corridor along much of the perennial reaches. The intermittent reach of the river was characterized by in-channel live oaks, sycamores, and scrub on established bars and islands, a vegetation community not documented anywhere along the Santa Clara River mainstem.

The research described in this report is designed to provide insight into the Ventura County that once was. We have tried to bring our research alive such that current residents, scientists, and planners may inhabit—if briefly, and imaginatively—the landscape that early Chumash inhabited and later residents inherited. We document historical patterns, as well as the layers of use and modification accumulated over the past centuries, some of which is still evident today to the keen eye. We do not suggest that future restoration efforts should necessarily aim to recreate the former features discussed here, or that these patterns should directly dictate what should or should not be done. Instead, this report seeks to provide insight into the dynamics and processes that shaped—and in many cases, continue to shape—the Ventura landscape, and to be a tool for understanding the past and imagining the future. It is a starting point for conversations about the goals and values of restoration, providing guidelines and framework for what may be desirable or possible.

The primary findings of this study are summarized below, as well as at the end of each relevant chapter. Management implications may be found at the end of each chapter. Taken together with an understanding of modern conditions, these findings can support scientists and managers working to identify restoration opportunities in the Ventura region.

Santa Clara River and Valley

1. **The historical (early 1800s) Santa Clara River valley supported a diverse array of natural habitats,** from the willow groves and wetlands of Saticoy Springs to the sycamores and oaks found on alluvial fans near Santa Paula and Fillmore (page 51). However, the valley floor was dominated by grassland and coastal sage scrub, with trees occurring singly or in stands and along creeks and rivers. Valley oaks were not documented in the Ventura County portion of the valley.

2. **Most substantial freshwater wetland complexes occurred within the river corridor of the Santa Clara River, not on the valley floor (page 87).** A rich array of aquatic habitats were found within the river corridor, including ponds, sloughs, and freshwater marshes in perennial reaches, and a suite of saline and brackish aquatic habitats associated with the estuary at the river mouth.

3. **Prior to modification, most small tributaries did not connect to the Santa Clara River (page 76).** With few exceptions, intermittent small creeks commonly sank into their alluvial fans before reaching the Santa Clara River, a characteristic common to many intermittent tributaries across California. Rather than maintaining defined channels all the way to the river, these creeks were connected hydrologically to the river through subsurface flow and poorly defined, transitory surface channels. Most of these creeks have now been connected to the Santa Clara River though constructed channels, increasing valley drainage density (that is, stream length per unit area).

4. **From the late 19th to the early 20th century, the position of the Santa Clara River corridor remained relatively laterally stable (page 66).** Inter-annual variability in the relative vegetation cover of the active channel and bottomlands is evident in the historical record, with

widespread changes occurring after each major flood. However, our findings support the overall lateral stability of the river even through the St. Francis Dam break in 1928.

5. **In the relatively recent geologic past, the lower Santa Clara River shifted its outlet from near Point Hueneme to its present location (page 71).** While the date of this shift is not clear, it may have occurred in the past 200-500 years based on edaphic, ecological, and ethnographic evidence. This shift is reflected in historical alkalinity patterns on the Oxnard Plain (see page 177).

6. **The Santa Clara River was an interrupted perennial stream,** with alternating perennial and intermittent (summer dry) reaches (page 77). Only two intermittent reaches were clearly documented on the river, near Saticoy and Piru (though additional intermittent reaches may have been present). The location of perennial reaches was informed by a variety of factors, including artesian influence, tributary inputs, valley narrowing, and geologic constraints. Many of these factors continue to affect surface flow patterns today.

7. **The Santa Clara River supported a diverse mix of riparian species,** including trees such as sycamore, live oak, willow, cottonwood, box elder, and alder; scrub species such as scalebroom, buckwheat, mulefat, golden-aster, sagebrush, black sage, and cactus; and understory species such as wild grape and wild blackberry (page 83).

8. **Dense, persistent riparian forest and in-channel wetlands occurred in discrete patches along the Santa Clara River (page 85).** Rather than a continuous corridor, willow-cottonwood riparian forest was found at a few notable locations along the river, corresponding with areas of rising or perched groundwater. Other reaches supported a different matrix of non-vegetated riverwash, willow scrub, mulefat, and alluvial scrub. This longitudinal heterogeneity tied to patterns in groundwater-surface water interactions suggests that different restoration targets are appropriate for different reaches. It suggests nodes for riparian forest restoration centered around former persistent wetland riparian areas, as well as a focus on maintaining the water resources (rising groundwater) that would support these habitats.

9. **Alluvial scrub was a likely component of the driest portions of the Santa Clara River (page 92).** While more research is needed, compiled data suggest that alluvial scrub is a more suitable riparian restoration target for drier reaches (notably the Piru reach) than riparian forest.

10. **Live oaks and sycamores occurred frequently on the Santa Clara River river outer banks (page 85).** Numerous live oaks and sycamores were documented on high banks on the edge of the river corridor. Live oaks and sycamores documented within the river corridor occurred largely in Santa Paula and Sespe creeks (likely on higher bars or islands) and as individuals within large areas of willow-cottonwood forest on the mainstem Santa Clara River.

Ventura River and Valley

1. **The historical Ventura River valley supported a diverse array of natural habitats,** including valley freshwater marsh, grassland, coastal sage scrub, oaks, and sycamores (page 124). While we were unable to map the valley floor in detail, our data indicate a broad transition from grassland in the lower valley (Avenue area) to predominantly oaks, sycamores, and scrub above Foster Park to Matilija Dam. As in the Santa Clara River valley, valley oaks were not documented anywhere in the valley. Only one wetland feature was documented on the valley floor within the study area (not including Mirror Lake).

2. **Most substantial freshwater wetland complexes occurred within the Ventura River corridor.** Aquatic habitats such as ponds, sloughs, and freshwater marshes were likely found in many perennial reaches (page 138), and a suite of saline and brackish aquatic habitats was associated with the estuary at the river mouth.

3. **The Ventura River supported a broad range of riparian species,** including trees such as sycamore, live oak, willow, cottonwood, box elder, alder, and walnut; understory species such as wild grape, wild rose, and wild blackberry; and mulefat and alluvial scrub species (page 138).

4. **Unlike on the Santa Clara River, live oaks and sycamores were common within the river corridor of the Ventura River (page 138).** While on the Santa Clara River live oaks and sycamores were almost exclusively found bordering the river's high (outer) bank, both trees were common on benches, bars, and islands in the Ventura River channel, particularly in the intermittent Oak View reach.

5. **The Ventura River mouth has shifted location numerous times over the past several hundred years,** from the hills west of the river mouth to Figueroa Street in Ventura. Many of these former river mouth areas are still susceptible to flooding (page 130). A brackish lagoon, formerly at the site of what is now the Derby Club across from Seaside Park, marked the route of one of these former river mouths.

6. **The Ventura River was generally perennial for much of its length (page 135).** The uppermost reach (below the present-day location of Matilija Dam) consistently supported year-round surface water, as did the lower half of the river (below the San Antonio Creek confluence). In contrast, the middle reach, through the western Ojai Valley and downstream of Oak View, was typically dry during the summer. The precise extent and location of summer water fluctuated in response to annual variations in rainfall and runoff.

Oxnard Plain

1. **The Oxnard Plain supported a diverse array of habitats,** from the freshwater wetlands and lakes of the lower Calleguas watershed to the alkali meadows and flats, grassland, coastal sage scrub, and chaparral of the broader plain (page 174). Just under half of the plain supported alkali meadows and alkali flats, with the remainder mostly covered by grassland and coastal sage scrub.

2. **The distribution of these habitats reflected underlying physical processes and characteristics (page 163).** Topography, soils, geology, and groundwater availability were primary factors in determining historical habitat distribution.

3. **Few trees were found on the Oxnard Plain (page 174).** Only a small number of trees were documented on the plain by 19th century observers, mostly sycamores (and one live oak) on the sand and sandy loam soils marking the former route of the Santa Clara River to Point Hueneme.

4. **Few streams traversed the Oxnard Plain, particularly in its western portion (page 167).** The plain was notable for its extremely low drainage density (only 1.7 miles of creek per square mile). The few creeks and barrancas that did cross the plain were almost exclusively discontinuous, sinking into coarse alluvium or spreading into and across seasonally wet alkaline areas. Large sloughs such as Revolon Slough (a former channel of the Santa Clara River) formed the backbone of drainage for the central plain.

5. **Calleguas Creek did not maintain a defined channel across the Oxnard Plain,** instead spreading into a broad wash around present-day Highway 101 before re-emerging downslope near Conejo Creek (page 168). The creek terminated in a lake and distributary system near the current location of CSU Channel Islands. Calleguas Creek was hydrologically connected to Mugu Lagoon through shallow sloughs and sheet flow during floods.

6. **Calleguas and Conejo creeks were intermittent on the Oxnard Plain (page 168).** Though sources describe readily available water located below the surface in both creek beds, they are consistently described as dry for much of the year.

7. **Sources document a concentration of perennial freshwater wetlands, ponds, and lakes along the eastern margin of the Oxnard Plain,** particularly east of Conejo and Calleguas creeks (page 182). The majority of these wetlands occurred near the base of small alluvial valleys of creeks tributary to Calleguas and Conejo creeks, near contacts between alluvial deposits and the Conejo Volcanics of the western Santa Monica Mountains.

Ventura County Shoreline

1. **A diversity of coastal systems characterized the Ventura shoreline,** each with differing habitat patterns and hydrologic dynamics (page 191). The overall habitat distribution is well documented, though available historical sources only begin to indicate the range of coastal processes that created these patterns, from Mugu Lagoon to the backbarrier lagoons, dunes, salt flats, and tidal marshes of the Oxnard Plain.

2. **Coastal wetland habitats covered about 4,300 acres,** accounting for a large proportion of former Ventura County wetlands (page 191). Differences in freshwater input, extent of vegetative cover, and closure regime led to varying support functions for native fish and wildlife.

3. **Three distinct types of coastal estuarine systems characterized the Ventura County shoreline**: the freshwater-brackish, intermittently or seasonally closed estuaries of the Ventura and Santa Clara rivers; the non-tidal lagoon complexes marking former Santa Clara River mouths; and the large, more tidally-influenced wetland system at Mugu (page 191).

4. **The Ventura and Santa Clara River estuaries were periodically open to the Pacific Ocean (page 194)**. Regular, seasonal cycles of closure were documented for the Santa Clara River mouth. The Ventura River mouth closed only occasionally (less frequently than the Santa Clara River), reflecting its greater historical volume of summer flow in the lowest reach, steeper channel gradient near the mouth, and lesser wave exposure.

5. **The estuaries of both rivers also shared similar habitat mosaics (page 194).** Both rivers had fairly compressed estuaries, with the relatively limited saline and brackish wetland habitat near their mouths bordered by extensive freshwater habitats, most notably the willow-cottonwood forest and wetland documented at both mouths.

6. **McGrath Lake is a regionally significant feature,** unique because of its persistence over the past centuries and its freshwater character (page 203). Though the lake has persisted, its location has shifted substantially since the mid-1850s; only a small portion of its current area overlaps with its historical extent.

7. **An extensive suite of marsh, salt flats/pannes, and lagoons stretched from south of the Santa Clara River to the western edge of Mugu Lagoon (page 205).** Prior to drainage and agricultural expansion, these systems were a significant component of the Ventura County shoreline. They exhibited a range of habitat patterns based on variable salinity gradients and hydrologic inputs, from the spring-fed brackish Laguna Hueneme to the hypersaline Salinas near Point Hueneme.

8. **Mugu Lagoon was the largest wetland complex in Ventura County, and the site of a broad range of coastal wetland habitats,** including salt and brackish marshes, large salt flats, and extensive tidal channel networks (page 225). Dominant habitat cover was tidal marsh. There is some indication that the complex formerly extended substantially further inland than currently recognized. Its acreage has been dramatically reduced.

9. **Salt flats and high marsh transition zone were major components of Mugu Lagoon (page 228).** These transitional, high elevation habitats were particularly characteristic of the semi-arid climatic setting (Ferren et al. 2007), and have been disproportionately lost from this system. These features likely provided breeding habitat for shorebirds such as least tern and snowy plover (as small present-day remnants still do), as well as an inland migration zone for tidal marsh transgression in response to naturally rising sea level in the past.

ACKNOWLEDGEMENTS

We would like to express our appreciation to the volunteers and staff at the historical societies, libraries, archives, and agencies where we gathered the data that form the backbone of this report. Particular thanks to Charles Johnson at the Museum of Ventura County, Jan Timbrook at the Santa Barbara Museum of Natural History, and Alex Williams at the Ventura County Surveyor's Office. We are also indebted to the volunteers and staff at the local historical societies and public libraries where we collected data, including the Ventura County Public Library, Camarillo Historical Society, Fillmore Historical Society, Ojai Valley Historical Society, Santa Paula Historical Society, Ventura County Surveyor's Office, and Ventura County Recorder's Office. Staff at The Bancroft Library, Water Resources Collections and Archives, Bureau of Land Management, California Historical Society, California State Library, Santa Barbara Museum of Natural History, Santa Barbara Mission Archive-Library, UC Santa Barbara Map and Imagery Library, and Huntington Library were also instrumental in the data collection effort.

Over the course of the project, a number of researchers contributed time and input to data collection and interpretation. Veronica Rojas and Michael Beland of CSU-Northridge collected data at many institutions in Southern California. Murray McEachron at United Water Conservation District, Mark Capelli at the National Marine Fisheries Service, and Mark Bandurraga at the Ventura County Watershed Protection District provided relevant contemporary literature and data layers. Assistance was also provided by a number of SFEI staff, including Chuck Striplen, Josh Collins, and Sarah Pearce.

We would like to thank our Technical Review Team for contributing their expertise to the interpretation and discussion of historical conditions and providing comments on the report. The group included Mark Capelli, Frank Davis, Tom Dudley, Dave Jacobs, Paula Schiffman, and Camm Swift. We also received support and advice from Bill Sears.

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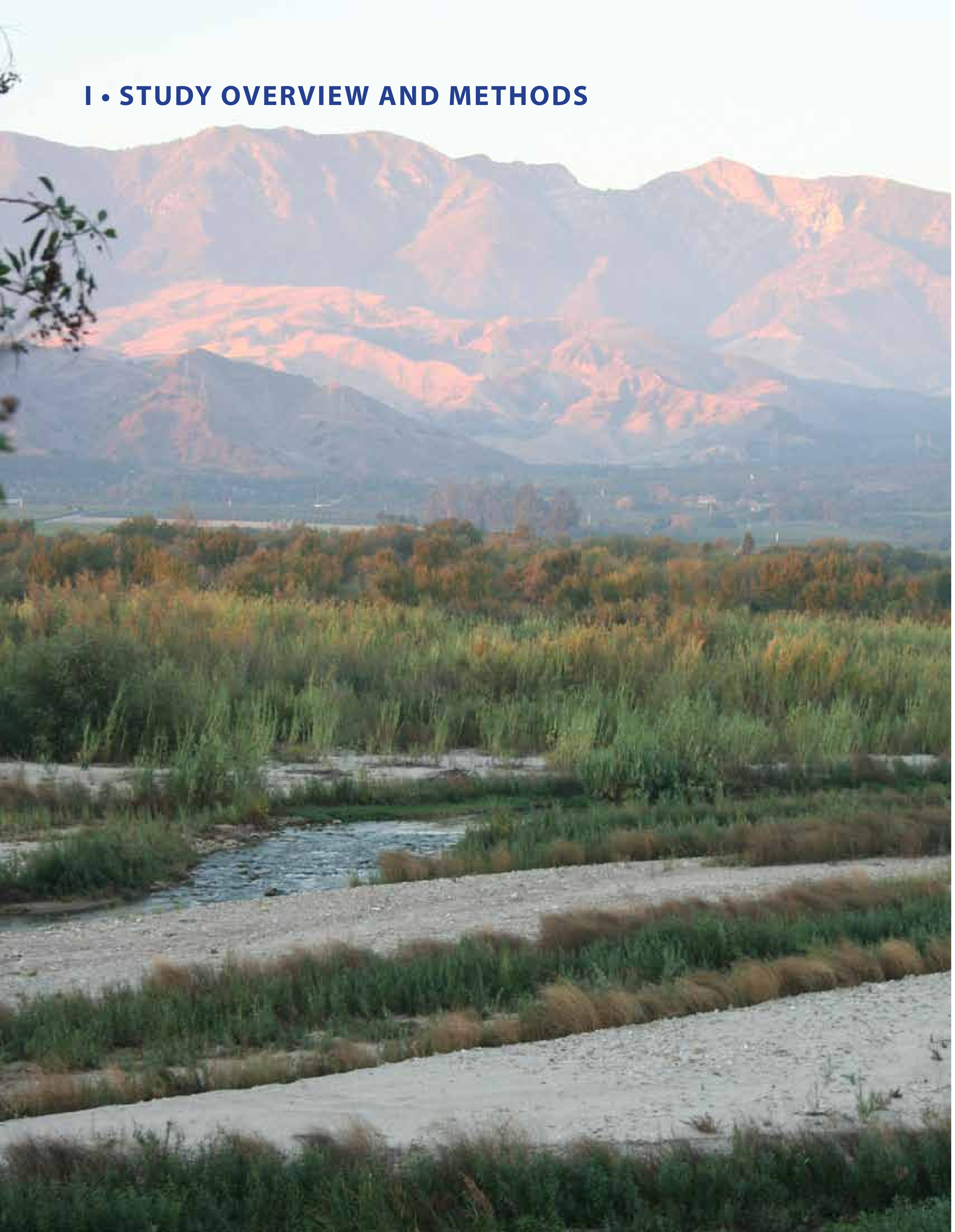
1 • STUDY OVERVIEW AND METHODS



Every day makes a little history or a few changes on the map.

—VENTURA FREE PRESS 1914

Introduction

This report synthesizes an array of historical records to document historical landscape patterns, ecological and hydrologic dynamics and trends, and environmental management opportunities in Ventura County lowland watersheds. This report and associated geo-database provide a spatially comprehensive dataset describing the historical distribution, abundance, and (where possible) functions of habitats of the Ventura River, lower Santa Clara River, and Oxnard Plain prior to significant Euro-American modification.

While substantial ecological resources still remain, the region has been subject to extensive modification over the past 250 years. Understanding the scope of these modifications, and the nature of the historical landscape patterns formerly present in the region, is not a trivial task. Regular hydrogeomorphic and ecological monitoring was not present in the county until the 20th century, and the data that do exist are idiosyncratic, challenging to interpret, and scattered in archives across the state. Despite these impediments, historical ecology is an essential component of crafting sound, site-specific environmental restoration objectives, which demand detailed data as the basis for management strategies. Without a detailed understanding of the former characteristics of the region—and how these characteristics changed in response to human alterations of the landscape—appropriate ecological and hydrological restoration targets can be difficult to determine.

This study was designed to support acquisition and restoration efforts by the California State Coastal Conservancy, in particular through the Santa Clara River Parkway project, Ormond Beach Wetlands Restoration project, and on the Ventura River through the nascent lower Ventura River Parkway plan. The characterization of historical ecological conditions developed here aims to inform these and other restoration and conservation opportunities throughout the region, helping managers develop strategies for choosing and designing restoration projects.

A previous report prepared for the Coastal Conservancy (Stillwater Sciences 2007b) analyzes the historical geomorphology of the Santa Clara River from 1938-2005. This current study extends this documentation of

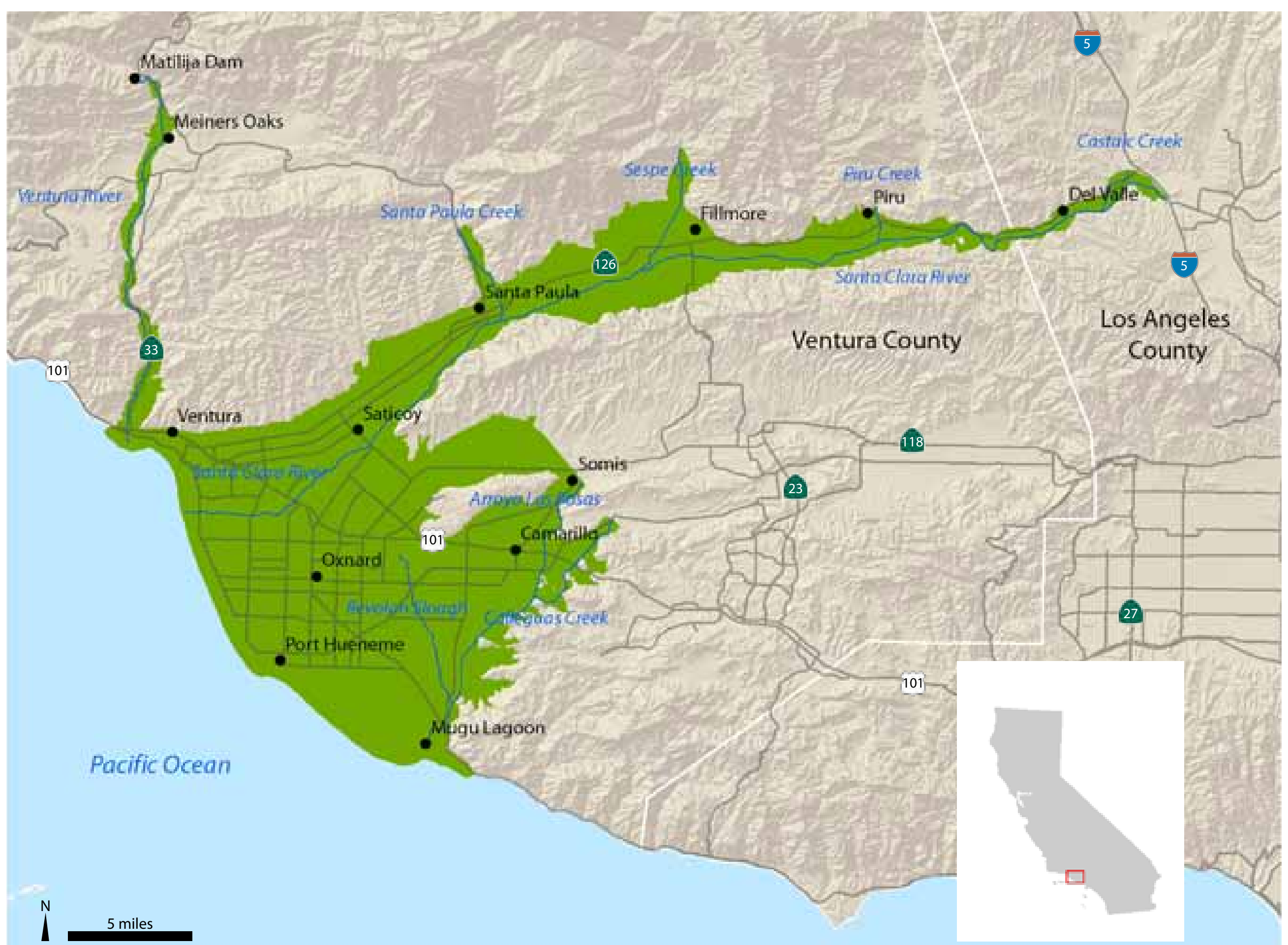
Fig. 1.1. Santa Clara River east of Santa Paula, looking north (November 2008; opposite page).

former river characteristics to include 1769-1938 by integrating historical cartographic, textual, and visual accounts to create a heterogeneous but substantial dataset describing hydrologic, geomorphic, and riparian characteristics back to 1769—the date of the first land-based European exploration of the region.

Regional Setting

This study focuses on the habitat and drainage patterns of the region's lowlands, where change has been most pronounced. The study area encompasses three major contiguous areas: the Ventura River, the lower Santa Clara River, and the Oxnard Plain (fig. 1.2). Specifically, the geographic scope is the Ventura River and valley from its mouth to the Matilija Dam (exclusive of the Ojai Valley), and the Santa Clara River and adjacent valley floor from its mouth to its intersection with Interstate 5 in Los Angeles County (including only the lowest reaches of major tributaries, and focused on the Ventura County portion of the valley). It also includes the lowlands and coastal margins south of the lower Santa Clara River, including the Oxnard Plain and lower Calleguas Creek watershed west of Somis and the edge of the Santa Monica Mountains and south of South Mountain.

Fig. 1.2. Study area and regional geographic context. The project area included the Ventura River to Matilija Dam, the Santa Clara River to Interstate 5 in Los Angeles County, and the Oxnard Plain.



Ventura County is geologically active, with substantial uplift and lateral displacement occurring related to the San Andreas fault system. The region experiences a Mediterranean climate (cool/mild wet winters and war warm dry summers), characterized by high inter- and intra-annual variability. Most precipitation occurs from November through March. There is significant regional variation in precipitation between drier, low-lying coastal areas and wetter, more mountainous parts of the county.

Land use and population trends have taken a radically different trajectory in Ventura County than in its more urban neighbors to the south, and the region is still relatively unmodified in comparison to the other large coastal watersheds of Southern California. Major population centers in the study area include Oxnard (over 200,000, the county's largest city), Ventura, and Camarillo. The total population of the county is just under 850,000 (Herdt 2010).

DESIGNING RESILIENT LANDSCAPES: HISTORICAL ECOLOGY, RESTORATION, AND CLIMATE CHANGE

Restoration goals should be informed by knowledge of landscape conditions before modern development. Historical ecology research improves our understanding of the habitats we seek to restore, including the physical and cultural processes that governed their former distribution. Studying the landscape under earlier, less impacted conditions facilitates a landscape perspective that addresses questions fundamental to the restoration planning process: What habitats were supported where, and why? Where have certain habitats persisted? How have landscape patterns and process changed over time? Most importantly, how do we choose appropriate restoration and management targets?

Historical ecology has particular relevance to these questions in the context of global climate change. The historical Southern California landscape was well adapted to a highly variable, episodic climatic regime, and buffered the effects of environmental extremes while providing diverse ecological functions. As we anticipate a more variable climate in the future, we can learn from the ways in which dynamic historical ecosystems were able to respond and adapt to extreme conditions in the past. For example, broad floodplain surfaces along the Santa Clara and Ventura rivers would have attenuated flood peaks and recharged groundwater during high flows, while side channels and pools in perennial reaches would have provided refugia critical to the survival of native fish and other wildlife during times of drought and floods. Recovering these attributes will make systems more resilient and adaptable to climate change.

Historical ecology is an essential component of restoration design, but it is not an answer in and of itself. It is a tool for scientists and managers seeking to understand and ameliorate the dramatic landscape changes of the past 250 years. When integrated with contemporary data and future projections, historical information helps identify restoration opportunities and develop realistic management strategies. Often these would not be recognized without a historical perspective. Though controls on habitat distribution such as land use and climate may change, others, such as topography and geology, remain relatively stable. Historical ecology helps us understand which characteristics supported native species of concern and how these can be recovered or enhanced. Understanding the landscape patterns and processes of the recent past can help us establish functional, resilient systems that improve the ecological health of the region.

Lowland Ventura County is dominated by the Santa Clara River and its delta, the Oxnard Plain. The Santa Clara River watershed is one of the largest coastal watersheds in Southern California, draining approximately 1,620 mi². The last 38 miles of the river run through Ventura County, southwest through the Santa Clara River valley and across the Oxnard Plain before reaching the ocean. The Santa Clara River is regionally significant because it is relatively unchannelized and unregulated by dams, and its watershed is not as densely or extensively urbanized as other systems of comparable size in Southern California. As a result, many habitats and processes no longer viable on other comparable systems are still intact to some degree on the Santa Clara River, and there is great potential to restore former ecological and hydrogeomorphic patterns and functions.

Report Structure

The report is divided into six chapters, each of which treats a different topic or geographic region. This introductory chapter describes the project's geographic setting and management context, data collection and mapping methodology, and our habitat and channel classification system. The second chapter includes a discussion of 19th and early 20th century trends in agricultural land use and irrigation practices in the region. The third chapter describes ecological patterns and riverine dynamics for the lower Santa Clara River and valley, and the fourth chapter discusses the same topics for the Ventura River and valley. The fifth chapter describes habitat and drainage network patterns on the Oxnard Plain, and the sixth chapter provides a brief treatment of the habitat patterns along the shoreline from the Ventura River mouth to Mugu Lagoon.

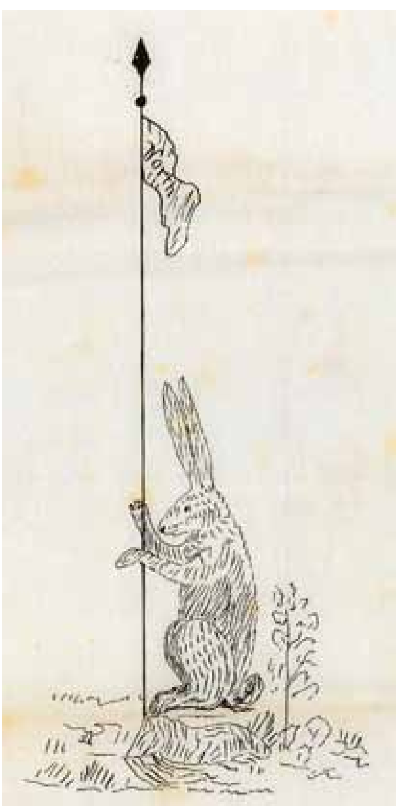


Fig. 1.3. Detail from a map of Rancho San Miguelito and the lower Ventura River, 1897. A jackrabbit serves as the compass, pointing north. (Barry 1897, courtesy of the Museum of Ventura County)

Methods

The discovery, organization, and interpretation of historical data forms the foundation of this project. The complex process through which data spanning disparate places and eras were synthesized for this study is outlined in this section.

Data Collection

A substantial variety and quantity of historical data are needed for accurate assessment of the historical landscape (Grossinger 2005). With this in mind, we assembled a diverse range of historical records spanning about two and a half centuries and compiled these data into a map of historical landscape patterns prior to substantial Euro-American modifications.

Assembled material includes: (1) textual data (e.g., Spanish explorers' accounts, Mexican land grant case court testimonies, General Land Office records, early travelogues, and county histories and reports); (2) maps (e.g., Mexican land grant maps, early city and county maps and surveys, US Department of Agriculture soil surveys, and U.S. Geological Survey maps); and (3) photography (ground-based, aerial, and oblique) and paintings.

To acquire these sources, we visited local historical archives, public libraries, county offices, and regional archives. In total, we visited twenty-seven source institutions across California to collect data (table 1.1). We also reviewed material available online and conducted searches of over twenty electronic sites and databases. We acquired scans, copies, or photographs of a diverse array of primary and secondary sources pertaining to the historical landscape of Ventura County (fig. 1.3; also see "Historical data for Ventura County" spread, pages 6-7).

We acquired full or partial copies of approximately 500 maps, 250 documents, and 500 photographs. These represent a small fraction of the documents reviewed at the archives themselves. While we reviewed

Local Historical Societies and Public Libraries
Camarillo Historical Society
Fillmore Historical Society
Museum of Ventura County
Ojai Valley Historical Society
Santa Paula Historical Society
Seabee Museum
United Water Archives
Ventura County Public Library
County Agencies
Santa Barbara County Recorder's Office
Santa Barbara County Surveyor's Office
Ventura County Recorder's Office
Ventura County Surveyor's Office
Regional Archives
Air Photo Archives, UCLA Department of Geography
The Bancroft Library, UC Berkeley
Bureau of Land Management
California Coastal Conservancy Archives
California Historical Society
California State Library
California State Railroad Archives
CSU Northridge Library
The Huntington Library
Los Angeles County Seaver Center
Mark H. Capelli Southern California Steelhead Watershed Archives, Davidson Library, UCSB
NARA Pacific Region
Santa Barbara Mission Archive-Library
Santa Barbara Museum of Natural History
UC Davis Map Collection
UC Santa Barbara Map and Imagery Library
Water Resources Collections and Archives
Western Foundation of Vertebrate Zoology
Whittier College

Table 1.1. Archives, libraries, and historical societies visited to collect data for the Ventura Historical Ecology study.

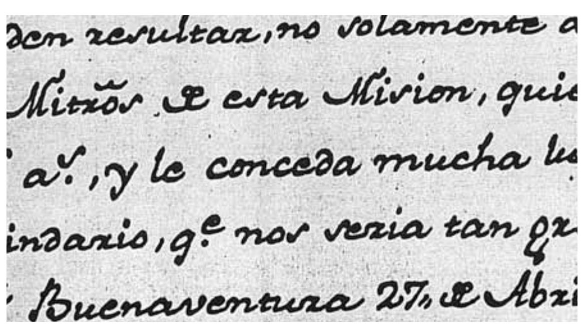
HISTORICAL DATA FOR VENTURA COUNTY

This study involved the collection and compilation of a wide array of historical sources, spanning mutliple centuries, languages, and formats. Historical documents form the backbone of our historical mapping and analysis, from Spanish-language explorer's journals (1769) and correspondence from the San Buenaventura Mission (ca. 1800) to soils mapping and aerial photography of the mid-20th century.

Since each source was produced by individuals in different social contexts and with variable goals, understanding the provenance of the sources we draw on is a fundamental starting point for understanding our findings. Shown below are examples and brief descriptions of some of the primary sources used in this study.

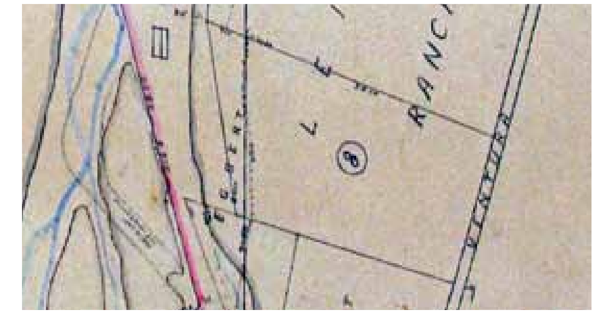
Mexican land grant sketches (1840s-1850s). As the Mission system disintegrated, influential Mexican citizens submitted claims to the government for land grants. A *diseño*, or rough sketch of the solicited property, was included with each claim. *Diseños* often show notable physical landmarks which would have served as boundaries or natural resources, such as creeks, wetlands, springs, and forests. While *diseños* are not as spatially accurate as subsequent surveys, they provide extremely early glimpses of former landscape features and patterns. (U.S. District Court ca. 1840d, courtesy of The Bancroft Library, UC Berkeley)

General Land Office Public Land Surveys (1853-1900). In areas not claimed through the land grant system, the U.S. Public Land Survey imposed a grid of straight lines on the landscape, dividing property into six-mile square townships. Each township was further subdivided into 36 one-mile sections, each section containing 640 acres. Surveyors methodically surveyed section lines along these transects, noting cultural and natural features they encountered along the way. Survey notes and plat maps from these surveys are useful for their ecological information. (Hoffman 1868d, courtesy of the Bureau of Land Management)



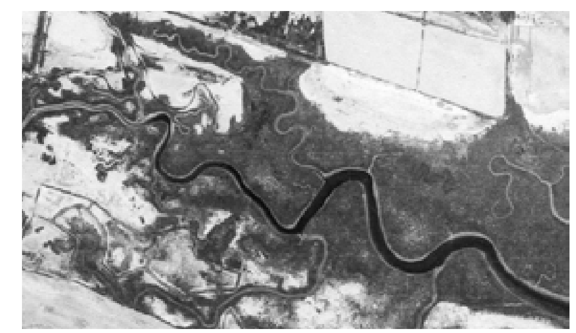
Textual accounts (1769-2011). Written accounts can provide a wealth of detailed information with nuance about landscape dynamics not available on maps. Spanish expeditions provide the earliest accounts; later sources such as land grant case testimonies, newspaper articles, ornithological records, county histories, and travelogues give rich perspectives from early visitors and residents. (text courtesy of the Santa Barbara Mission Archive-Library)

U.S. Coast and Geodetic Survey maps (1855-1934). The U.S. Coast and Geodetic Survey was established in 1807 by Thomas Jefferson to create navigation maps. Though the maps only cover the coastline and immediately adjacent areas, they are a highly valuable source because of their impressive detail and accuracy, scientific rigor, and relatively early survey dates. (Johnson 1855c, courtesy of the National Oceanographic and Atmospheric Administration)

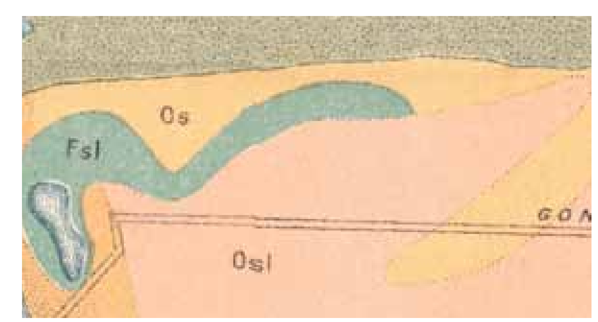


City and county surveys (1860-1930). Local surveyors produced abundant maps, including many surveys of individual parcels. These maps, often surveyed at a large scale, contain details not included in other regional mapping efforts such as sloughs and side channels, smaller ponds and wetlands, or clusters of trees. Though coverage is inconsistent, these maps are invaluable in constructing an understanding of local ecosystem dynamics. (Barry 1894, courtesy of the Ventura County Surveyor's Office)

U.S. Geological Survey topographic maps (1903-1943). Shortly after 1900, the USGS (established in 1879) began producing topographic quadrangles at 1:62,500 for the Ventura County region. Though the maps are relatively coarse, they provide some of the earliest consisent, comprehensive coverage for the entire region. (USGS 1904, courtesy of the CSU Northridge Geography Map Library)



Historical aerial photography (1927-1959). A Depression-era program to ensure crop stability and soil conservation practices resulted in extensive aerial photographic coverage for much of the county. The bulk of historical aerial imagery used in this study is from 1927 and 1938. While the photographs were taken after substantial modification, the photos nevertheless reveal relict ecological features, traces of which are often still present in the landscape. (Fairchild Aerial Surveys 1927, courtesy of Whittier College)



U.S. Department of Agriculture soil surveys (1901-1917). Early soil surveys were developed to describe variability in the agricultural viability of regional soils. These maps, and their accompanying reports, are a key source in the inference of historical habitat extent and location. Descriptions of soil properties and agricultural use can provide insight into former habitats, in particular providing spatially accurate detail on the extent of wet meadows and alkaline habitats. (Holmes and Mesmer 1901b)

Landscape photography (1860s-1950s). Historical photographs represent a category of diverse historical data that can provide extremely localized, accurate information. Photographs can capture the conditions of a given place and time in a manner that provides substantial detail about specific species presence and landscape structure. (Isensee 1928b, courtesy of Museum of Ventura County) thousands of documents for this study, historical research is never completely exhaustive, and the local historical record is extensive. Additional sources will undoubtedly surface showing ecological information that enrich the descriptions and information incorporated in this report. In particular, we were unable to focus substantial efforts on data collection for the major Santa Clara River tributaries (e.g., Santa Paula, Sespe, and Piru creeks) and the Los Angeles County portion of the Santa Clara River. As a result, it is likely that much more information exists detailing the historical landscape of these regions. Future research exploring other sources, such as early court cases and oral histories, may also reveal more detail about this area.

Data Compilation

Data compilation is the process of organizing the large volume of collected, heterogeneous data used in this study into more accessible formats for interpretation at the local and landscape scale. As part of this process, we read narrative sources and transcribed relevant quotes into one comprehensive document, georeferenced maps and spatially locatable quotes, and created large-scale maps, or "base maps," displaying compiled data onto which we transferred non-georeferenced data. High-priority maps were chosen for georeferencing based on their spatial resolution, mapping accuracy, and relevance (e.g., types of features shown and date of mapping). They were georeferenced to contemporary orthorectified aerial imagery (USDA 2005), using ESRI's ArcGIS 9.3.1 software. Approximately 150 maps were georeferenced.

One heavily used source was historical aerial photography, which required orthorectification and mosaicking of 238 aerial photographs into a comprehensive, continuous coverage of the entire study area (fig. 1.4). Aerials were acquired from a number of source institutions and spanned a number of different years. The earliest imagery (1927), used where available, makes up about one half of the entire photomosaic. Later imagery (from 1938, 1945, and 1959) was substituted where 1927 imagery was not available. The spatial consistency, accuracy, and high level of detail available made these an invaluable source for the project.

Relevant quotes were extracted from textual material and transcribed into a Microsoft Word document. Quotes were organized by broad geographic area (Santa Clara River valley, Ventura River valley, Oxnard Plain) and by subject (e.g., riparian vegetation, channel geometry, or wetland habitats). In addition, quotes pertaining to land use history, irrigation history, and climate were transcribed. Over 160 pages of quotes were transcribed. Of these quotes, about 240 were spatially specific enough to be locatable on our base maps. These were mapped and included in our project geographic information system (GIS) as an independent data layer.

In addition, we adapted methods developed by the Forest Landscape Ecology Lab at the University of Wisconsin-Madison that use GIS to store, display, and analyze General Land Office (GLO) data obtained from the microfilm archives at the Bureau of Land Management Office in Sacramento, CA (Manies 1997, Radeloff et al. 1998, Sickley et al. 2000). For Ventura County, survey notes ranged from 1853-1900. Just under 1,700 data points collected from the General Land Office notes were included in this layer.

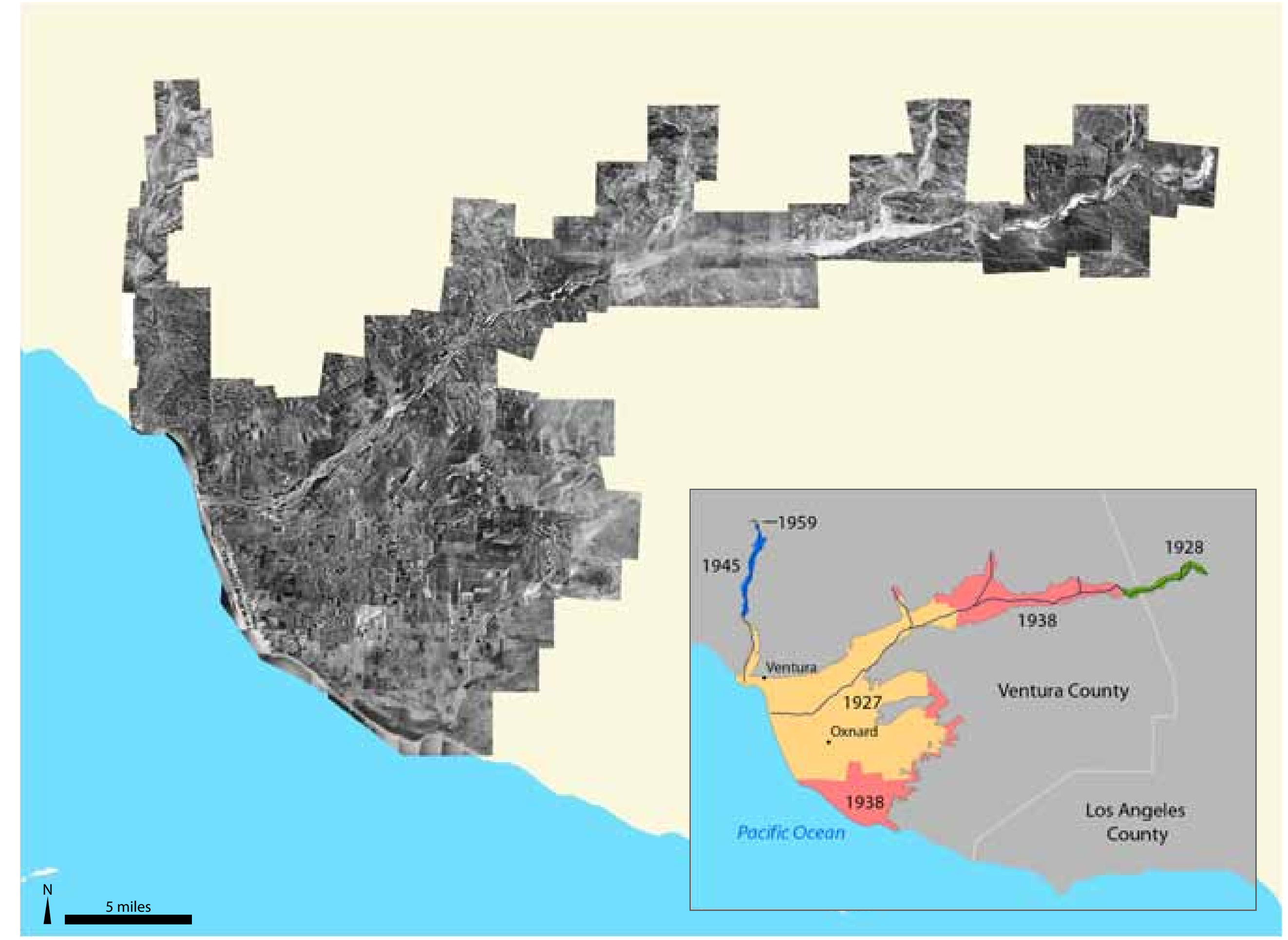


Fig. 1.4. Earliest date of aerial photo coverage. Two hundred and thirty-eight historical aerial photographs were orthorectified and mosaicked to provide continuous coverage of the study area. Aerials spanned from 1927-1959, with the bulk of photos from 1927 and 1938.

Data Interpretation

We examined historical data for evidence of landscape characteristics prior to significant Euro-American modification. Our goal was to map landscape features as they existed, on average, prior to and during the early decades of Euro-American settlement (1770s-1850s). Despite inter-annual and decadal variability, mean climatic characteristics during the period for which historical data were obtained (1769-1940s) were relatively stable (Lynch 1931, Dettinger et al. 1998; see also Haston and Michaelsen 1997). Many later sources (i.e., outside of the target time period) were found to record features that clearly corresponded to features documented by earlier sources, and thus provided more accurate mapping of these features. For example, a feature shown on an early source (e.g., a *diseño*) that confirms the general presence of the feature but not its location, could be confirmed and mapped from a later source (e.g., a historical aerial), despite surrounding land use changes.

Accurate interpretation of documents produced during different eras, using different methods or techniques, for differing purposes, and with different authors, surveyors, or artists can be challenging (Harley 1989, Grossinger and Askevold 2005). To address these issues, we interpreted collected data through an iterative process of source inter-calibration using GIS and other techniques. Our dataset of sources, often overlapping in geography and depiction, allowed us to compare an array of complementary documents, and in doing so assess the accuracy of individual documents and to promote accurate interpretation of landscape characteristics. This approach provided independent verification of the accuracy of original documents and our interpretation of them (Grossinger 2005, Grossinger et al. 2007). In addition, through this process we were able to take a large body of often subjective information (e.g., a traveler's description of the Santa Clara River) and form a reliable, comprehensive, and coherent body of data.

To ensure persistence and accurate interpretation, we documented each feature using multiple sources from varying years and authors where possible. In some cases, a high density of sources documenting a particular feature allowed for high mapping confidence of both presence and extent. However, many features are documented by only one source or simply may not have any specific early source that describes the habitat. In these cases extrapolation based on soil types, topography, hydrology, and general descriptions was necessary.

To document the mapping sources used and the classification and mapping accuracy certainty associated with individual features, we assigned a set of attributes including each feature's derivation and estimated certainty levels (table 1.2). Our confidence in a feature's interpretation (classification), size, and location was assigned as a set of three certainty levels based upon the number and quality of sources, and our experience with the particular aspects of each data source (following standards discussed in Grossinger et al. 2007). These attributes provide for data transparency and allows subsequent users to assess accuracy and identify original data sources.

Table 1.2. Certainty level standards used in the interpretation and mapping of historical features.

Certainty Level	Interpretation	Size	Location
High/ "Definite"	Feature definitely present before Euro-American modification	Mapped feature expected to be 90%-110% of actual feature size	Expected maximum horizontal displacement less than 50 meters (150 ft)
Medium/ "Probable"	Feature probably present before Euro-American modification	Mapped feature expected to be 50%-200% of actual feature size	Expected maximum horizontal displacement less than 150 meters (500 ft)
Low/ "Possible"	Feature possibly present before Euro-American modification	Mapped feature expected to be 25%-400% of actual feature size	Expected maximum horizontal displacement less than 500 meters (1,600 ft)

Mapping Methodology

We used a geographic information system (ESRI's ArcGIS 9.3.1 software) to interpret and synthesize our information into digitized data layers representing historical landscape characteristics of the lower Santa Clara River, the Oxnard Plain, and the Ventura River. GIS was used to collect, catalog, compile, digitize, analyze, and display our sources. By spatially relating sources from many time periods, we were able to examine habitat location and change through time (fig. 1.5). The relational database component of GIS allows for storage of many attributes about a single feature, which we used to integrate our disparate sources and document the provenance of our interpretation of the historical landscape. Using GIS, we were able to synthesize complex arrays of sources by assembling maps and narrative information from different periods, allowing us to assess each data source, more accurately map each feature, and better understand change over time.

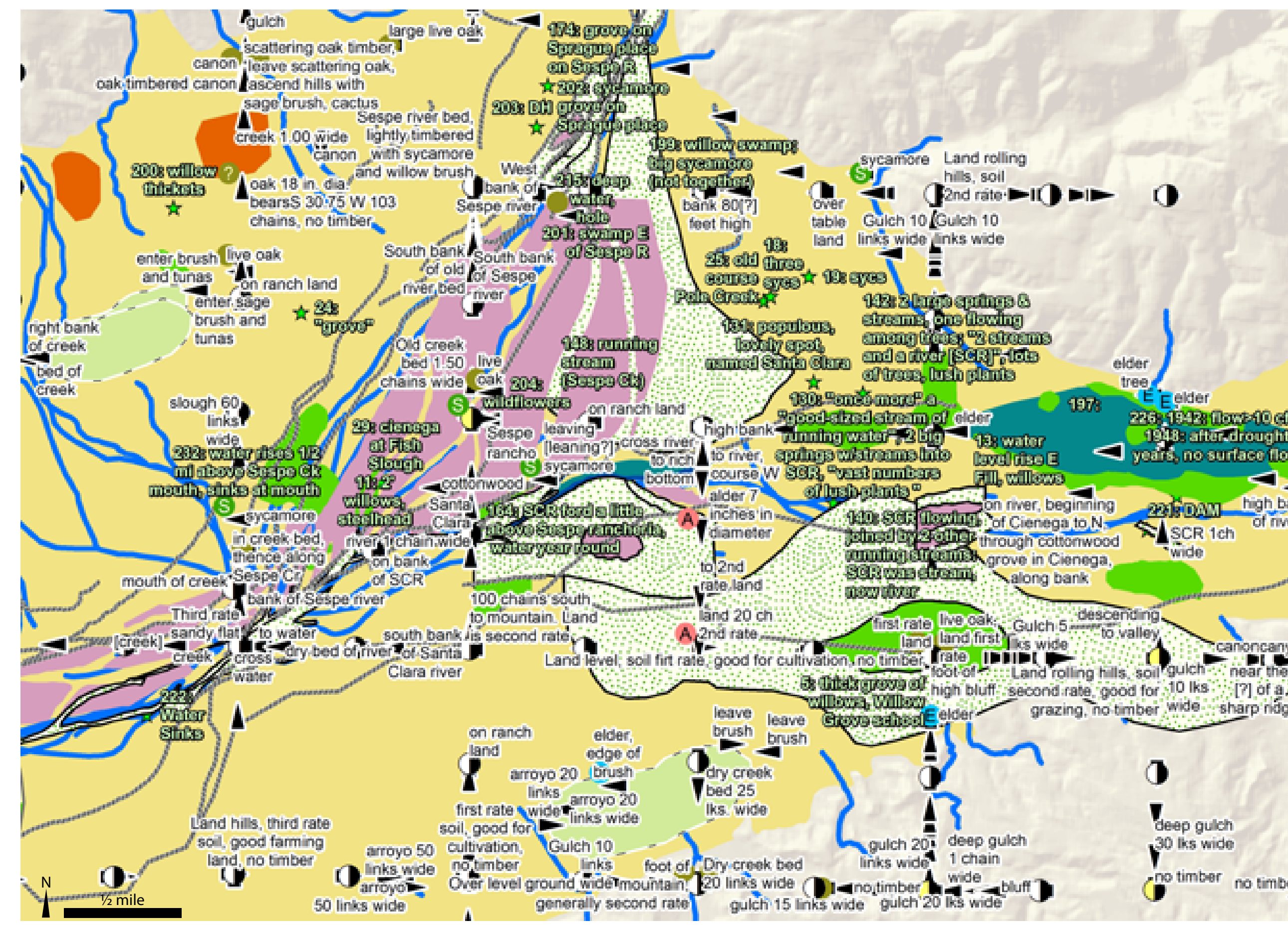


Fig. 1.5. Draft historical habitat and channel mapping at Santa Clara River-Sespe Creek confluence, early 1800s. Features from dozens of historical maps, texts, and photographs were digitized before being synthesized through an intensive process into one integrated map of the region's historical ecology.

The habitat map produced through this process depicts our understanding of landscape features as they existed before major Euro-American modifications (1770s-1850s; referred to as "early 1800s" for simplicity). Individual creek and habitat features were digitized from historical sources, and ultimately synthesized into the study area habitat map (included at the beginning of this report).

The primary purpose of the mapping process and resulting habitat map is to represent habitat diversity and heterogeneity at the watershed scale, leading to a better understanding of regional patterns and processes. While many individual habitat polygons have been mapped with precision (see table 1.2), others have higher error margins for their mapped size. Clearly, our dataset of disparate sources (each representing a different scale, time period, and level of accuracy) prevents mapping each area at the same level of detail. In addition, many former features were undoubtedly not documented by any historical source, and therefore were not mapped. However, these issues do not undermine the map's usefulness as a tool to characterize and understand the region's historical ecological patterns and the underlying processes that shaped them.

The following section outlines the methods used to integrate and synthesize data in GIS to depict broad classes of habitats on the map, both for the purpose of visual representation of historical habitats and channels and for analysis of the historical landscape. For more information on the accuracy of a particular habitat polygon, please refer to the GIS metadata.

RIVER CORRIDORS AND RIPARIAN HABITATS For the river systems (Santa Clara, Ventura) and major tributaries to the Santa Clara River (Santa Paula, Sespe, Hopper, and Piru), the entire river corridor (from outer bank to outer bank) was mapped as a polygon in the habitat layer (fig. 1.6). (Major tributaries to the Ventura River, such as Coyote, San Antonio, and Matilija creeks, were on the edge of the study area boundary and were not mapped as polygons.) This area includes the predominantly sandy active channel (mainstem; high disturbance) in addition to vegetated areas that show evidence of erosion/deposition (medium disturbance) and more densely vegetated areas that may be subject to flow during flood events, but without evidence of major erosion/deposition (low disturbance). Benches or bottomlands with evidence of flow during at least some flood events are also included. This definition of the river corridor was based on research conducted by Stillwater Sciences (2007b) for 1938-2005. More detailed definitions of riverine terms used in this report is can be found on page 61.

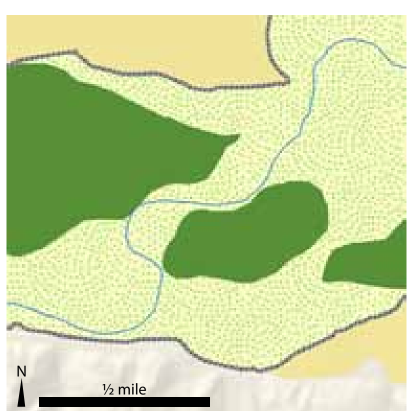


Fig. 1.6. Detail of mapping of outer river banks and river corridor extent. Outer banks were mapped as a broken black line, and river corridor extent with a green and yellow stippled pattern. (The dark green polygons are willow-cottonwood forested wetlands.)

We used Stillwater Sciences' mapping as a starting point for defining the river corridor for the Santa Clara River (Stillwater Sciences 2007b). For other major channels, including the Ventura River, mapping from the earliest available historical aerial served as a base layer. These base layers were then modified where earlier historical sources showed clear evidence of a change in outer bank position. For more details on mapping

methodology for the river corridors of major streams, see the Santa Clara River morphology section (page 63).

For these main river corridors, the mainstem channel lines were mapped from the historical aerial photomosaic. Since the location of the low-flow channel would have changed regularly, these lines are only used to represent the presence of mainstem channels in the broadest sense, and do not indicate a persistent feature. They were mainly used as a tool to map seasonality for the Santa Clara and Ventura rivers and main tributaries. Stream seasonality (presence of summer flow) was mapped based on historical USGS mapping, and amended where earlier additional evidence was available.

In general, we did not develop detailed maps of riparian habitats (in-channel and on the outer bank), given their inconsistent documentation and their dynamic nature on a yearly or decadal scale. Riparian vegetation features represented on historical maps within the active channel and on the floodplain were difficult to interpret and impossible to map meaningfully, given inter-annual variability in distribution and characteristics. As a result, riparian vegetation such as live oaks along canyons at the edge of the valley were mapped as the surrounding habitat. In addition, riparian habitat in the active channel was subsumed under "other in-channel riparian" habitat. Historical riparian habitat patterns are described qualitatively in the text.

While many areas of riparian forest inside the active channel were ephemeral, shifting with major flood events, there were a few reaches of the river with large wetland riparian features whose presence was consistently documented through major flood events. These areas are notable in their extent (over 200 acres), their persistence over time (as documented by multiple historical sources), and their relative importance to early residents (as indicated by their prevalence in the historical record). These features are included in our habitat mapping as willow-cottonwood forested wetland.

CHANNELS All other watercourses (including Calleguas Creek and tributaries to the rivers and creeks mapped as polygons, as described above) were mapped as line features in ArcGIS (fig. 1.7). The contemporary National Hydrography Dataset (USGS 2004) was used as a basis for mapping the historical channel network. The NHD GIS layer was modified where historical sources (such as historical aerial photos or maps) clearly showed evidence of a historical plan form differing from the contemporary alignment. This process produced a depiction of our best understanding of the historical channel network based on earliest available source.

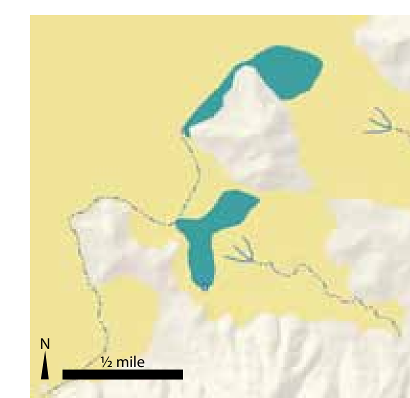


Fig. 1.7. Detail of channel mapping. Small creeks were mapped with a single line, dashed to indicate intermittent/ephemeral conditions. A forked symbol was used to indicate a distributary (that is, the point at which a creek spreads or sinks).

Contemporary stream lines were altered only where historical sources clearly indicated a different channel position or shape than that mapped by NHD (greater than 50 feet difference). This approach accounts for differences in mapping scale between historical and modern mapping, differences in georeferencing, and the accuracy of historical sources.

Although this method will not capture all changes in plan form, it allows us to more accurately analyze major changes in drainage density (stream length per unit area), connectivity, and total stream length while preventing us from over-mapping change. All editing was performed at a scale of 1:4,000.

To map the historical drainage network, we first compared NHD mapping and modern aerial imagery (USDA 2005) to early aerial imagery (1927-1959) to identify 20th century modifications. Engineered channel reaches, such as ditches and artificial flood control channels, were removed from the data set. To evaluate change predating the historical aerials, NHD mapping was compared with earlier maps depicting channel plan form. We also incorporated information from General Land Office (GLO) survey notes, other textual descriptions, topography, and early soils maps. (Contributing sources and certainty levels associated with each creek segment are recorded in the GIS attributes.)

Channels (over 500 feet long) depicted by a historical source but not present in NHD were included in the historical channel layer. To maintain a consistent depiction of channel density over time, we attempted to map channels roughly to the same level of detail as contemporary NHD mapping. As a result, our mapping excludes some small channels for which there is evidence in historical sources (such as small barrancas, creeks, or sloughs). In particular, a number of small channels visible in the historical aerial photomosaic, but of uncertain size or origin, were not included in our historical channel mapping. This approach allows for more accurate comparison between the historical stream layer and modern mapping.

Many channels historically lost definition on the alluvial plain rather than directly connecting to another channel. We represented the terminus, or distributary, of defined channels with a forked symbol on the habitat map. In cases where channels did connect to a large river (Santa Clara or Ventura river) or a major tributaries (Santa Paula, Sespe, Hopper Canyon, Piru, or Castaic creek), the channels were clipped to the historical outer channel banks layer, signifying probable connectivity to the mainstem.

WETLAND HABITATS We documented the extent and distribution of wetland types prior to significant Euro-American modification based on available historical evidence (fig. 1.8). Wetland types mapped include palustrine habitats (alkali meadow, alkali meadow/flat, wet meadow, valley freshwater marsh, perennial freshwater pond, willow thicket, and willow-cottonwood forested wetland) and also a number of coastal habitat types (see habitat crosswalk, table 1.3).

Salt-affected, seasonally-flooded alkali meadows covered large areas of the Oxnard Plain, and were by far the most extensive wetland habitat type in the region. Extent of alkali-associated habitats was mapped almost exclusively from historical soils maps (Holmes and Mesmer 1901b, Nelson et al. 1917). Alkali meadow was first mapped from the

later historical soils map (Nelson et al. 1917), which shows large bodies of land with alkali present (designated with an "A") or alkali present "in spots" (designated with an "S," and covering most of the alkali-affected area). This mapping provided the general extent of alkali influence on the Oxnard Plain. A map of alkali extent accompanying the earlier soils report (Holmes and Mesmer 1901b), which distinguishes between six grades of alkali influence from 0.2% to over 3%, coarsely matches the extent of alkali-affected land as shown on the 1917 map, but provides much more resolution on the extent of highly affected (greater than 1% alkali) land. Highly affected alkaline areas, or alkali flats, were drawn from this map (the alkali meadow/flat category includes areas with 1% or greater alkali concentration in the top six feet of soil).

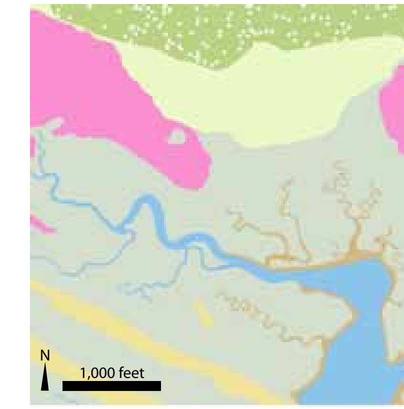


Fig. 1.8. Detail of wetland mapping, northwestern edge of Mugu Lagoon wetland complex. We mapped seasonal wetlands (such as alkali meadows, shown here in green with white stipple) in addition to perennial wetlands (such as the tidal marsh shown in grey-blue).

To map coastal features, we digitized and interpreted features from the earliest available U.S. Coast and Geodetic Survey (USCS) topographic sheets (T-sheets), from 1855 and 1857 (Johnson 1855b,c; Johnson 1857). High-resolution, full-color digital imagery of original T-sheets were obtained from the National Archives and Records Administration in College Park, Maryland (thanks to Dr. John Cloud of NOAA) and georeferenced. This work was completed as part of the Historical Wetlands of the Southern California Coast project, which contains further detail on the digitization and interpretation process for the T-sheets (see Grossinger et al. 2011). This mapping was then compared to additional sources (e.g., later T-sheet resurveys, independent historical maps, GLO survey notes, and other textual descriptions) and modified where appropriate.

Other wetland habitats were mapped from reliable, spatially explicit historical sources documenting the presence and extent of wet meadows, depressional marshes, ponds, and willow groves on the alluvial plains. Where multiple sources showed the same feature, evidence was synthesized to produce the most likely representation of historical feature. Topography, historical soils maps, and early aerial imagery were used to refine the shape and extent of wetland features in the absence of other available documentation.

This process undoubtedly under-represents the historical extent and distribution of wetland features. Some known wetland features are documented in the textual record or on coarse maps, but are ultimately not recorded with enough accuracy to render them mappable. Other wetlands were undoubtedly present, but were left undocumented by the available historical record. Subsequent research may reveal more information about the presence or location of additional wetland features.

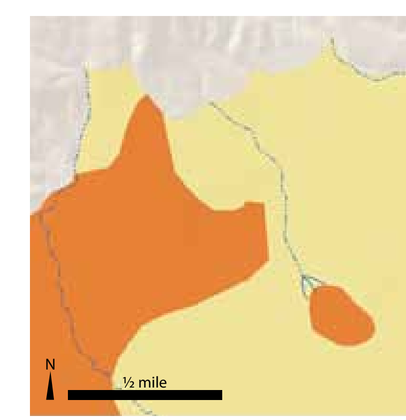


Fig. 1.9. Detail of dryland mapping. We mapped dryland habitats in a generalized fashion, including grassland/coastal scrub (in yellow) and oaks and sycamores (in orange).

DRYLAND HABITATS We documented the extent and distribution of dryland habitat types prior to significant Euro-American modification based on available historical evidence (fig. 1.9). Here we define "dryland" habitats to be well drained terrestrial habitats without regular cycles of flooding. Mapped terrestrial habitat classes include grassland/coastal sage scrub and oaks/sycamores (see habitat crosswalk, table 1.3). This layer provides the background into which we incorporated wetland and river corridor mapping.

Historical sources generally contained much less spatially explicit documentation of dryland habitat features (unlike for many wetland types, where multiple historical sources often document a single feature's location and characteristics). As a result, the goal of dryland habitat mapping was to produce a meaningful representation of patterns of dryland vegetation cover at the landscape scale. Given the lack of spatially specific information in most early sources, we relied predominantly on the few sources that did address dryland habitats, including GLO surveys, historical soil surveys, and historical aerial photography. Where available, textual descriptions, cartographic sources, and landscape photography provided additional support.

In particular, the GLO survey data provided early, detailed information about habitat boundaries and characteristics along survey lines. Later sources (such as historical soil surveys and aerial photography), in addition to edaphic or topographic information, were used to shape polygons in areas where a GLO transect was the only other source of evidence. In some cases, habitat boundaries were defined by the descriptive text associated with the soil surveys. These survyes often describe the native vegetation of the soil type, such as "brush and grass" on Yolo fine sandy loam or "scattered oak and brush" on Vina fine sandy loam (Nelson et al. 1920). Aerial photography was used to confirm the presence of trees identified by earlier sources and to map the extent of that area based on the vegetation pattern.

The "grassland/coastal sage scrub" class covers the majority of the study area (53%). It encompasses a wide range of subtypes of different moisture regimes and vegetation types. Our data suggest that the grassland/coastal sage scrub areas ranged from rich, relatively moist coastal prairie, to barren land, to dense scrub and cactus with little or no grass. This habitat type may also include areas of sparse tree cover or regions with small groves (below the minimum mapping unit, not locatable, or not documented by historical sources). We use the term "coastal sage scrub" because California sagebrush (*Artemisia californica*) was likely the predominating species. However, other chaparral or cactus species also occurred in many areas. In this report, we use grassland to mean a predominantly upland herbaceous cover, encompassing both forbland and coastal prairie types.

We were unable to map grassland and scrub separately at a consistent scale across the region, given the indistinct boundaries between types and the absence of early historical evidence for many parts of the study area. In addition, due to early invasions and the effects of grazing, dramatic changes in extent of grassland and scrub may have occurred shortly after European contact in the late 1700s, which complicates interpretation of

mid-1800s sources (see box on page 18). Generalized accounts of the Ventura County lowland describe it as largely dominated by herbaceous cover, and documentation of non-riparian trees was confined to a few select areas (see specific chapters for more details). To address this data gap, we used the grassland/coastal sage scrub habitat class as a default type when no historical evidence existed. As a result, this habitat classification often carries greater interpretation uncertainty than other mapped classes. This is captured in the GIS historical habitat layers.

The "oaks and sycamores" habitat type includes woodland or savanna areas supporting coast live oak (*Quercus agrifolia*) and/or California sycamore *(Platanus racemosa*). It was mapped in areas where tree cover was documented by historical sources (e.g., a GLO survey recording "timbered tableland" or "scattering oaks"; Thompson 1868, Craven 1874g). Polygon boundaries were drawn from a synthesis of historical aerial photography, soils and other historical maps, and textual data. In many of these instances, sycamores were explicitly mentioned (e.g., a map depicting "scattering oak and sycamore" or a GLO surveyor noting "scattering live oak and sycamore with undergrowth sage brush"; Hare 1876, Orcutt 1900); this information is included in the GIS metadata. The "oaks and sycamores" class would have included understory cover ranging from predominantly grassland to predominantly scrub, though this distinction is not represented in our mapping.

As for wetland habitat types, it is likely that mapping of these wooded areas is a conservative representation of extent, since trees were mapped only where there was supporting historical evidence. Some areas of this type are undoubtedly assigned grassland/coastal sage scrub as a default due to lack of documentation.

Inevitably, historical documents reveal more details about the historical landscape than is represented in the habitat map. For example, not all features noted by the GLO surveyors were subsequently mapped in the habitat layer, as some information was more detailed than our mapping standards allowed (e.g., an area with a small patch of cactus noted within grassland was all mapped as part of the grassland/coastal sage scrub class). As is the case with most ecosystems, transitions between woodland, scrub and low herbaceous cover were often gradual and diffuse, extending over broad areas. The habitat mapping represents regional-scale transitions as opposed to local-level detail (such as small groves, patches of scrub, or narrow zones of riparian oaks along ravines). Many of these local characteristics, though not mapped, are explored further in this report. Though the broad habitat classifications we use obscure some of the detail present in the historical record, they provide meaningful classification units that are comparable across the study area, allowing us to map at a consistent scale even in areas with relatively sparse documentation.

GRASSLAND, FORBLAND, OR COASTAL SAGE SCRUB?

The original composition of pre-contact herbaceous cover on Ventura County valley floor—indeed, across all of California—is far from clear. The historical dominance of perennial bunchgrasses in California grasslands has been hypothesized by many ecologists, and was the dominant theory for most of the 20th century (e.g., Clements 1934, Burcham 1956; see Bartolome et al. 2007 and Martinez 2010 for more detail). More recently, however, a number of researchers have proposed the historical prevalence of annual grasses and forbs in Southern California (the Los Angeles coastal prairie; see Mattoni and Longcore 1997, Schiffman 2005) and California as a whole (see Schiffman 2007, Minnich 2008). In the absence of precise, explicit historical evidence, we broadly refer in this report to the low herbaceous cover that dominated much of the Ventura County lowlands as "grasslands." These areas may have included perennial bunchgrasses and annual grasses, in addition to annual forbs and wildflowers and even some shrubs.

In our historical habitat mapping, we lumped these "grassland" habitats with the shrubbier coastal sage scrub. One reason for doing so is the ambiguity of the historical record. While habitat type is clearly indicated in a few areas by the historical record (for example, references to "cactus and sage brush" (Craven 1874f) or a "spacious plain, covered with grass" (Costansó and Browning 1992)), in most areas no such historical resolution exists.

A second reason for combining the herbaceous and shrub classes is the uncertainty surrounding impacts of Chumash land management practices, in particular the burning of grasslands. Widespread Chumash burning of grassland areas in the Santa Barbara Channel region has been exhaustively documented by Timbrook et al. (1982). Frequent (every 1-3 years) burning of valley grasslands, a technique used to increase yields of seeds and other foods during the late summer, would have maintained these areas at the expense of coastal sage scrub. Conversely, the suppression of burning practices in the late 1700s by Mission officials would have led to the encroachment of coastal sage scrub into former grassland areas.

The effects of Chumash burning practices on the extent and distribution of Ventura grasslands and shrublands further compounds the ambiguity surrounding each habitat's historical distribution in the county, and even calls into question the relevance of 19th century ecological observations for these habitat types. Heavy grazing pressures from Mission cattle in the late 1700s and early 1800s may have also distorted these observations. Since distinctions between grasslands and shrublands could not be consistently made across the entire study area, we chose to display the two communities together rather than risk making uninformed decisions.

The cessation of Chumash fire management, grazing impacts, and the introduction and invasion of exotic species all contributed to a rapid change in the character of Ventura grasslands by the early 19th century. Descriptions of widespread non-native cover, particularly wild oats (*Avena fatua*) and wild mustard (*Hirschfeldia incana/Brassica nigra*), were abundant during this time on lowlands across the study area: GLO surveyor Hancock (1854) repeatedly noted "dense mustard" and "belts of grass and mustard" on the Oxnard Plain; a description corroborated by other observers who saw "thickets of wild-mustard" (Roberts 1886), "thousands of acres actually overrun with wild mustard" (Rothrock 1876), a "vast forest of bee-haunted mustard-blooms" (Eames 1889), "meadow grass and wild oat" (*Daily Alta California* 1865), and "wild oats, wild burr-clover [*Medicago polymorpha*], and alfilaria [filaree; *Erodium cicutarium*]" (Storke 1891).

Timbrook et al. (1982) provides a list of grasses that were likely abundant in the Santa Barbara Channel region during active Chumash management. They include California brome (*Bromus carinatus*), ryegrasses (*Leymus [Elymus] condensatus, L. glaucus,* and *L. triticoides*), meadow barley (*Hordeum brachyantherum*), coast range melic (*Melica imperfecta*), bluegrass (*Poa secunda*), needlegrass (*Nassella pulchra, N. lepida,* and *N. cernua*), chia (*Salvia columbariae*), and red maids (*Calandrinia* spp.), among other grass and herb species.

Habitat and Channel Classification

We developed twenty different habitat types based on historical evidence and modern classification systems (table 1.3). These classes balance a desire to preserve the detail often available in the historical record, while creating meaningful classes that are comparable to contemporary classification systems and applicable across the entire study area. In some cases, the character of historical data creates difficulty in direct translation to a single contemporary vegetation class. We divided the 20 habitats or vegetation types into wetland, dryland, riparian, and coastal habitat types reflective of the historical ecology of the region (see table 1.3 for complete list). (In this report, we use the term "riparian" to refer exclusively to streamside vegetation.)

The following definitions provide brief explanation of the habitat types outlined in table 1.3. They are in large part derived from contemporary descriptions and classification systems outlined elsewhere (e.g., Ferren et al. 1990, 1995; Mertes et al. 1996; Holstein 2000; Ornduff et al. 2003; Barbour et al. 2007; Ferren et al. 2007; Grossinger et al. 2007; Stillwater Sciences 2007a,c; Coffman 2008; Orr et al. 2011). For more detailed descriptions of each type, please refer these documents.

Palustrine and Terrestrial Habitats

PERENNIAL FRESHWATER POND Freshwater ponds are permanently inundated, non-vegetated depressional areas containing year-round standing water. They often occur within larger complexes of marshland, willows, and seasonal wetlands.

VALLEY FRESHWATER MARSH Valley freshwater marshes can be associated with low-lying depressions and ponds, in-channel sloughs and areas of high groundwater, or groundwater-fed springs. They are flooded for most or all of the year, and are permanently saturated. Dominant plant species include bulrushes (*Scirpus [Schoenoplectus]* spp.), cattails (*Typha* spp.), sedges (*Carex* spp.), spikerushes (*Eleocharis* spp.), and rushes (*Juncus* spp.).

WILLOW THICKET This category includes stands of willow (*Salix* spp.) not found along rivers or creeks. It includes dense thickets dominated by shrub-sized willows with occasional larger trees (e.g., historically documented box elder; *Acer negundo*), in addition to willow "groves," which tended to include stands of more mature, established trees. Since willows are dependent on a relatively high groundwater table, these areas are often temporarily flooded.

WET MEADOW Wet meadows are temporarily or seasonally flooded grasslands characterized by poorly-drained, clay-rich soils. They can be flooded for days or weeks depending on precipitation and topography, and stay moist longer than adjacent, better-drained areas. The dominant plant species were probably rhizomatous ryegrasses (*Leymus* spp.), with a significant component of obligate and facultative wetland species such as wire rush

Table 1.3. Crosswalk between historical habitat type and modern classification systems.

Historical Habitat Type	California Terrestrial Natural Communities (CNDDB 2003)	Wetland Classification and Water Regime (Cowardin et al. 1979)/ USFWS Riparian Mapping System (2009)
Palustrine and Terrestrial Habitats		
Perennial Freshwater Pond	N/A	Palustrine permanently flooded wetland.
Valley Freshwater Marsh	Valley Freshwater Marsh (52.100.01)	Palustrine persistent emergent freshwater/saline wetland. Temporarily to permanently flooded, permanently saturated.
Willow Thicket	Scrub Willow (63.100.00), Willow Riparian Forests and Woodlands (61.200.00)	Palustrine forested wetland. Temporarily flooded, permanently saturated
Wet Meadow	Native Grassland (41.000.00); Meadows and Seeps not dominated by grasses (45.000.00)	Palustrine emergent wetland. Temporarily flooded, seasonally saturated.
Alkali Meadow	Alkali Meadow (45.500.00), Salt - Alkali Marsh (52.200.00), Saltgrass (41.200.00)	Palustrine emergent saline wetland. Temporarily to seasonally flooded, seasonally to permanently saturated.
Alkali Meadow/ Alkali Flat	Alkali Meadow (45.500.00), Alkali Playa Community (46.000.00), Saltgrass (41.200.00)	Temporarily to seasonally flooded, seasonally to permanently saturated.
Oaks and Sycamores	California Sycamore-Coast Live Oak (61.312.01), California Sycamore (61.310.00)	N/A
Grassland and Coastal Sage Scrub	Native Grassland (41.000.00); Venturan Coastal Scrub (32.190.00), Wildflower Field (41.290.00)	N/A
Characteristic Riparian Habitat Types		
Willow-Cottonwood Forested Wetland	Willow Riparian Forests and Woodlands (61.200.00), Black Cottonwood Riparian Forests and Woodlands (61.120.00), Southern Cottonwood-Willow Riparian (61.130.02), Marsh (52.100.00)	Riparian Forested Deciduous
Other In-Channel Riparian	Scrub Willow (63.100.00), California Buckwheat-Scalebroom (32.070.01), Mulefat Scrub (63.510.00), California Sycamore-Coast Live Oak (61.312.01), Willow Riparian Forests and Woodlands (61.200.00)	Riparian Scrub-Shrub Deciduous, Riparian Forested Deciduous/Evergreen
Coastal and Estuarine Habitats		
Beach/Dune	Coastal Dunes (21.000.00), Native Dunegrass (41.260.00)	N/A
Tidal Lagoon (mostly open?)	N/A	Estuarine subtidal, unconsolidated bottom
Tidal Lagoon (seasonally open)	N/A	Estuarine subtidal/Palustrine intermittently flooded. Unconsolidated bottom.
Non-tidal Lagoon	N/A	Estuarine subtidal/Palustrine intermittently flooded. Unconsolidated bottom.
Tidal Flat	N/A	Estuarine intertidal. Intermittently flooded, unconsolidated bottom.
Tidal Marsh	Coastal Brackish Marsh (51.100.02), Pickleweed Wetland (52.201.00)	Estuarine intertidal persistent emergent wetland. Temporarily to seasonally flooded, permanently saturated.
Seasonally Tidal Marsh	Coastal Brackish Marsh (51.100.02), Pickleweed Wetland (52.201.00)	Estuarine intertidal persistent emergent wetland. Seasonally flooded, permanently saturated.
Salt/Brackish Marsh	Coastal Brackish Marsh (51.100.02)	Estuarine intertidal persistent emergent wetland. Temporarily to seasonally flooded, permanently saturated.
Salt Flat/ Seasonal Pond	N/A	Estuarine intertidal. Intermittently flooded, unconsolidated bottom.
High Marsh Transition Zone	Saltgrass (41.200.00), Alkali Meadow (45.500.00)	Palustrine emergent or unconsolidated bed, possibly hypersaline at times

(*Juncus balticus*), irisleaf rush (*Juncus xiphiodes*), buttercup (*Ranunculus californicus*), and blue eyed grass (*Sisyrinchium bellum*).

ALKALI MEADOW Similar to wet meadows, alkali meadows are temporarily or seasonally flooded grasslands on poorly-drained, clay-rich soils. Unlike wet meadows, however, alkali meadows are characterized by salt-affected soils. The dominant vegetation is salt grass *(Distichlis spicata*), though other salt-tolerant species such as alkalki goldfields (*Lasthenia ferrisiae*), salt marsh birds beak (*Cordylanthus maritimus* ssp. *maritimus*), spreading alkali weed (*Cressa truxillensis*), shaggyfruit pepperweed (*Lepidium lasiocarpum*), and hairy gumweed (*Grindelia hirsutula*) may have also been present.

ALKALI MEADOW/FLAT Some alkali meadows were characterized by a particularly high degree of soil salinity (over 1% in the first 6 feet; Holmes and Mesmer 1901c). These areas are composed of a mosaic of alkali meadows and more sparsely vegetated alkali playas or flats (e.g., "scalds"). Saltgrass (*Distichlis spicata*) is still a significant component, but this category also includes large expanses of open, non-vegetated seasonally flooded areas (<10% plant cover) with local alkaline concentrations too high to support substantial vegetation.

OAKS AND SYCAMORES This classification includes areas not along active stream courses but with documented coast live oak (*Quercus agrifolia*) and/or California sycamore *(Platanus racemosa*). With few exceptions, the dominant tree is coast live oak. Shrubs and herbaceous cover were both documented below the canopy. Since it is unevenly specified by historical documents in this region, we were unable to specify tree density. These areas likely ranged from savanna to woodland densities. They occurred predominantly on well drained terraces and alluvial fans in the Ventura and Santa Clara river watersheds.

GRASSLAND/COASTAL SAGE SCRUB This is a general category encompassing herbaceous and shrub cover, mostly occupying well drained portions of the Ventura County alluvial valleys. Vegetation communities included in this category range from treeless herbaceous cover and coastal prairie (which may have included native perennial bunchgrasses and annual grasses, in addition to annual forbs, wildflowers and shrubs) to Venturan coastal sage scrub (including coyote brush (*Baccharis pilularis)* and California sagebrush (*Artemisia californica*)).

Riparian Habitats

WILLOW-COTTONWOOD FORESTED WETLAND This category includes large areas (over 200 acres) of wetland riparian habitat whose presence has transcended significant flood events of the late 19th and early 20th centuries. Each of these areas is well documented in the historical record as broad forested groves or marshes; many were even named (e.g., West Grove, East Grove, the Cienega). They are distinguished from other in-channel riparian areas by their size, their breadth (in some places over 3,300 ft wide), their persistence, and their notoriety. They are also described in the report as "persistent wetland riparian areas."

These areas included valley freshwater marsh and winter-deciduous riparian forest, with species extent and distribution varying by location. Some areas would have been predominantly forest stands on higher benches, while in other areas forest would have been interspersed with open wetland patches. Mixed willow forest (*Salix* spp., including arroyo willow, red willow, narrowleaf willow, sandbar willow, and shining willow), mulefat (*Baccharis salicifolia)*, black and Fremont cottonwoods (*Populus balsamifera* ssp. *trichocarpa* and *P. fremontii*), and occasional sycamores (*Platanus racemosa*) would have been present in varying proportions in these areas, in addition to wild grape (*Vitis Californica*), wild rose (*Rosa californica*), and California blackberry (*Rubus ursinus*). Freshwater marsh-associated species such as tule (*Scirpus* [*Schoenoplectus*] spp.), cattails (*Typha* spp.), sedges (*Carex* spp.), spikerushes (*Eleocharis* spp.), and rushes (*Juncus* spp.) were also present.

OTHER IN-CHANNEL RIPARIAN Since the variability of historical data precluded detailed riparian mapping for this study, most riparian habitats are included in this category. The character and distribution of these habitats varied with water availability and flood disturbance regime. At one extreme, areas of frequently flooded sandy riverwash occupied the lowest portions of the active channel, and were either unvegetated or sparsely vegetated with willow, mulefat, or alluvial scrub. At the other, established, infrequently flooded bars and islands along portions of lower Santa Paula Creek and the Ventura River supported stands of California sycamore and Coast live oak. Intermediate riparian habitats included willow forest, sycamore-alder-California bay forest (on the Ventura River; Mertes et al. 1996), mixed riparian forest, thickets of willow scrub and mulefat, and alluvial scrub (including mulefat, California buckwheat (*Eriogonum fasciculatum*), and scalebroom (*Lepidospartum squamatum*)). These patterns, while lumped in the GIS, are discussed extensively in the report.

Coastal Habitats

BEACH/DUNE Beaches and dunes are coastal habitats located immediately along the shoreline. Beaches and foredunes are sandy and sparsely vegetated, while backdunes are located inland from foredunes and are generally more stable and more densely vegetated. While foredune vegetation is mostly composed of forbs, backdunes also support some shrubs in addition to herbaceous cover.

Beach and foredune vegetation would have likely included sand verbena (*Abronia maritima*) and pink sand verbena (*Abronia umbellata*), beach bur (*Ambrosia chamissonis*), beach saltbush (*Atriplex leucophylla*), beach primrose (*Camissonia cheiranthifolia*), beach morning glory (*Calystegia soldanella*), dune lupine (*Lupinus chamissonis*), mock heather (*Ericameria ericoides*), dune buckwheat (*Eriogonum parvifolium*), and salt grass (*Distichlis spicata*). Backdunes would have likely supported coastal sagebrush (*Artemisia pycnocephala*), Heather goldbush *(Ericameria ericoides*), dune lupine (*Lupinus chamissonis*), and buckwheat (*Eriogonum* spp.), in addition to species also present in the foredune community. Scattered willows (probably *Salix lasiolepis*) were documented in dune swales south of McGrath lake.

TIDAL LAGOON (MOSTLY OPEN?) These are coastal bodies of water with a more frequent connection to the ocean, although precise historical closure dynamics are generally unknown. Subtidal communities of eelgrass (*Zostera marina*), Pacific eelgrass (*Zostera pacifica*), and surf-grass (*Phyllospadix torreyi*) occur in subtidal portions of estuarine lagoons.

TIDAL LAGOON (SEASONALLY OPEN) These are coastal bodies of water with a seasonal connection to the ocean. They are typically non-tidal during the summer, when the mouth is closed, and open during the winter, when greater freshwater flows breach the barrier.

NON-TIDAL LAGOON Mostly-closed tidal lagoons are coastal bodies of water with infrequent tidal connection. These lagoons may have salinity gradients ranging from fresh to brackish to saline, with freshwater inputs from springs and streams upslope and occasional tidal inputs. Through stratification, these lagoons may support distinct saline and fresh zones. Some lagoons may have occasionally dried out during the dry season.

TIDAL FLAT Tidal flats are unvegetated intertidal habitat, found on gradually sloping shorelines between estuarine open water and the lowest salt marshes. They are exposed between low and high tides.

TIDAL MARSH Tidal marshes occur along the perimeter of tidal lagoons, and are regularly inundated by the tides. Plant species distribution within the tidal marsh is determined largely by salinity and elevation (and thus inundation frequency); dominant plant species include Pacific cordgrass (*Spartina foliosa*), pickleweed (*Salicornia virginica*), and high marsh species such as saltgrass (*Distichlis spicata*), Parish's pickleweed (*Arthrocnemum subterminale*), and shoregrass (*Monanthochloe littoralis*).

SEASONALLY TIDAL MARSH Found adjacent to seasonally open tidal lagoons, seasonally tidal marsh shares similar vegetative characteristics to tidal marsh but with the addition of brackish emergent vegetation such as prairie bulrush (*Scirpus [Bolboschoenus] maritimus*), tule (*Scirpus [Schoenoplectus] californicus*), and cattail (*Typha domingensis*). Seasonally tidal marshes have brackish to saline hydrology, depending on season, elevation, and precipitation.

SALT/BRACKISH MARSH Found adjacent to non-tidal (mostly closed) lagoons, non-tidal brackish marsh hydrology originates largely from runoff and precipitation, with occasional dune overwash during large storm events contributing saline water. As a result, non-tidal brackish marshes can be fresher than the more marine-influenced tidal marshes, with corresponding shifts in vegetation distribution and frequency. The infrequent presence of an outlet can also make some non-tidal brackish marshes hypersaline. Dominant plant species probably overlap with high marsh plants (e.g., saltgrass), with additional presence of brackish-tolerant species such as bulrush (*Scirpus [Bolboschoenus]* spp.), tule (*Scirpus [Schoenoplectus] californicus*), and cattail (*Typha domingensis*). Little is known, however, about the pre-modification plant community of these marshes.

SALT FLAT/SEASONAL POND/MARSH PANNE Tidal marsh pannes or salt flats are unvegetated, open depressions within tidal marshes. They are irregularly or seasonally flooded. Their hydrology (alternately flooded and dry) and evaporate concentration precludes most plants from establishing. Some seasonal ponds may have occasionally retained open water year-round.

HIGH MARSH TRANSITION ZONE The high marsh transition zone is the ecotone between estuarine and terrestrial communities, with habitats intergrading between upland habitats and the tidally-influenced saline habitats of the coast. High tidal marsh species (e.g., saltgrass) overlap with alkali meadow species and freshwater (non-tidal) species. This area generally receives overflow by extreme high tides.

2 • HISTORICAL BACKGROUND AND CONTEXT

It was late in the afternoon of the next day ere we started for our seven miles ride to Saticoy. Our way led through the upper portion of one of the finest avenues in California…Clinging to the road on both sides are extensive orchards of apricot and walnut trees, while countless acres of beans stretch away to the mountains on one hand, and to the river on the other.

And to think! When I was a little girl this was all a vast forest of bee-haunted mustard-blooms, in which the traveler would get lost as easily as in an Indian jungle.

—NINETTA EAMES 1889,
TRAVELING FROM SANTA PAULA TO SATICOY;
AUTUMN DAYS IN VENTURA

Ventura County has a complex history of occupation, cultivation, and water use. Land and water use both reflect physical characteristics of the landscape (e.g., sugar beet cultivation indicates presence of alkaline soils) and affects landscape character (e.g., groundwater pumping decreases riverine flow). Because of this, understanding the cultural trends in the county is essential to interpretation of changes in landscape patterns and ecological function that have occurred over the past 250 years.

Since other reports have provided detailed histories of land and water use trends in the mid- to late 20th century (e.g., Schwartzberg and Moore 1995, AMEC 2004, Stillwater Sciences 2007b), we do not cover it again here (fig. 2.2). Instead, we focus on 19th- and early 20th-century trends in population, agriculture, irrigation, and resource use that provide context for the broad ecological and hydrologic changes occurring in the county concurrent with the changes detailed below.

Early Settlement History: Ventureño Chumash

The Chumash have been present in the Santa Barbara Channel region for about 9,000 years (Timbrook 2007). Ventureño Chumash occupied most of the study area, including the Ventura River valley, the Oxnard Plain, and the Santa Clara River valley to around Castaic (Van Valkenburgh 1935). The Uto-Aztecan Tataviam lived in the upper portion of the Santa Clara River watershed.

An estimated 15,000 Chumash lived in the Santa Barbara Channel area (including the Channel Islands) in 1769, at the time of Crespí's expedition

Fig. 2.1. Planting lima beans on the Dixie Thompson Ranch, near Ventura. This photo (opposite page), taken around the turn of the 20th century, shows a team in the process of planting lima beans, and is part of a series of such photos. Other photos in the sequence state that the rows were 1.75 miles long, and that teams could plant 150 acres a day. (Unknown ca. 1900c, courtesy of the Society of California Pioneers)

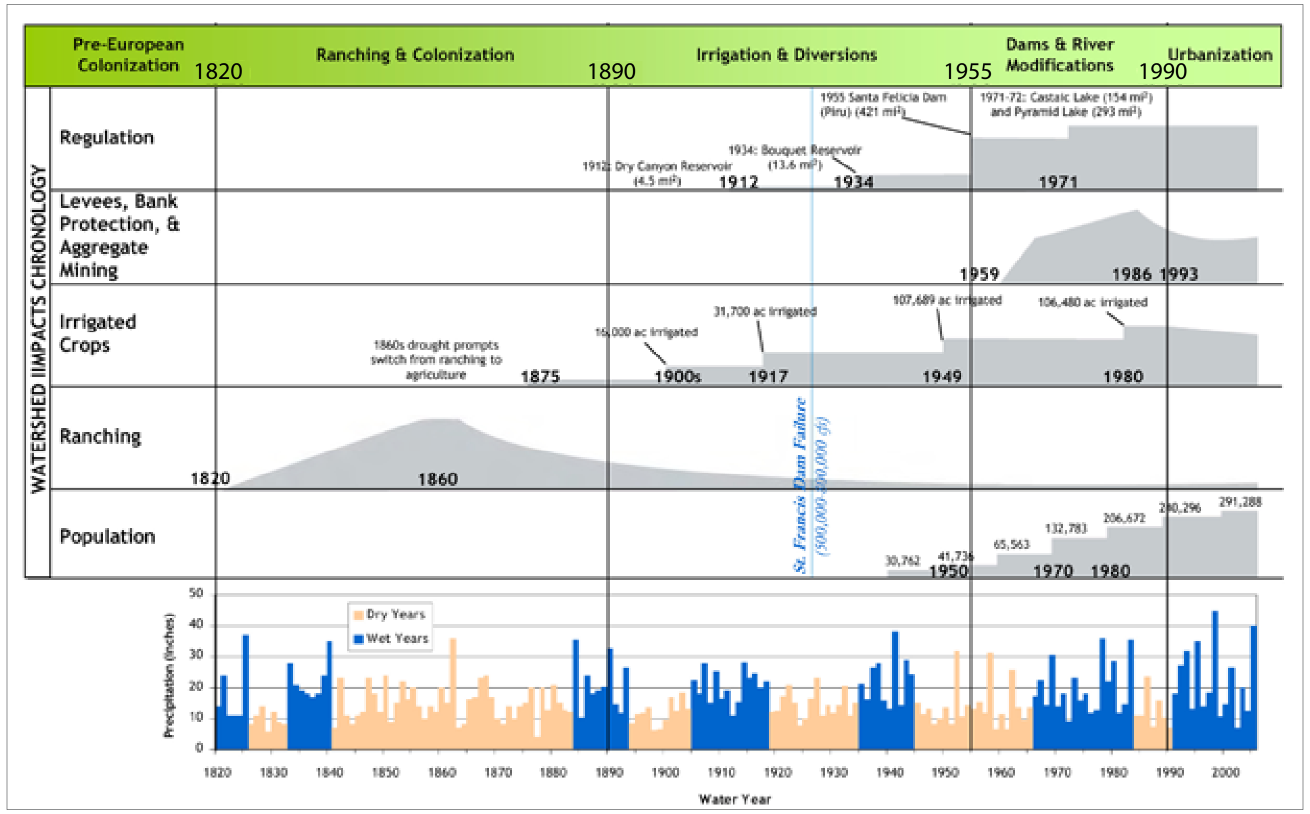


Fig. 2.2. Chronology of land and water use modifications, population, and precipitation on the lower Santa Clara River, 1820-2005. This graphic, produced by Stillwater Sciences (2007b), provides hydrologic and land use modification context useful in the interpretation of historical sources. (Precipitation data extended and adapted from Freeman (1968) by Stillwater Sciences (2007b); graphic courtesy of Stillwater Sciences)

(Timbrook et al. 1982). On a sea voyage in 1542, Juan Rodríguez Cabrillo noted a seaside town which he called Pueblo de las Canoas, a large village with many canoes (in Kelsey 1986). This site has been variably identified by researchers as near Mugu Lagoon (Wagner 1941, Kelsey 1986, King 2005) or near Ventura (Bancroft 1884, Davidson 1887, Bolton 1959; see Moriarty and Keistman 1963 and Kelsey 1986). When Crespí's party traveled through the Ventura region in 1769, they noted a number of large Chumash settlements: a village of about 200 near the confluence of Sespe Creek and the Santa Clara River (Costansó mentions that including this village, he saw 500 Chumash between Piru and Sespe); a village near the Santa Clara River at its confluence with Santa Paula Creek; a large village near Saticoy Springs; and a large village near Ventura (Costansó and Browning 1992, Crespí and Brown 2001).

A large number of other important settlement and use sites have been identified by archaeologists and ethnographers. In particular, ethnographer and linguist John Peabody Harrington worked closely with the Ventureño Chumash during the early 1910s, recording information about places and place names. Harrington's research documents a rich landscape of place names for springs, lagoons, and other natural features, as well as settlement sites. Sites of particular note recorded by Harrington and other researchers were located all over the county, including near Ventura, Matilija, Saticoy Springs, Montalvo, El Rio, Somis, Springville, Hueneme, Mugu, Santa Paula and Sespe creeks, Camulos, and Castaic (Harrington 1913e, Van Valkenburgh 1935).

The Chumash made extensive use of a wide variety of plant species in the county, as documented in detail by Timbrook (2007). Mission friar José Señán noted in a report that the Chumash at the Mission still ate the "wild seeds and fruits which they love dearly and cannot forget" (Señán 1822). In addition to supplying food sources, plants were also used for producing material items. Riparian plants along the Santa Clara River, such as carrizo grass (*Phragmites communis*), giant reed (*Arundo donax*), tule, and cattail were used by the Chumash to create housing, boats, and other objects (Schwartzberg and Moore 1995, Timbrook 2007). Tule from the mouths of the Santa Clara and Ventura rivers was used to thatch houses (Harrington 1986b), and canoes were stored in the tule marsh at the mouth of the Ventura River (Harrington 1986b, Timbrook 2007). (One of Harrington's informants recalled that canoe builders "bent tule that was growing there on both sides over the canoe" to shade the boat.)

Along the margin of the river Buenaventura are many small gardens belonging to the Indians, where they raise fruits and vegetables…

—ROBINSON 1846

Deliberate, systematic burning of coastal grassland was also used as a method to create food sources, as documented in the Santa Barbara Channel region by a number of historical accounts (cf. Timbrook et al. 1982). Santa Barbara Mission records from 1793 indicate that Chumash to the north of Ventura County frequently burned the region's grassland, complaining that the Chumash "set [fire] to the grazing lands every year" (Arrillaga 1793, in Stewart et al. 2002). The extent of these practices in the Ventura valley areas, and their effects on vegetation cover, are unknown. It is possible that cessation of native burning may have increased shrub cover in areas where burning may have favored bunchgrass species (e.g., on the alluvial portions of the Oxnard Plain). However, this is impossible to determine from our data set, and is complicated by the impacts of grazing in many areas during the first half of the 19th century, which likely served to inhibit shrub/scrub growth.

San Buenaventura Mission and the Ranching Era (1782-1877)

The San Buenaventura Mission was founded in 1782, introducing stock-raising and small-scale agriculture to what was to become Ventura County (fig. 2.3). Fruit trees and small gardens of vegetables such as melons, corn, and potatoes (Vancouver [1798]1984, Señán 1822) were planted near the Mission, along the lower Ventura River, and in the Santa Paula area (Bowman 1947). By the 1820s, the Mission also tended cultivated fields on the eastern portion of the Oxnard Plain, likely the Las Posas/Calleguas region (Uría 1828). ("Las Posas" means a "pool" or "water hole," features often associated with springs; Gudde and Bright 1998.)

Stock (notably cattle and sheep) ranged over large portions of the Mission property, including the Ventura and Santa Clara River valleys and large

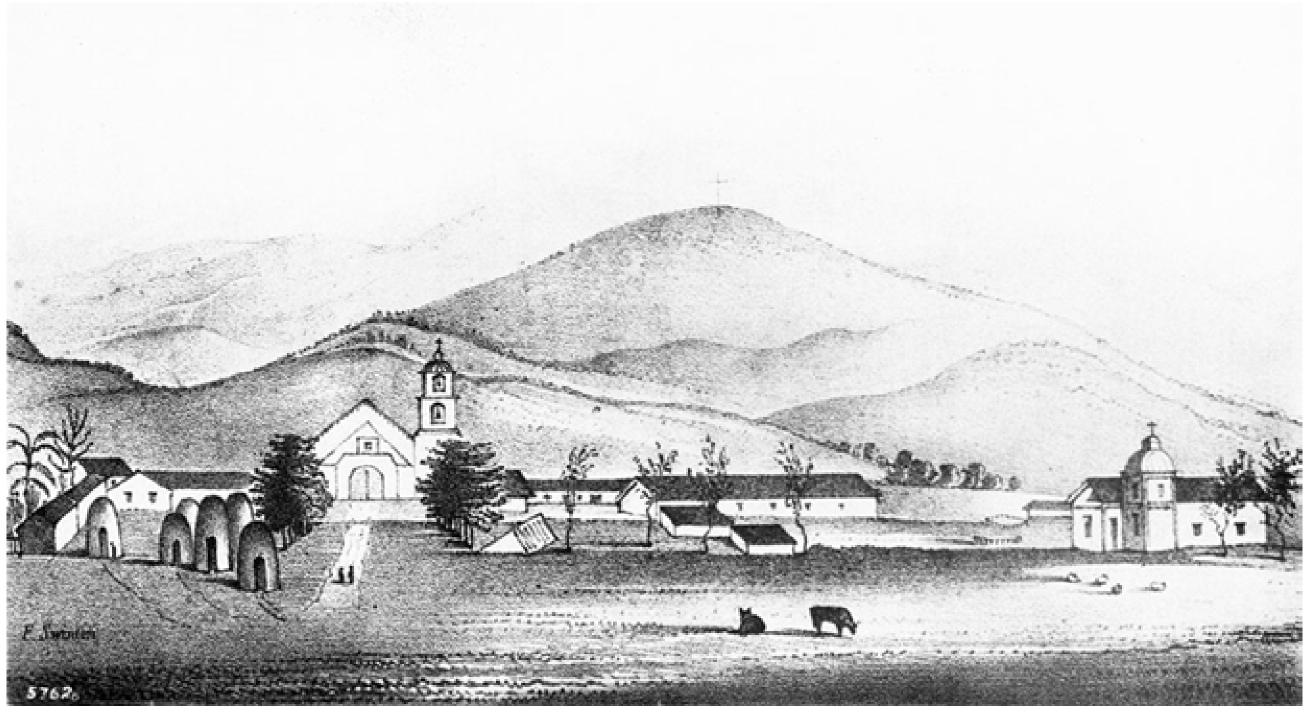


Fig. 2.3. Mission San Buenaventura, ca. 1829. This remarkably early sketch, from Alfred Robinson's book *Life in California*, shows the mission complex as it existed before secularization. Cows graze in the foreground, with what appear to be sheep further back. Two people are on the path to the church complex. In the book Robinson describes his visit to the mission: "At dinner the fare was sumptuous, and I was much amused at the eccentricity of the old Padre…After concluding our meal, we walked with him to the garden, where we found a fine fountain of excellent water, and an abundance of fruits and vegetables." (Text: Robinson [1846]1947; Image: Robinson ca. 1829, courtesy of the USC Digital Archive and the California Historical Society)

portions of the Oxnard Plain (Bowman 1947). The Mission's main site for grazing and breeding cattle was in the Sespe-Pole Creek region (modern day Fillmore; Señán 1822, Van Valkenburgh 1935), though significant numbers of cattle also grazed near Piru (which Señán called "the consolation of this Mission" for its benefit to cattle). Sheep were kept in four flocks in the Ventura River valley north of the Mission (Señán 1822) and also near the current location of the Olivas adobe near the Santa Clara River (Harrington 1913e). Fray José Señán described the extensive ranging of the Mission's cattle:

> The considerable numbers of animals belonging to this Mission do their grazing, in large part, just above the beach. When the pasture there is exhausted or dried up, the cattle go in search of more plentiful or better grazing elsewhere, following the beach inland and spreading out toward Mugú [Santa Paula]. The animals farthest from the beach make their way to a place called Saticoy, and when the grazing there is exhausted (that locality not being very productive and most of the growth being sword grass), they roam farther up to the meadows along the river and through a rather wide canyon into Sécpey, some bands of mares penetrating as far as Camulus. (Señán and Santa María 1804)

At the Mission's peak inventory in 1816, holdings included over 41,000 head of stock, including about 23,000 cattle and 12,000 sheep (Bowman

1947, California Missions Resource Center 2010). Around this time (1815), from 45 to 120 cows were slaughtered per week (Señán 1815). This provided an overabundance of meat, and since cows were kept predominantly for their tallow and hides this extra meat was simply discarded: "the large parts of the meat are taken in carts to the fields and burnt, since there is no one to collect them and there is plenty of fresh meat in the houses" (Señán 1815).

A drought around 1828-9 diminished the Mission's cattle and sheep herds (Lynch 1931, Smith 1972). After the secularization of the California Missions in 1834 holdings were further reduced, until by 1842 a traveler noted "at most, one thousand head of cattle, large and small"(de Mofras [1844]1937). (Interestingly, de Mofras also noted that at this time Mission fields were irrigated with water from the Santa Clara River.) The Mission was illegally sold in 1846 to José Arnaz.

By this time, though, former Mission territory had been largely divided into large ranchos amongst Spanish and Mexican families. By the time the Mission was sold in 1846, what was to become Ventura County had been divided into 19 ranchos (Triem 1985), many of which were heavily stocked with cattle. One resident recalled that in 1850 "the whole country was overrun with cattle…The cattle were so thick and plentiful in those days that vaqueros would have to go ahead of parties traveling through the country to clear the way for them" (Sheridan 1912). By 1860, there were more than 90,000 cattle and 65,000 sheep in Santa Barbara County (including Ventura County, which was not formed until 1873; Gregor 1953; fig. 2.4). (While the numbers cited above seem large, they account for modern-day Ventura and Santa Barbara counties, quite an extensive area.)

The drought of 1863-4 killed massive numbers of cattle all over California. Lack of pasture and water caused thousands of cattle to die of starvation, or be slaughtered in anticipation of the lack of food and water. In Santa Barbara County, a newspaper article noted that 18,000 cattle "have been slaughtered for their hides and tallow, and from one-third to one-half of the remainder have died by starvation" (*Daily Alta California* 1864). (Others report a much larger figure, stating that 2/3 of the County's cattle died; cf. Thompson and West [1883]1961.) This effectively marked the end of extensive cattle raising in the area. By the 1870 U.S. Census, only 10,000 cattle remained in Santa Barbara County (Gregor 1953).

As a result of this sharp decline in cattle numbers, after 1864 sheep ranching became the dominant land use in the region, in part because of their greater tolerance to drought. In 1870, about 190,000 sheep grazed in Santa Barbara County, nearly three times the number in the county a decade earlier. This was consistent with a wider statewide trend: while the 1850 census recorded under 20,000 sheep, by 1876 (the peak of the industry) there were over 6,400,000 sheep in the state being raised for meat and wool (Johnston and McCalla 2004).

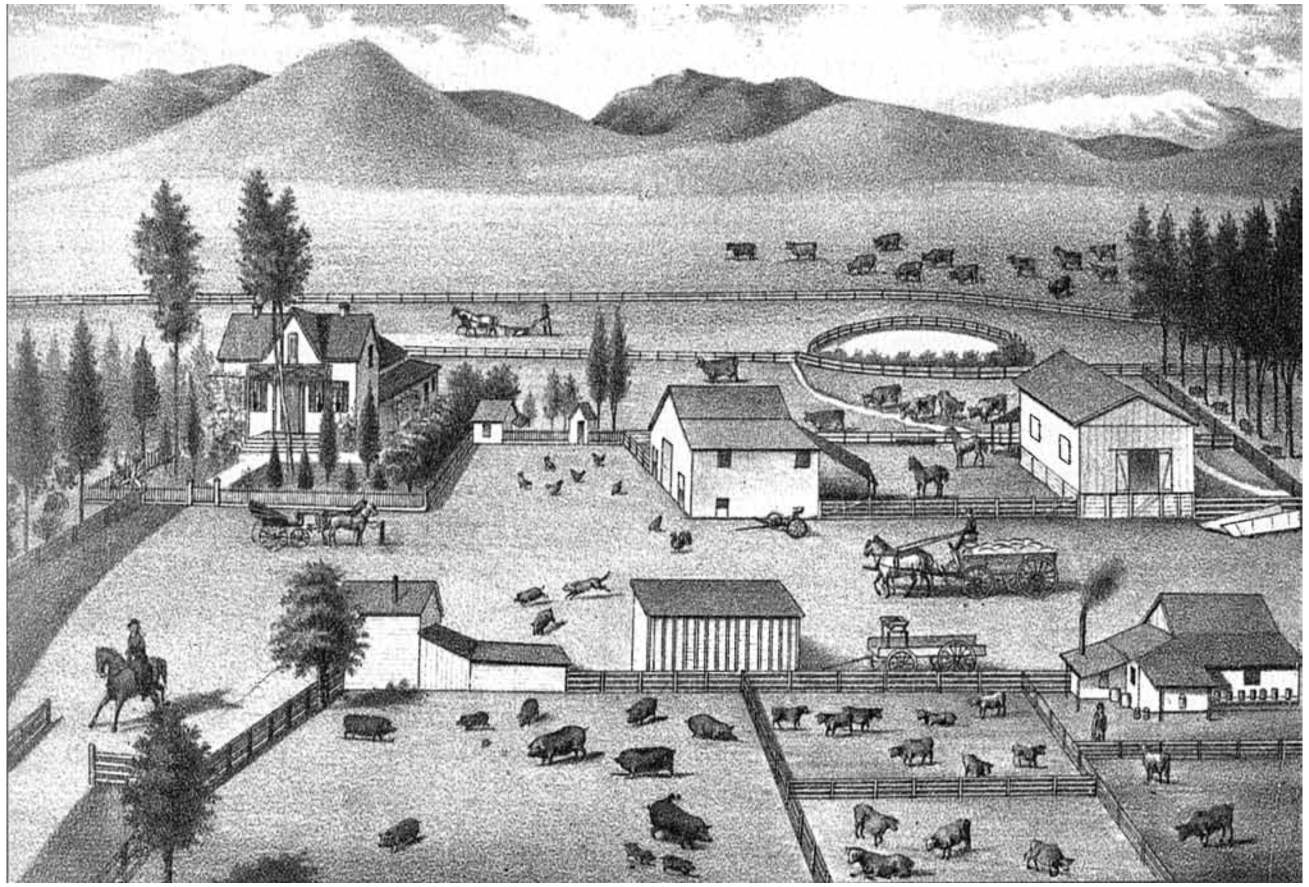


Fig. 2.4. Cattle, horses, pigs, and chickens on the George G. Sewell ranch near Santa Paula, 1881. Unfenced cattle graze in the background, and a dog chases a pig in the enclosure. The farm had 400 acres under cultivation and an additional 500 acres for grazing, including 1,000 hogs and 20 cattle. While the heyday of large cattle ranches had ended, this farm still had a number of stock. (Thompson and West [1883]1961)

The drought of 1877 marked the end of the large-scale stock raising in the county, and decimated the massive sheep flocks of the previous decade:

> The year 1877 was very dry. In Santa Barbara county, hay was forty dollars a ton. I have heard men say, with a sigh, "It was the dry year of '77 that broke me up. My sheep all died." Many a man grew gray that year, as he saw his living withering away. (Rindge 1898)

After this, Ventura County ranchers transitioned to grain farming. Large-scale sheep and cattle ranches, while still present in the county in reduced numbers, were largely pushed onto less desirable lands, either upland areas or uncultivatable or remote lands. An exception was in the upper (Los Angeles County) portion of the Santa Clara River valley, where cattle and sheep grazed near the river into the 20th century (Tait 1912) and still do today. In some areas, sheep and cattle pastured Ventura uplands most of the year, and in valley floor fields during the winter (Nelson et al. 1920, Gregor 1951).

The impact of early cattle and sheep grazing on historical lowland habitats in Ventura County is unknown. At the peak of Mission stock holdings in 1816, stock ranging densities in the county reached an estimated one head for every four to five acres of grazing land (Bowman 1947). This may be considered a relatively low to moderate stocking density: in the late 19th century appropriate stocking densities for cattle in Southern California were considered to be five acres per head for "valley land," and approximately one acre per head for sheep (Bancroft et al. [1890]1970). Furthermore, these standards were based on American cattle, which were only introduced to Southern California by the 1860s (Adams 1946) and were much larger and required more forage than their Mexican counterparts (Cleland [1941]1990, Burcham 1956). The Mexican cattle ubiquitously raised by the Mission and early ranchos would have required less land than the above densities. Impacts of Mission-era cattle grazing were likely limited by the relatively small size and moderate grazing intensity of Mission-era cattle.

However, by the 1850s and 1860s it is possible that cattle and sheep grazing may have had significant effects on ecological and morphological processes in the county. Potential effects of early livestock grazing include alteration of the distribution and type of valley floor habitats (e.g., relative proportion of herbaceous cover and scrub and increased spread of invasive plant species), changes in rainfall runoff and erosion (and a resultant increased sediment supply to Ventura County waterways), and an increase in the depth and density of barrancas (Stillwater Sciences 2007b). These effects are treated only peripherally here (see pages 18 and 172).

A few sources do describe the effects of livestock on portions of the county's pasturelands. Hassard (1887) described some of the effects of the upland shepherding in Ventura County common subsequent to the drought of 1877: "herders… drive thousands of sheep over the government wild lands, and, when they have stripped a region, put the torch to the brush, to improve the pasturage for the next season." Rothrock (1876) described the immense changes wrought by sheep on the Conejo Ranch during the 1876 dry period, noting that

> Hitherto sheep-raising has been the principal interest of the ranch, and of this we had the most indubitable evidence in the appearance of the land, everywhere pastured off the very surface. How long it will take California to regain the rank pasturage the State once had is a question.

Up Sespe Canyon, Rothrock described "a country where in the most accessible spots the soil had been stripped of the meager supply of herbage it perhaps once possessed." While this was an exceptionally dry year, this type of heavy grazing would have likely altered the hydrodynamics of Ventura County streams.

Early Commercial Agricultural Development (1878-1920)

After the collapse of the large sheep ranchos of the 1860s and 1870s, farmers quickly began to switch to other livelihoods. Barley, which thrived in the foggy coastal areas better than other grains, had been cultivated on the Oxnard Plain since the 1860s (Storke 1891, Gregor 1953) and was a major crop of the Ventura lowland areas. Descriptions of the lower Santa

And '77, that ghastly year, child as I was, is still with me, when the relentless sun looked down from cloudless blue skies and set red in the west day after day, when the hills were dry and brown from year's end to year's end, and the lowing of cattle being driven out to the country and the bleating of the dying sheep filled my heart with sorrow…

—Francis 1912

If the stranger ever wondered where Boston got its beans, he found out now, as the land fell away to the Pacific with the soil becoming richer and finer as it expanded into the broad plains of Santa Paula and Hueneme, green for miles with grain and springing corn and beans…

—VAN DYKE 1890

Clara Valley and Oxnard Plain from the mid- to late 1870s describe an agricultural landscape dominated by barley (and, to a lesser extent, corn on the moister portions of the plain):

> [traveling west from Conejo], we crossed the western end of the Santa Clara Valley, and found the farmers engaged in harvesting their barley… Large fields of good corn were seen. It was just in tassel, and gave abundant promise of a heavy crop. It is hardly overreaching to say that on that day we saw thousands of acres actually overrun with wild mustard, which attained a height often of 8 or 10 feet…In some places, indeed, it might well be doubted as to whether it was a mustard or barley field we were passing, both of which were luxuriant enough. (Rothrock 1876)

> [describing "the section east of the Santa Clara River"] As we drove through that region, it seemed as though we were gazing upon a vast sea of grain, and here and there a dark spot looming up like a distant island, and contrasting strongly with the billowy waves of green barley on every hand. The dark spots marked the tracts of corn ground… (Sheridan 1878)

Lima beans were first planted on the Oxnard Plain around 1875 (Storke 1891; fig. 2.5). Like barley, the beans grew well in the fog on non-alkaline lowland soils (Holmes and Mesmer 1901c, Gregor 1953). By the late 1880s, beans had become a major commercial crop for the region; one account describes "one vast field of green and gold—ripening wheat and barley and growing corn and beans" (Oge 1888). A few years later, beans had surpassed even barley in prominence; Ventura County was described in 1891 as "preeminently a bean county" (Storke 1891) and one observer noted "seemingly limitless stretches of beans" (Eames 1890). Oxnard sand and Oxnard sandy loam, the two major soil types mapped on the Oxnard Plain in 1901, were "when free from alkali…the very best for the growing of lima beans. Almost every foot of such land was planted to this crop year after year, with only an occasional crop of barley planted for rotation" (Holmes and Mesmer 1901c). Beans continued to be a major product on the Oxnard Plain well into the 20th century; in 1951 Ventura County produced over 25% of the large lima beans in the United States (Gregor 1953).

However, in 1898 the establishment of the Pacific Beet Sugar Company's sugar factory shifted the agricultural dynamics of the county (fig. 2.6). Sugar beets thrived on the plain's alkali soils, allowing cultivation of land which had previously been only slightly productive or not farmed at all:

> A few years ago only indifferent crops of barley were grown on the greater part of this soil which was considered practically worthless, as quite often the barley hay contained such a great amount of salt that stock would not eat it. Now a great deal of the alkaline portion of this soil is planted to sugar beets with surprising results. (Holmes and Mesmer 1901c)

Only three years after the creation of the factory and the city of Oxnard, sugar beets were considered second in importance in the county only to the bean (Holmes and Mesmer 1901c); in 1913 beets and beans were called "the staples of the county" (Chase 1913). Beets were grown on the low, alkali

Fig. 2.5. "Dixie Thompson's bean threshing," ca. 1899. Workers threshing beans on the Oxnard Plain. (Unknown ca. 1899, courtesy of the California State Library)

Fig. 2.6. Hauling wagon loads of beets on the Oxnard Plain, ca. 1900. (Unknown ca. 1900b, courtesy of Jeff Maulhardt)

land that would not support other crops, while beans were often grown on slightly higher alluvial deposits (Tait 1912). A crop rotation of beans and beets (or beets and barley on land too alkaline for beans) was often practiced in lowland areas, since the beans fixed nitrogen for the beets and the beets removed some alkali from the soil (Gregor 1953). Beans, beets, and barley remained the primary crops for the region until around 1920. By 1917, barley was only grown "on soils less desireable [sic] for other crops and in remote situations" (Nelson et al. 1920), and sugar beet planting peaked in 1919 (Schwartzberg and Moore 1995).

The extensive acreage of the Oxnard Plain meant that the agricutlural statistics for Ventura County essentially reflected the trends of the Oxnard Plain. Through the 1870s, 1880s, and 1890s, beans, beets, and barley were the dominant crops in the county. Barley and beans were also grown at this time in inland valley areas, in addition to wheat in areas not influenced by the coastal fog (such as the Ventura River valley; Hampton 2002).

The lack of fruit culture in the region in the 1870s, and in particular on the Oxnard Plain, was notable to travelers used to seeing orchards in other parts of Southern California. In 1876, botanist J. T. Rothrock (1876) wrote that after traveling along the Oxnard Plain, "What more than anything else surprised me in the day's march was that no attention was paid to fruit-culture. I find recorded in my notes that not a single fruit-tree was seen that day. There was no apparent reason for this." The reason, of course, was the alkaline lowland nature of most of the plain.

While (as Rothrock observed) alkali concentrations and seasonal flooding precluded fruit culture on the plain in the 19th century, by the 1890s orchards began to proliferate in a few areas in the Santa Clara River valley. Early experiments in 1870s, notably around Santa Paula, had proven that walnuts and fruits (such as oranges, nectarines, peaches, and apricots) could succeed in the county (*Ventura Free Press* 1878a, Gregor 1953, Heil 1975, Hampton 2002). One newspaper mused that "some day the whole of the Santa Clara Valley will be a great fruit garden instead of, as now, a barley field" (*Ventura Signal* 1874a); another projected that by about 1880 the county would have fruit available to export (*Ventura Free Press* 1878a). However, fruit culture during this period was largely limited to the Santa Paula (and to some extent, Sespe) region; Rothrock (1876) noted that "With the exception of the Cumules [sic] Ranch…but little cultivation is attempted in the valley above Santa Paula."

The grain was knee-high, the groves were in bloom, the wildflowers carpeted all the fields.

—EDWARDS ROBERTS, 1886, SANTA PAULA

By the mid-1880s, orchards had become more prevalent in the lower Santa Clara River valley (fig. 2.7). One traveler journeying upriver from Ventura described "level fields, some planted with grain and flax, others covered with fruit-groves" (Roberts 1886). Another noted "extensive orchards of apricot and walnut trees…[and] countless acres of beans" between Saticoy and Santa Paula (Eames 1889). ("And to think!" Eames further writes, "When I was a little girl this was all a vast forest of bee-haunted mustard-blooms, in which the traveler would get lost as easily as in an Indian jungle.") Residents of the county who had been present in the 1870s were amazed by the agricultural changes that had taken place in only a decade:

> The individual who viewed the broad, treeless, uncultivated extent of the Santa Clara valley of Ventura county, less than twelve years ago, would now marvel at the transformation that has been wrought during this comparatively short period in that flourishing section. (*Ventura Free Press* 1883a)

> Riding from Santa Paula to San Buenaventura a short time ago, I could not but mark the difference in the style of farming now, in the Santa Clara valley as compared with ten years ago. Then it was nearly all barley, and scarcely a clean field of that, so abundant was the mustard, sometimes taking possession of hundreds of acres. Now it is very different. Cultivated crops are raised to a great extent, and the land is considered too valuable to give over to weeds and everywhere is carefully farmed. Beans, corn, and flax are raised largely, and hundreds of acres have been put to fruit trees. (*Pacific Rural Press* 1886)

The expansion of the Southern Pacific Railroad to Ventura (1887) helped provide a wider market for the burgeoning commercial agriculture of the county and spurred development of both beans and orchards in the Santa Clara River valley (Warner 1891, Gregor 1953). Many towns sprung up along the railroad in the Santa Clara River valley, such as Montalvo, Fillmore, and Piru. While Ventura county was still considered "bean country," it was clear that fruit growing would be the next wave of agriculture in many parts of the valley (Storke 1891). In 1891, a *Ventura Free Press* article opined that "the days of raising barley, corn and potatoes for market, as in days gone by in the Fillmore, Sespe, and Bardsdale sections of Ventura county are numbered. It is essentially a fruit section and the past few years and particularly the past year has seen the convertion [sic] of fields, heretofore given up to the commoner cereals, planted to fruit trees" (*Ventura Free Press* 1891c).

Limoneira Company began growing citrus on a large scale around Santa Paula in 1890; by 1920, citrus had become a dominant crop of the region (Gregor 1953, Schwartzberg and Moore 1995). As artificial drainage (beginning in 1918) and irrigation began to lower the water table and decrease the alkalinity of parts of the Oxnard Plain in the 1930s and 1940s, farms in this area began to convert former beet and bean acreage to citrus and walnuts (Gregor 1953). For detailed information on agricultural trends after 1920, see Gregor (1951, 1952, 1953) and Schwartzberg and Moore (1995).

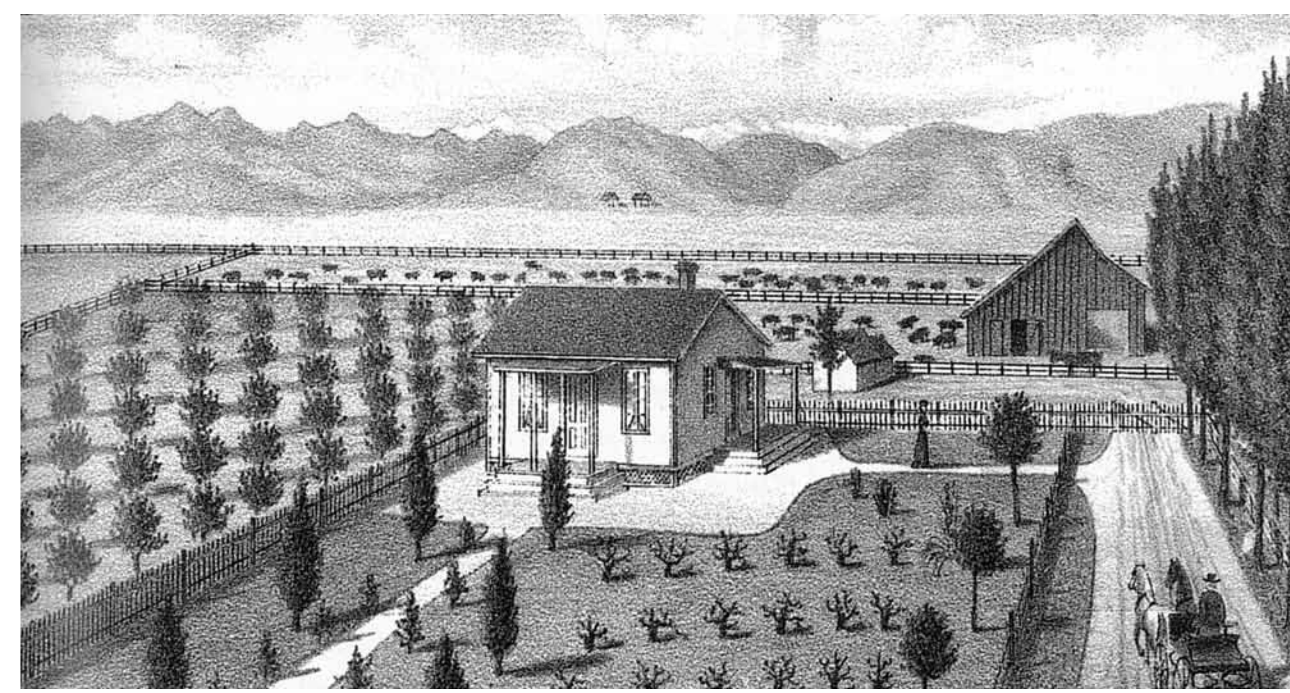


Fig. 2.7. Young orchard on J.H. McCutcheon's farm near Santa Paula, 1883. Young orchard trees—less than a decade old—are shown surrounding the McCutcheon home. Many of these orchards were planted on the site of the barley farms of the previous decade. (Thompson and West [1883]1961)

Hydromodifications: Surface Diversions and Groundwater Extraction

The history of irrigation in Ventura County has been extensively covered by others (Gregor 1953, Freeman 1968, Schwartzberg and Moore 1995). For detailed information on water use in the county, please refer to these texts. What we provide here is a brief overview of surface water use and groundwater extraction as context for the historical data discussed throughout the report.

To address the water needs of Mission residents and their fields, in the early 19th century (ca. 1805-1815) an aqueduct was built bringing water from the Ventura River near the confluence of San Antonio Creek to the Mission and its fields (CERES 2004). The aqueduct, which was destroyed during the floods of 1861-2 and 1866-7 (Greenwood and Browne 1963), was the predominant component of the larger Mission water system. In addition, the Mission used three reservoirs for water storage, two about three miles north of the Mission and one near Santa Paula (Uría 1828). The Mission also diverted water from Santa Paula Creek to irrigate fields in that area (Freeman 1968). Surveyor W. M. Johnson, in a U.S. Coast Survey report, notes that the Ventura River valley is "thoroughly irrigated by water from the river of the same name, which is carried to every part of it by means of ditches" (Johnson 1855a). Saticoy Springs also provided a year-round source of water (*Ventura Signal* 1871b, Freeman 1963).

The mission aqueduct supplied water to the city of Ventura through 1862; after its destruction during that year's floods, water was hauled in barrels from the river (Triem 1985). This was common practice after the secularization of the mission and before the extensive construction of ditches, when many early residents relied on surface water hauled from perennial reaches of Ventura County waterways for domestic use. Anticipating the completion of the Farmers Ditch, one newspaper article celebrated that residents of the area north of the Santa Clara River (around Ventura) "shall not have to buy barrels and haul water from the river or Saticoy twice a week or thrice—the year round" (*Ventura Signal* 1871b). (After its construction, if the Farmers Ditch failed to produce water—such as during the drought of 1876-7—residents would still resort to hauling water; *Ventura Signal* 1876b). Sheridan (1926) recounts that Egbert's Spring (north of downtown Ventura and east of the Ventura River; Barry 1894) used to provide water for domestic use for Ventura city during the early American period: "In the early days of the American occupation, the water of the spring was hauled on a wagon, in barrels, to the back doors of the residences of the settlers, at a cost of 25 cents per barrel. That was the drinking water of San Buenaventura." When artesian water was found on the Ventura side of the Santa Clara River in 1898, a newspaper article noted that "they have been hauling water in that vicinity for thirty years" (*Pacific Rural Press* 1898). Farmers on the Oxnard Plain also hauled water in barrels from the Santa Clara River (Gregor 1952).

From the mid-1860s on, more substantial development of surface water diversions occurred on Ventura County waterways. Flow from perennial reaches of rivers and creeks was transported to fields and for domestic use. An 1864 map of the Camulos area shows a ditch leading to fields and vineyards from the perennial reach of the Santa Clara River about a mile upstream (Sprague 1865). This was likely one of the first diversions from the river (Freeman 1968). By the end of the 1870s, however, an abundance of canals brought water to fields. While many of these ditches had their sources or heads on tributaries (notably Santa Paula, Sespe, and Piru for the Santa Clara River, and San Antonio Creek along the Ventura River), others tapped into the Santa Clara River and Ventura mainstems (Crawford 1896).

These ditches brought water often long distances from perennial reaches near Santa Paula and Sespe creeks down to fields and population centers in need of water (fig. 2.8). The Farmers Ditch (1871) was 16 miles long, and brought water along the north side of the Santa Clara River from a branch of the river above Santa Paula Creek down to Prince Barranca (Hall Canyon), just east of Ventura (*Ventura Signal* 1871b, Freeman 1968). (One old-timer recounted to Vern Freeman (1968) that any extra water from the ditch was "disposed of" in the barranca.) The Santa Clara Irrigating Company's ditch (1871) traveled 12 miles, bringing water to farmers

Fig. 2.8. Diversion ditch from Santa Paula Creek, ca. 1900. Surface diversions, such as this ditch taking water from Santa Paula Creek downvalley, brought water from areas with abundant surface flow to drier portions of the valley. (Unknown ca. 1900a, courtesy of the Santa Paula Historical Society)

At Satacoy [sic] we stopped for supper. From the excitement around the station and the water running down the street I thought an irrigating dam had sprung a leak; but a flowing artesian well had been struck instead, and its bursting forth had caused the commotion. These wells are the life of the country. There is much jealousy among rival settlements, and when one develops a copious flowing well it means beans, and walnuts; grain, vegetables and fruits, and the people shout with an exceeding joy thereat. They bite their thumbs at their envious neighbors and boast vaingloriously. This feeling is not known in the East, where the rain falls on all alike, and the land is all taken up. Here water rights go with the land, and when water in flowing quantities is found it means wealth to that section and the selling of land at good prices.

—Kenderdine 1898

south of the river from near the west end of South Mountain (southeast of Saticoy) to near Hueneme (Freeman 1968). The Cienega Ditch (ca. 1874) diverted water from the river near the marsh (or *ciénega*) east of Fillmore. On the Ventura River, the Santa Ana Water Company built a ditch about seven miles long from the perennial reach around the Ventura River/San Antonio Creek confluence along the route of the old Mission aqueduct to supply water to the city of Ventura (Triem 1985).

The development of an artesian water supply on the Oxnard Plain beginning in the early 1870s changed the hydrologic landscape of Ventura's lowland areas. While several springs, wetlands, and ponds were present along the eastern boundary of the Plain (i.e., in the Calleguas Creek drainage), there was very little potable water available in the main section of the plain (Thompson and West [1883]1961; see Chapter 5), and artesian wells transformed the non-alkaline portions of the lowland into a desirable farming region. The first artesian well in the county that we found evidence for was drilled near Saticoy in 1868, and was only 18 feet deep (*Daily Alta California* Sept 16, 1868). On the Oxnard Plain, artesian wells were first drilled the same year the town of Hueneme was founded (1870). By 1871, artesian wells were proliferating on the Plain within the artesian zone, which included much of the plain (very roughly) below Highway 101 (Schuyler 1900, Lippincott ca. 1930; see fig. 5.3). Artesian wells were also drilled in the bed of Calleguas Creek (*Ventura Free Press* 1878c). By 1899, there were at least 200 artesian wells in the artesian belt south of the Santa Clara River (Schuyler 1899). While wells were also drilled in the Santa Clara River valley, these were largely reliant on pumping.

The effects of surface water diversions and artesian development on riverine flow and groundwater levels were noted by the early 1880s. Around 1894, all the dry season flow of Piru Creek was being diverted for irrigation (Lippincott ca. 1894). By 1912, it was asserted that all the summer surface flow of the Santa Clara River was diverted for irrigation (Tait 1912).

In addition, groundwater extraction likely contributed to changes in surface water levels, possibly shifting previously perennial stream reaches to intermittent flow (Hanson et al. 2009). An 1883 article from the *Ventura Free Press* described some of the perceived impacts of groundwater extraction on the Oxnard Plain. While it is unclear what role artesian wells on the plain actually played in causing these effects on groundwater levels, the effects are interesting in and of themselves:

> The people living on both sides of the Santa Clara, between where the water of the river at a point below Camulos Ranch down a short distance above the Sespe Creek, have been wondering why, their surface wells are failing year by year since about 1877—the time when the artesian well boring was begin [sic] on a large scale on the Colonia. Since the six large wells lately bored in the Las Posas, for the Hartman ditch, the water has sunk nearly 2 feet in these surface wells, and the Scienega, which was formerly a marsh, that would shake a rod from a man walking over it, is now dry enough to plow. The same volume of water is seen, below the Camulos Ranch, as in former years, and it is thought that the artesian well-boring on Colonia is these [sic] cause of the decrease of these surface wells in and about the Scienega. (Ventura Free Press 1883b)

The Colonia…Its abundant supply of water through its artesian wells give it an immense advantage over any part of the country.

—Ventura Signal 1876a

Similar effects were felt on the Oxnard Plain. By the turn of the century, coincident with the construction of the Pacific Beet Sugar Company's sugar factory in 1898, many artesian wells on the plain had begun to stop flowing (Freeman 1968). The construction of the factory caused a significant spike in water demand on the Plain, as wells were built to supply water needs for the factory and new town of Oxnard. That year, the *Ventura Free Press* noted the impending problem of declines in groundwater levels:

> The artesian water supply of this valley is soon to become an absorbing problem. Every year scores of new wells are being bored, often close together in the same artesian belt. The result is that wells which a few years ago gave a good flow have now ceased flowing and have to be pumped. The number of these must increase as the as the [sic] new wells increase. (*Ventura Free Press* 1898)

In 1900, the newspaper recorded that "quite a number of the Colonia artesian wells are falling of late on account of the factory wells running steady" (*Ventura Free Press* 1900). It was reported that factory water extractions caused a drop of five to ten feet in wells near Oxnard (Freeman 1968). As artesian water failed, water began to be pumped instead.

Through the 1910s and 1920s, groundwater levels in the Oxnard Plain and greater Santa Clara Valley continued to decrease (Freeman 1968). By the mid-20th century, summer surface flow in the Santa Clara River had sharply decreased; Gregor (1952) noted that the river was "dry most of the year." At this time, almost all (90%) of the Santa Clara Valley and Oxnard Plain's water demand was supplied by deep turbine pumps drawing groundwater (Freeman 1968). Urban development on the Oxnard Plain (and in other areas of the county) further strained groundwater resources.

Water Use and Irrigation

Ventura County was noted for its comparative lack of substantial irrigation development relative to other Southern California regions. On the Oxnard Plain, high groundwater tables and fog reduced the need for substantial irrigation of many crops (Rothrock 1876). In addition, the presence of alkali, coupled with a high groundwater table, impermeable clay subsurface soils, and extremely flat topography actually precluded irrigation over large swaths of the Oxnard Plain, since irrigation water only further saturated surface soils (Gregor 1953). Early farmers on the Plain understood this, and it was observed that they "do not irrigate more than they can avoid, for the reason…it brings the alkali to the surface" (Rothrock 1876).

For this reason, substantial crop irrigation lagged behind the development of large-scale agriculture in the county. The main crops of the 1880s—barley and beans, along with corn—were largely dry-farmed in the foggy, high groundwater table areas near the coast (Thompson and West [1883]1961, Gregor 1952, Swanson 1994).

In 1889, only about 1% of the county's farms were irrigated (Gregor 1952). This was a point of pride for some residents: "In Ventura County… as our farmers do not desire to get rich in a day, corn is planted after the winter rains are over, and but one crop a year is raised and that without irrigation" (Storke 1891). In 1893, citrus orchards near Fillmore were described as one of the "few irrigation enterprises in the county," while in other parts of the county even citrus was grown without irrigation (Brook 1893). By 1900 irrigation was still not widespread, though it was recognized that irrigation would increase the productivity of county cultivation: "the ease with which crops have generally been grown in this district without irrigation, has made the people indifferent to the advantages of skillful irrigation and chary of undertaking it…the prosperity and value of the greater portion of Southern California have been the result of irrigation" (Schuyler 1900).

The general sentiment expressed in historical texts that "irrigation is not used at all in Ventura County" (Storke 1891) was undoubtedly an overstatement, as some farmers irrigated crops during extremely dry years, or during the dry season to increase yields. Other crops were more predictably irrigated, such as alfalfa and (later) citrus. By the turn of the century, staple crops beans, beets, and barley were all irrigated in some sections of the county (Holmes and Mesmer 1901c).

Irrigation is not extensively practiced in the area and is confined principally to the Santa Clara River Valley, a small part of the plains north of Oxnard, the lower part of the valley along the Ventura River… and part of the lands along Santa Paula, Sespe, and Piru Creeks.

—NELSON ET AL. 1920

By the 1910s, much of the Santa Clara River valley from Saticoy to Piru that was planted to orchards was under irrigation (Tait 1912). It was widely held that "all orchards are better for irrigation" (Unknown ca. 1909). Citrus was almost universally irrigated, and it was recognized that other fruits, walnuts, and beans would be more productive with irrigation. During this time, all of the citrus in the county, and about half of the walnuts and apricots, were irrigated, while only a quarter of the sugar beets and less than 1/5 of the beans were irrigated (Unknown 1914). For orchards, irrigation was focused mostly in the dry season (around May to September).

However, even at this time irrigation was not practiced by the majority of Ventura County farmers, particularly on the Oxnard Plain. "The idea has prevailed in Ventura County," wrote Tait (1912), "especially on the coastal plain…that irrigation is not necessary and the success of the lima bean industry without irrigation has done much to divert attention from the development of the water resources of the county. Within the last few years more interest has been taken in irrigation." Irrigation was considered optional for most crops (excluding citrus) through the 1910s, though its role in increasing productivity was recognized (Nelson et al. 1920).

In 1918, extensive artificial drainage projects aimed at flushing out alkali salts began on the Oxnard Plain. Over the next years, these drainage projects leached salts out of alkaline areas on the plain (Gregor 1953). Coupled with the falling water table from groundwater extraction, many of these areas began to be non-alkaline and well drained enough to support tree crops, such as lemons and walnuts. These crops required irrigation, and the tile drains provided a drainage pathway for irrigation waters for these higher value crops.

The transition to irrigation occurred gradually over the 1920s and 1930s as orchards expanded over large sections of the county's cultivatable land. In the decade between 1919 and 1928, irrigated acreage in Ventura nearly tripled, from 31,700 to 86,700 acres. This was largely due to land use shifts on the Oxnard Plain as orchards became more common: by 1947, over 93% of the plain's irrigable area was irrigated (Gregor 1952, fig. 2.9).

The explosion in water demand for irrigation, along with increasing pressure for water rights from outside the watershed, drove many of the major water management developments of the mid-20th century (see fig. 2.2). The most notable examples include the formation of the Santa Clara Water Conservation District (1927) and its successor, United Water Conservation District (1950); the construction of spreading grounds beginning in 1928 to replenish groundwater supplies and water levels in Oxnard Plain wells; and the construction of dams including the short-lived St. Francis dam (1926, failed in 1928) and Bouquet Reservoir (1934) in the upper watershed, and Santa Felicia Dam (1955) on Piru Creek. The Freeman Diversion Dam, also used for groundwater recharge, was completed in 1991.

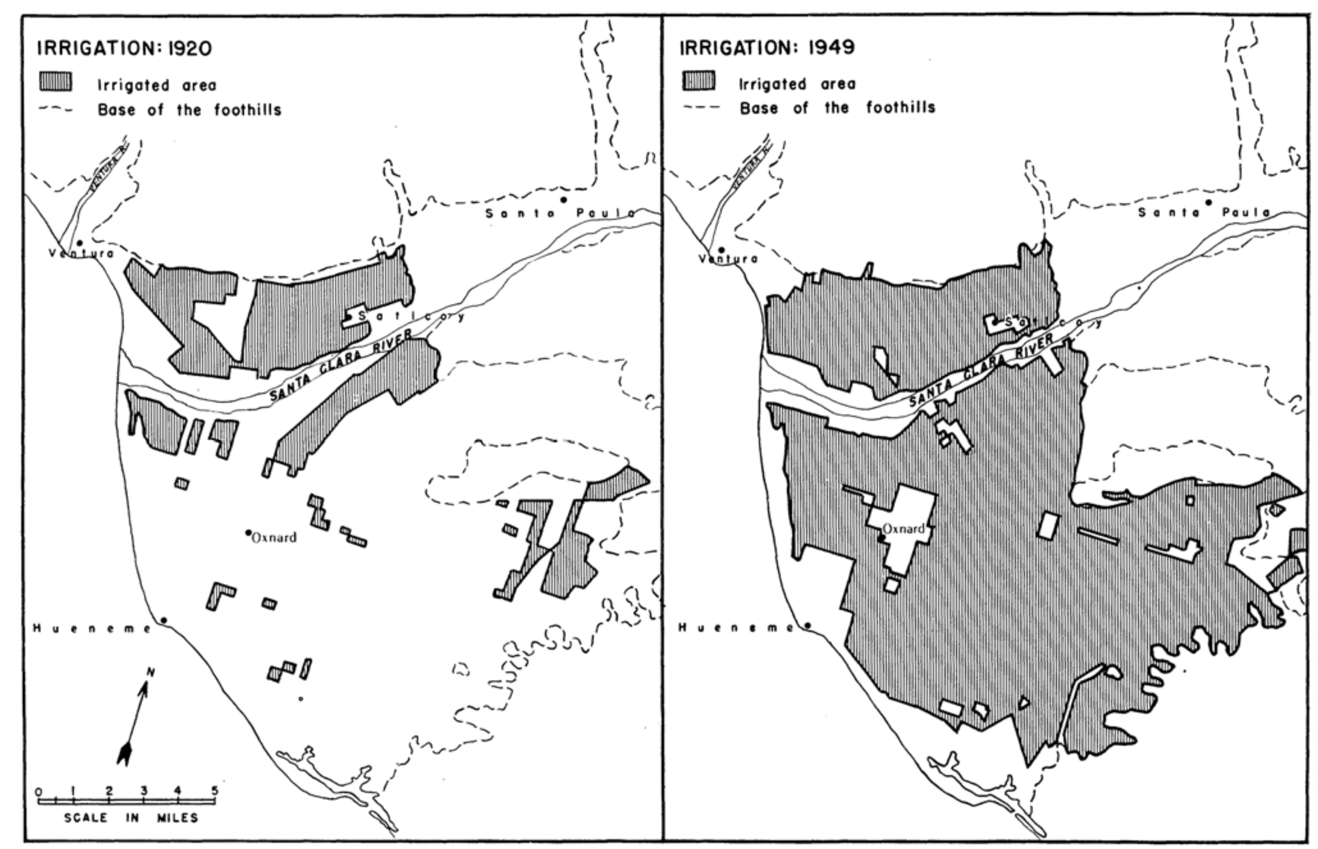


Fig 2.9. Extent of irrigated farms on the Oxnard Plain, 1920 and 1949. Irrigated acreage on the Oxnard Plain expanded rapidly from the 1920s through the 1940s. By 1947, over 93% of the Oxnard Plain's irrigable area was irrigated. (Gregor 1952)

FLOODING AND CLIMATE

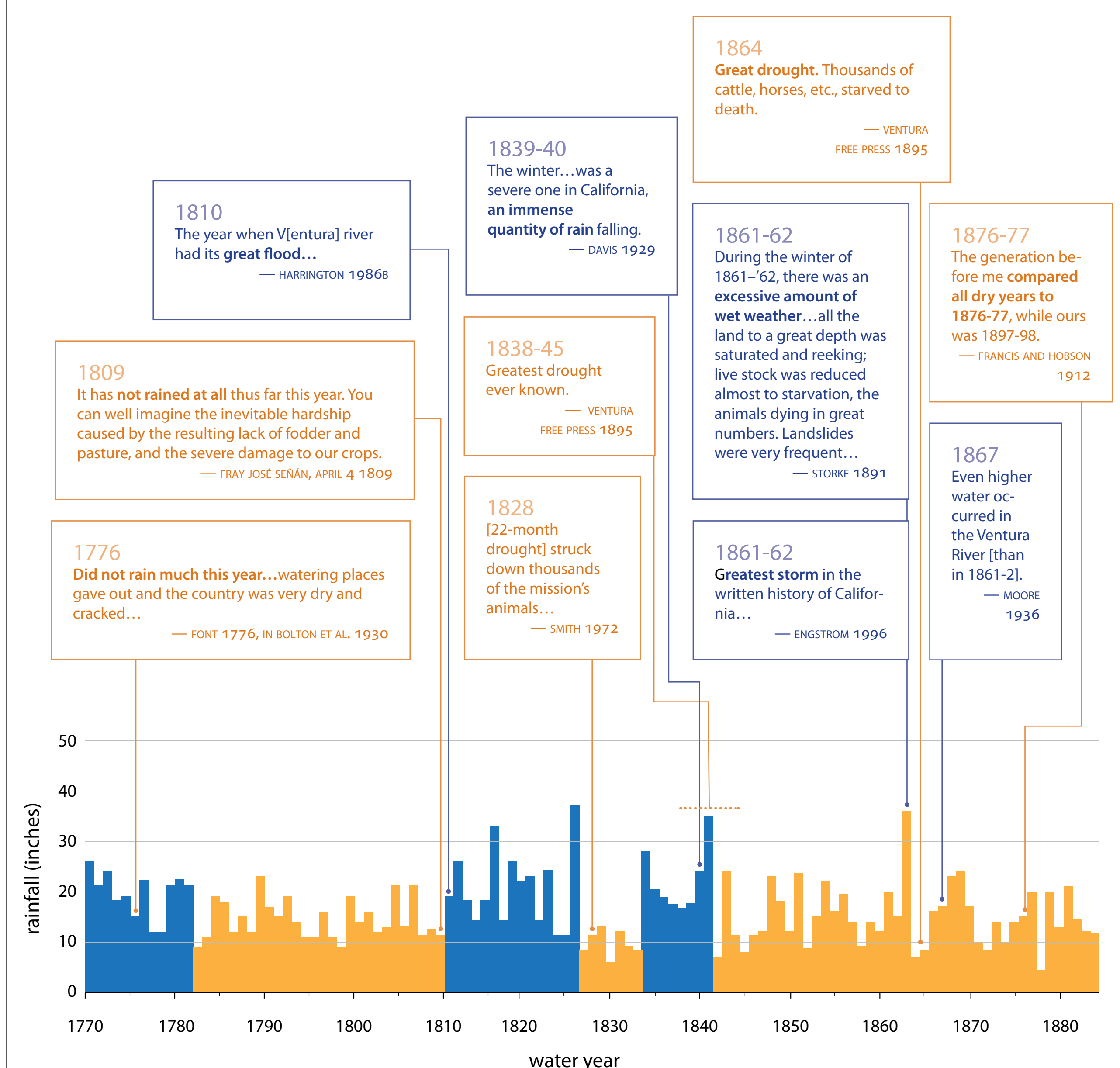
An understanding of the timing of major floods and droughts is an important aspect of historical data interpretation, particularly in a semi-arid environment such as Ventura County where channel form and riparian vegetation distribution are controlled by large flood events. In addition, short-term variations in climate can influence native habitat patterns indirectly by affecting land use: droughts can instigate greater reliance on groundwater, new irrigation practices, or the failure or abandonment of a crop, while extreme winter floods can catalyze stream channelization efforts and levee construction. For these reasons, it is essential to consider climatic patterns when interpreting former ecology and land use history.

We used precipitation records compiled by Freeman (1968) and Stillwater Sciences (2007b) to understand patterns of wet and dry years, in addition to qualitative narrative accounts of notable floods and droughts that occurred prior to standardized precipitation and flow monitoring (fig. 2.10). There are also a number of excellent general

treatments of historical climate in Southern California which were consulted (cf. Lynch 1931, Engstrom 1996, Haston and Michaelsen 1997).

Overall, Lynch (1931) concludes that the average Southern California climate has remained stable since 1769. The following coarse information on notable floods and droughts recorded in the historical record is provided so that the reader can better understand the context in which the historical data presented in this report were interpreted.

Of additional particular note is the flood caused by the St. Francis Dam break on March 12, 1928. The dam, located on San Francisquito Creek, was completed in 1926 at part of the Los Angeles water supply and storage system. After the dam failure, the resulting flood swept down the Santa Clara River valley, causing extensive damage and killing more than 450 people before reaching the ocean.



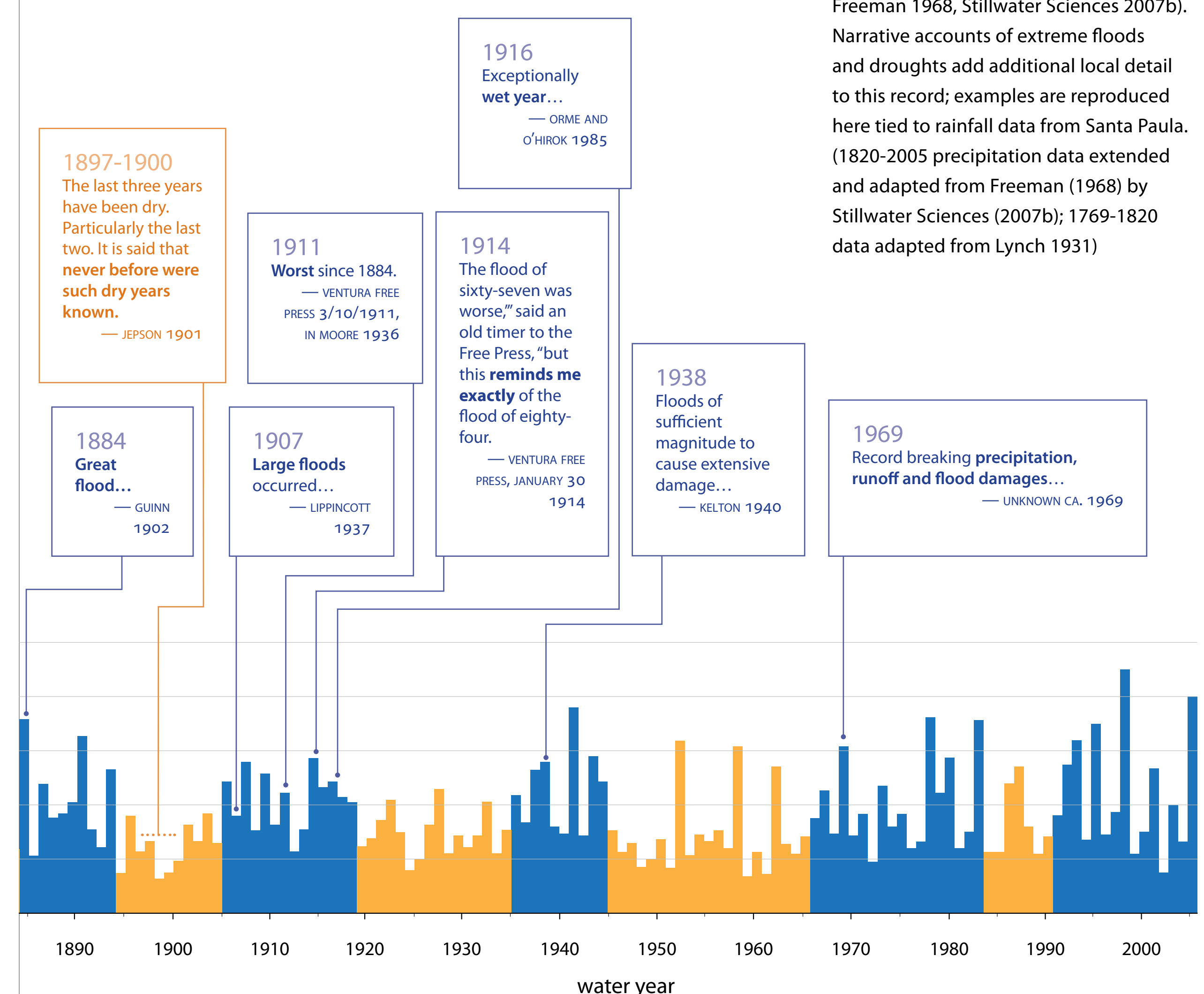


Fig. 2.10. Patterns of wet and dry years, 1769-2005. Cycles of dry periods (shown in orange) and wet periods (shown in blue) are well documented by the historical record (e.g., Lynch 1931, Freeman 1968, Stillwater Sciences 2007b). Narrative accounts of extreme floods and droughts add additional local detail to this record; examples are reproduced here tied to rainfall data from Santa Paula. (1820-2005 precipitation data extended and adapted from Freeman (1968) by Stillwater Sciences (2007b); 1769-1820 data adapted from Lynch 1931)

3 • SANTA CLARA RIVER AND VALLEY

Though Santa Clara on her buoyant breast
Bear neither steamer swift nor bellied sail--
No Palinurus, steering from the West,
Seeks shelter here from Neptune's threat'ning gale,--
Yet grandly on she flows through brake and dell,
Irriguous wide in many a sinuous line,
And Ceres sees with joy her banks o'erswell,
While Bacchus thanks her for his certain vine.
And there Vertumnus and Pomona, too,
Like timid lovers shrinking to the wood,
With bosky groves they shade the open view,
And gather freshness from the swelling flood.

—GOLD AND SUNSHINE: REMINISCENCES OF EARLY CALIFORNIA, AYERS 1922

Introduction

The Santa Clara River watershed is one of the largest coastal watersheds in Southern California, draining approximately 1,620 square miles and running 116 miles from its origin to the coast. Its headwaters are in the San Gabriel Mountains in northern Los Angeles County, and the lower portion of the river runs southwest though Ventura County before reaching the Oxnard Plain and draining to the Pacific Ocean.

The watershed is located within the Transverse Ranges geologic province, in a geologically active area west of the San Andreas Fault. The geology of the watershed includes younger, mostly marine-origin sedimentary rocks in the lower watershed, and older igneous and metamorphic rocks in the steep upper watershed. The sedimentary rocks of the lower watershed are generally poorly consolidated and highly deformed and fractured, making them highly erodible. Even the (generally relatively erosion-resistant) granites and other older rocks of the upper watershed are vulnerable to high erosion rates due to extensive fracturing, folding, and faulting (Orme 2005, Stillwater Sciences 2007b, Stillwater Sciences 2011). As a result, the watershed is subject to high rates of sediment production and transport. This is particularly true for the river's lower reaches (i.e., below Sespe Creek), where average sediment yield is roughly double the regional average (Warrick 2002).

This aspect of the river is intensified by the highly episodic, "flashy" nature of flood events on the river. Like other rivers in southern California, Santa Clara River flows are controlled by a Mediterranean climate, with peak flows in the rainy season and inter-annual variation of floods and droughts. Not only is precipitation mostly confined to the winter months, the majority of water and sediment in the system are transported during just a few high-

Fig. 3.1. Lower Santa Clara river, 1934 (opposite page). The remnants of West Grove may be seen on the south side of the river (right side of image), in addition to braided channels and riverwash. (Fairchild Aerial Surveys 1934, courtesy of the Benjamin and Gladys Thomas Air Photo Archives, Spence and Fairchild Collections, UCLA Department of Geography)

intensity, short-duration events: on average, more than half the flow from the Santa Clara and Ventura rivers takes place over only three to six days of every year (Warrick 2002).

The Santa Clara River is regionally significant because it has largely retained this natural variability, and consequently substantial aspects of its natural form and processes are still remarkably intact. In contrast to other Southern California rivers of its size, the Santa Clara River maintains a regularly scoured sandy bed, braided channel form, and highly variable flows still controlled largely by patterns of precipitation and groundwater availability. Despite substantial changes such as decreases in sediment load due to impoundment by dams and the loss of floodplain area, the overall morphology, hydrology, and sediment transport on the river mirror its historical attributes. (About 37% of the Santa Clara River basin area is behind dams, though the corresponding decrease in sediment delivery to the mainstem has been somewhat smaller – 27%; Orme 2005.) The mainstem has no large storage dam, though it is regulated by the Vern Freeman Diversion which diverts a majority of the river's low flows.

As a result of this episodic hydrologic regime (and again, in contrast to other southern California rivers), the Santa Clara River has retained much of the longitudinal habitat heterogeneity that has been mostly lost on other systems due to land use pressures, flow regulation, and channelization. While many of the region's rivers have had peak flows capped by regulated dam releases for flood control, the active vegetation scouring and habitat variability present on the Santa Clara River provide some of the habitat complexity needed by native plant and animal communities. The river also provides a migration corridor for several endangered species, such as the southern steelhead trout (anadromous *Onchorynchus mykiss*).

The extent of urbanization in the Santa Clara River watershed is still relatively low, and as a result it supports a variety of plant communities ranging from evergreen and deciduous woodlands to fire-susceptible chaparral and grasslands. Much of the mountainous northern portion of the watershed is part of the Angeles National Forest and Los Padres National Forest. However, the lower watershed is dominated by orchards and row crop agriculture and developed urban areas.

This chapter explores the historical characteristics of the Santa Clara River and valley prior to major urban and agricultural modifications (fig. 3.2). In particular, we focus on the pre-modification hydrology, morphology, and ecology of the Santa Clara River, describing each historical attribute at a reach scale.

Santa Clara River reach designations

For purposes of comparison, we identified six reaches of the lower Santa Clara River (fig. 3.3). These reaches were broadly defined based on physical characteristics of the system such as topography, flow dynamics, tributary inputs, and geology (Bisson et al. 2006). They are designed to provide meaningful units of analysis for reach-level investigations of channel dynamics and morphology.

The six reaches were based on (and thus compatible with) Stillwater Sciences' (2007b) reach designations for the lower river. Stillwater Sciences identified 11 reaches from the river mouth to the Los Angeles County line (slightly west of our study area boundary). In most cases we preserved their reach boundaries, aggregating multiple (two to three) Stillwater reaches into one reach (see fig. 3.3, table 3.1). While these more general reach designations capture fewer detailed changes in channel characteristics (such as average slope), they do

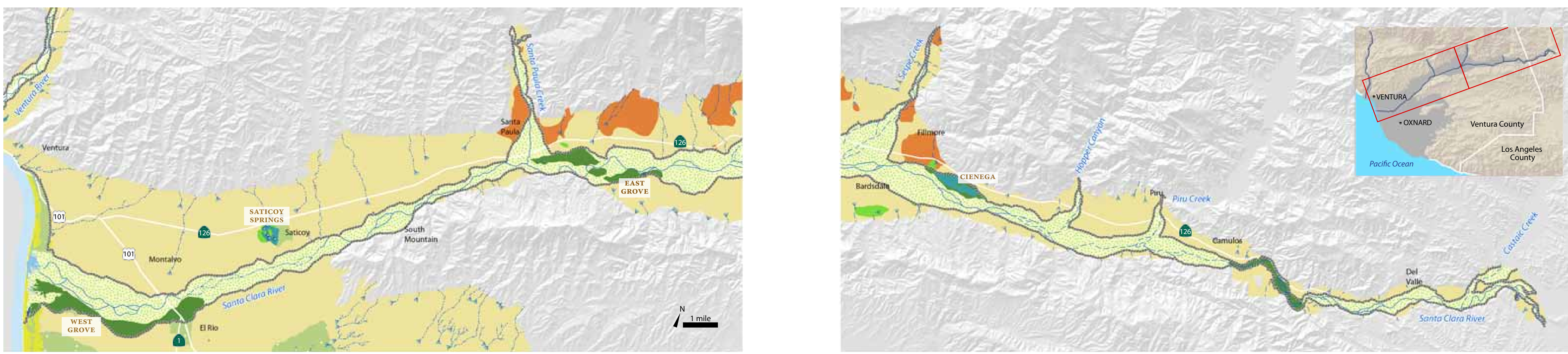


Fig. 3.2. Historical habitats of the Santa Clara River and valley, early 1800s. The Santa Clara River valley was dominated by broad, mostly treeless expanses of grassland and scrub. Trees, such as live oaks and sycamores, occurred on several alluvial fans north of the river and along many of the valley's tributaries, most of which sank into valley soils before reaching the Santa Clara River. A large wetland complex at Saticoy included willow groves, freshwater marsh, springs, and alkali meadow, and was the only significant wetland complex documented on the plain in the valley. Within the outer river banks, however, large areas of willow-cottonwood forest and freshwater wetlands marked areas of perennial flow and rising groundwater east of Camulos, at Fillmore (near the present-day fish hatchery), Santa Paula, and below the Highway 101 bridge.

Table 3.1. Upstream boundaries of Santa Clara River reaches (after Stillwater Sciences 2007b).

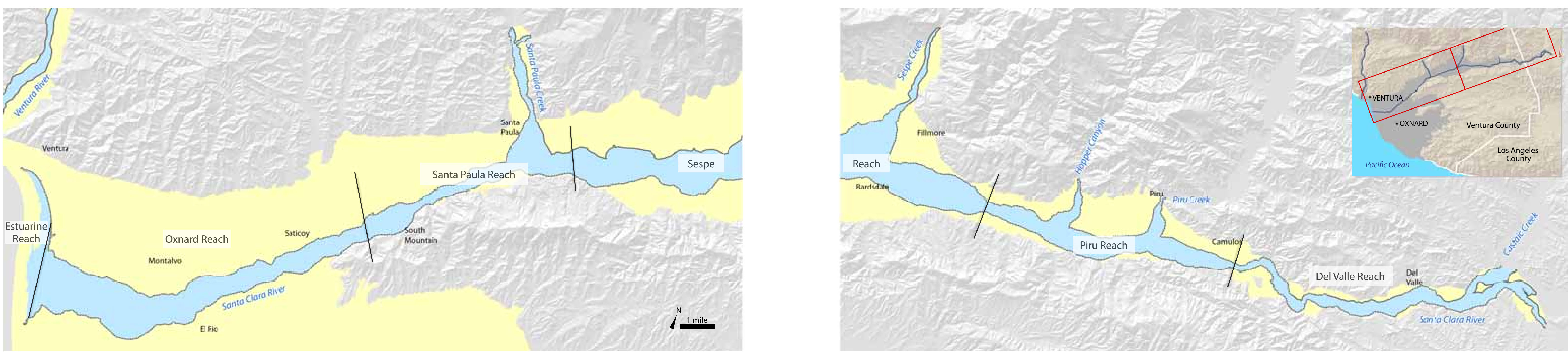
	Estuarine reach	**Oxnard reach**	**Santa Paula reach**	**Sespe reach**	**Piru reach**	**Del Valle reach**
Upstream end of reach	Harbor Blvd bridge	Freeman dam (roughly coincident with upper limit of summer dry reach)	Left bank impinges on South Mountain	Eastern edge of Cienega (upper limit of perennial reach)	2.5 miles east of Piru Creek (upper limit of summer dry reach)	Study area boundary

broadly distinguish between portions of the river with significant differences in hydrology, topography, and channel constriction and width.

While most of Stillwater Sciences' reach boundaries were preserved, one boundary (between our Sespe and Piru reaches) was modified from their original mapping. The reach boundary was moved approximately two miles east in order to reflect differences in the Sespe and Piru reaches and include the high-groundwater area near the old Sespe Cienega (Fillmore Fish Hatchery) in the Sespe reach. We also expanded Stillwater Sciences' last reach (upstream end at the Los Angeles County line) to include the area between the county line and Interstate 5.

From the coast upstream to Interstate 5, the six reaches of the river are designated as the Estuarine reach, the Oxnard reach, the Santa Paula reach, the Sespe reach, the Piru reach, and the Del Valle reach. Through this report, we will refer to these reaches, and use them as a practical scale at which to examine and analyze historical riverine processes and dynamics.

Fig. 3.3. Reaches of the Santa Clara River. We designated six reaches of the lower Santa Clara River as units of analysis for the following chapter. These reaches are aggregations of Stillwater Sciences' (2007b) more detailed reach designations for the river, with a few modifications to reflect historical conditions.



Valley Floor Habitats

Along much of the Santa Clara River, extensive alluvial fans from tributaries to the north have restricted the location of the river (pushing it southward, often directly up against the southern hills). Along with tectonic processes that have tilted the valley, this creates a sloping topography to the north of the river in places that has precluded the presence of depressional wetlands in many places on the valley floor. While there were a few exceptions (notably, the fault-controlled Saticoy Springs), the valley floor was generally composed of dryland features.

Many of these south-facing alluvial fans supported oaks, sycamores, and scrub, particularly between Santa Paula and Sespe creeks. Limited willow scrub habitat was also documented. The majority of the valley floor, however, supported extensive swaths of grassland and scrub. Trees occurred on south-facing alluvial fans, as well as within Santa Paula and Sespe creeks' banks, on the outer bank of the Santa Clara River, along many small creeks, and occasionally as individuals on the plain.

The following section outlines evidence for the composition and distribution of habitats on the Santa Clara River valley floor.

Dryland Habitats

For many 19th century observers, the Santa Clara River valley floor was notable for its sparse tree cover. With few exceptions (such as along watercourses, on some higher alluvial fans north of the river, and scattered sparsely across the plain), most of the valley was characterized by large expanses of grass and (in some areas) scrub. GLO surveys noted areas of "no timber" fifteen times across large portions of the valley from Santa

July 20 we entered Santa Clara Valley, and as we did so passed by a large flourishing mill which was evidently doing a good business. Well-tilled farms became more common, and there seemed to be still more room and water sufficient for a much larger population. The ground reaching down from the hills was a sage-brush covered slope, while on the flats bordering the river we found a greensward, much of which was made up of sour grass, that a mule will eat rather than starve. Earlier in the season it appears there is forage of a better character to be had in the valley. The water is alkaline, but less markedly so in the river.

—ROTHROCK 1876, TRAVELING IN JULY 1875 FROM SESPE CREEK DOWNSTREAM

Fig. 3.4. The Fremont sycamore, still standing at the intersection of Highway 126 and Sycamore Road west of Sespe Creek, is a California Historical Landmark. According to the Office of Historic Preservation, the tree "has served as a resting place, a polling place, a temporary post office, and an outdoor chapel" (OHP 2011).

Paula to Piru (Craven 1874b,d,e,f,g); others described the valley as "treeless" (*Ventura Free Press* 1883a). An 1879 newspaper article described it as a "broad and prairie like valley" (*Ventura Signal* 1879, in Hampton 2002).

The general absence of trees meant one was able to see long distances over the plain in many places without interruption. The Fremont sycamore, a lone tree north of Highway 126 at Sycamore Road/Hall Road (fig. 3.4), was a landmark tree on the plain; one GLO survey sighted 1.5 miles across the plain to the tree, a remarkable distance away for such a survey (Craven 1874c). (The tree, named after General John C. Frémont, still stands today and is a California Historical Landmark. Modern Sycamore Road follows this line of sight to the tree, and forms the northwestern boundary of the Sespe Ranch.)

This aspect of the valley was documented in a number of ways, across much of its extent. Above Sespe Creek east to Newhall, Holton (1880) broadly described "much fine meadow" in the valley along the river. Between Sespe and Santa Paula creeks in 1769, Crespí noted that the valley was "very grass-grown with very tall broad grass," comparing it to similar grassy areas they had just traveled through east of Sespe Creek (Crespí and Brown 2001). In the same area over 100 years later, an observer noted flats covered with "a greensward, much of which was made up of sour grass, that a mule will eat rather than starve," though this may have been in the floodplain (see page 87; Rothrock 1876). The grassy nature of the lower valley was documented by early San Buenaventura Mission records, in a letter describing the grazing patterns of Mission animals in 1804 (for full quote, see page 30):

> The animals [cattle] farthest from the beach make their way to a place called Saticoy, and when the grazing there is exhausted (that locality not being very productive and most of the growth being sword grass), they roam farther up to the meadows along the river and through a rather wide canyon into Sécpey [Sespe], some bands of mares penetrating as far as Camulus. (Señán and Santa María 1804)

The region near Saticoy (other than near the springs themselves) was known for its lack of timber. In this area, Crespí recorded that "no trees are to be seen nearby" (he could see all the way to the easternmost edge of West Grove, more than 2.5 miles away; Crespí and Brown 2001). Engineer N. King observed "a great scarcity of both wood and water" in the region, "farmers having to haul both for miles" (King 1883). Cooper (1887) noted the area was "naturally prairie land, producing no trees," and an early newspaper article described impediments to early settlers from the "lack of timber and water" (*Daily Alta California* 1868).

These grasslands also included an abundance of wildflowers in many places, as noted by one traveler riding upvalley from Santa Paula to Camulos:

> Four of us drove, and one mounted on her pony rode beside us, and kept us well supplied with wild-flowers, of which there were acres along the roadside. Beyond the Sespe River they became more and more abundant. They covered the hillsides, and lay in great patches by the side of the road… Near where we stopped to eat our luncheon, in the shadow of a huge live-oak tree, the fields were carpeted with flowers of every imaginable color, – clover and buttercups, sunflowers and wild sweet-sage, thistle and cacti, – all girded by green grasses. (Roberts 1886)

In a few areas, sagebrush and scrub were also documented. In particular, the valley floor around the intermittently-flowing Piru reach of the Santa Clara River was notably drier than other parts of the valley, so much so that one traveler called it a "desert" (Eames 1889; see margin). GLO surveyor Craven (1874f) recorded "cactus and sage brush" in this area, just north of the Santa Clara River southwest of Piru. Patches of sagebrush and cactus were also documented on alluvial fans north of the river and west of Sespe Creek and in lower Santa Paula canyon (Hoffman 1868b,c; Craven 1874g). Undoubtedly many more patches of scrub were found in dry portions of the valley and on coarse alluvial fans.

However, a few scattered trees—mostly sycamores and live oaks—also dotted the grasslands. Crespí noted trees "here and there on the level" between Fillmore and Santa Paula; in the same area ornithologist Barton Evermann (1886) described live oaks "scattered irregularly over the valley." Reflecting their rarity, some of these individual trees and groves were used as landmarks or for gatherings; some even had names (see Jarrett 1983), like the Fremont sycamore mentioned earlier. These trees were not included in our mapping, but would have been notable landmarks on the otherwise mostly treeless plain.

Ethnographer J.P. Harrington's Chumash informants recollected a couple of places in the plain between Saticoy and Santa Paula, "with some aliso [sycamore] trees"; his informants gave him the name for a sycamore grove (Kats'antuk) and sycamore tree (Sapk'onil; Harrington 1913e). Other sycamores on the grassy plain are documented by GLO surveys (Norris 1853, Craven 1874c,g). (Though *aliso* literally means "alder," in Spanish California the term was universally used to refer to sycamores.)

We left the Camulos at an early hour the next morning. As we crossed the Piru, De Forest gazed curiously about him, at last remarking in his usual spiritless manner,

"It is always an enigma to me why Mr. Cook should have chosen this desert for his home, when he is right in sight of a place like Bardsdale."

"Why, just because it ***is*** *a desert, comparatively speaking," the Judge emphatically rejoined. "What Nature has not done for Bardsdale and Saticoy, man has already accomplished, and Mr. Cook's energy demands tremendous obstacles to overcome…"*

—NINETTA EAMES, FALL 1889

Fig. 3.5. Fourth of July picnic under oaks on Bill Boosey's ranch, ca. 1910. Fourth of July picnics and celebrations were often held in the Santa Paula area's sycamore and oak groves. These live oak trees are still standing (Henderson pers. comm.). (Unknown ca. 1910a, Courtesy of Santa Paula Historical Society)

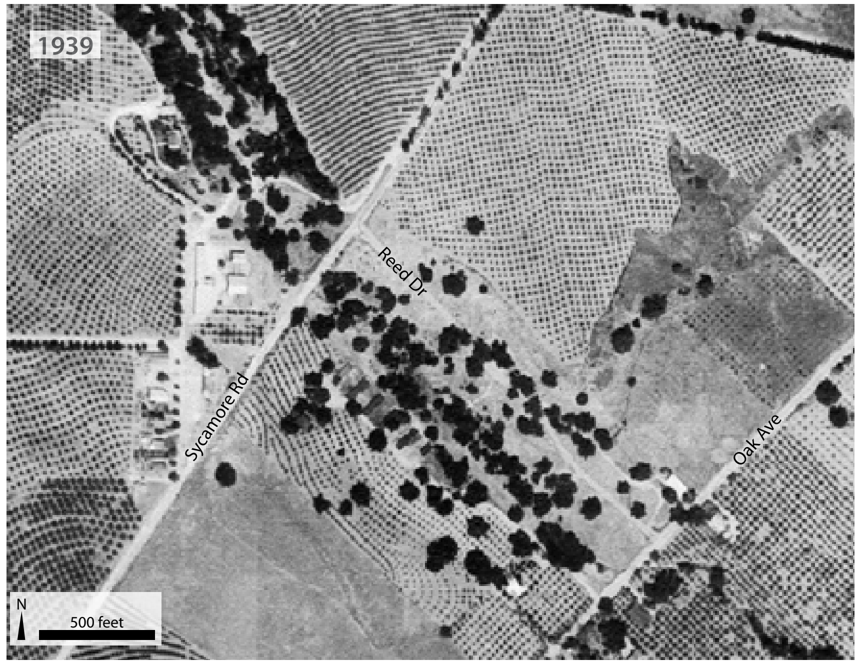


Fig. 3.6. Kenney Grove, 1939-2008. Kenny Grove is situated at the former distributary of a small creek, west of Sespe Creek and above Oak Avenue. Fourth of July picnics were common under these trees in the late 19th century. The trees, still present in 1938 (top), are currently an RV campground shaded by the oaks (bottom). (USDA 1938, courtesy of Ventura County)

Among the people in the east end of this county there has latterly been some quiet renewal of the agitation in favor of the purchase of Kenny Grove in the Sespe Canyon and its maintenance by the county for public park purposes…The grove is a very beautiful strip of woodland, situated in the center of a populous and growing section, and a public park is much needed there—and will be more needed with every passing year.

—VENTURA FREE PRESS 1909A

On the valley floor around Santa Paula and Sespe creeks, a number of live oak and sycamore groves provided shady locations for picnics and Fourth of July celebrations (fig. 3.5). Sprague's grove, a "beautiful sycamore grove" near Sprague's house and Sespe Creek, was one such gathering spot in the 1870s (*Ventura Signal* 1874b, Warring 1959, Jarrett 1983). Kenney Grove, a grove of live oaks between Sycamore Road and Oak Avenue west of Sespe Creek, was another in the 1880s and 1890s; today it is an RV campground owned by Ventura County (Ventura Free Press summary, 1888-1889, from Fillmore HS newspaper index; fig. 3.6). Other live oak and sycamore groves were also documented, including a live oak grove near Santa Paula Creek (*Ventura Free Press* 1879), a grove east of Fillmore called Sespe Grove (*Ventura Free Press* 1887b), and a sycamore grove northwest of the Sespe Creek-Santa Clara River confluence (Barry ca. 1890). Most of these groves

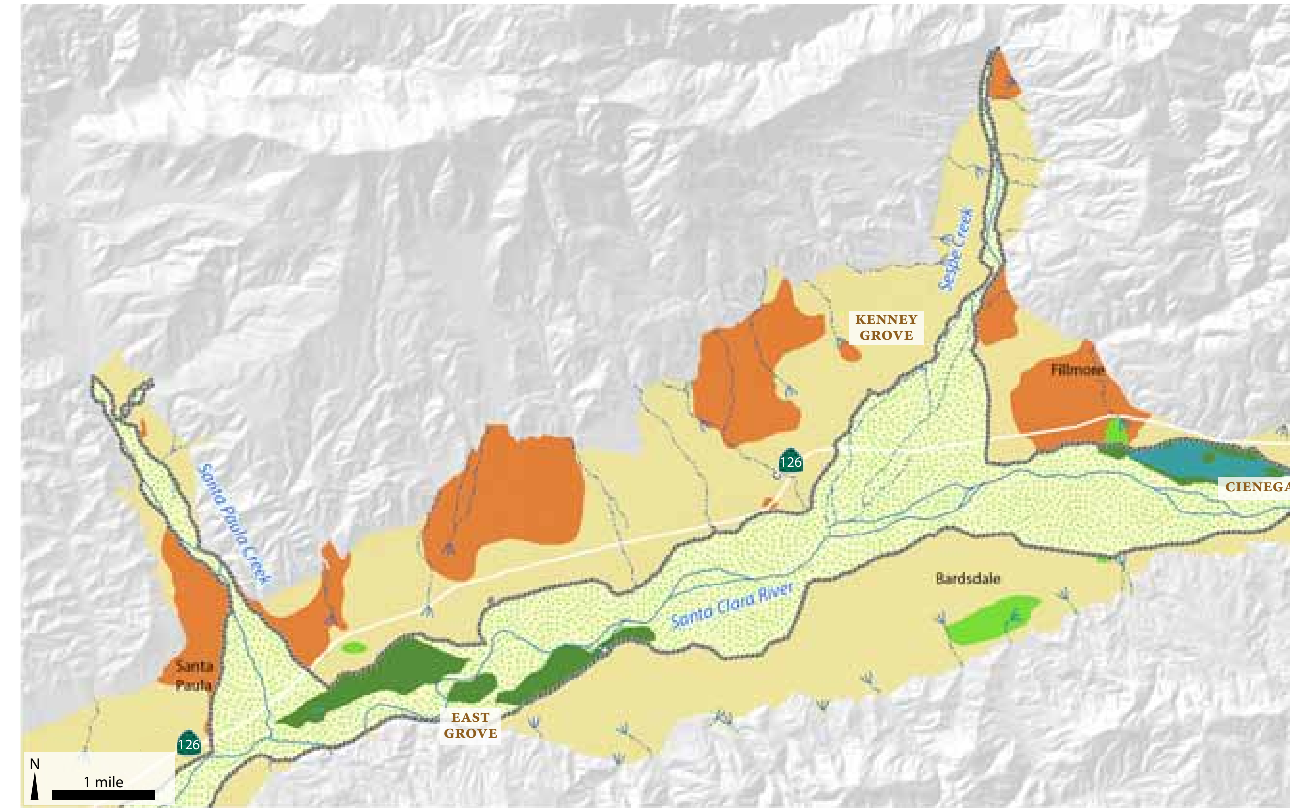
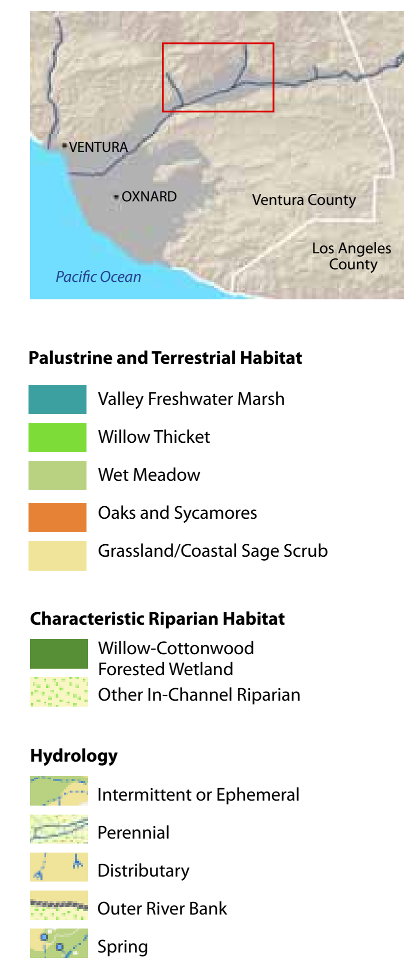


Fig. 3.7. Sycamores and oaks between Santa Paula and Sespe creeks. Scattered oaks and sycamores, documented by GLO, historical soils surveys, and early aerial photography, occupied coarse alluvial fans north of the Santa Clara River.



were lacking spatially specific information and were thus not included in our habitat map.

In addition to these isolated trees and groves, there were a few areas of denser tree cover on the valley floor. These timbered areas were documented exclusively on alluvial fans north of the Santa Clara River between Santa Paula and Sespe canyons (fig. 3.7). Using both GLO survey notes and historical aerial photography, we found that the gravelly fine sandy loam with stones (Yg) soil type from the historical soil survey (Nelson et al. 1917), prevalent on these alluvial fans, was well correlated with the documentation of historical oaks and sycamores. We subsequently used this soil type to delineate probable timbered areas (see page 15). GLO field notes for these areas describe "oak timber," "scattering oak timber," and "scattering live oak and sycamore with undergrowth sage brush" (Hoffman 1868c, Orcutt 1900).

The cities of Santa Paula and Fillmore, both established at least partly on this soil type, were both the sites of notable areas of live oaks and sycamores. A few notable sycamores in Fillmore have survived to the present day, many marking the former route of Pole Creek (Jarrett 1983; fig. 3.8). In Santa Paula, oaks and sycamores are still widespread, particularly in the northern part of the city (fig. 3.9). In addition to these trees, many other

Fig. 3.8 (top right). Sycamore on Kensington Street being trimmed, July 2008. This giant sycamore was part of a group of three sycamores on this block (Jarrett 1983).

Fig. 3.9 (above and bottom right). Oaks and sycamores are still common in this residential part of northern Santa Paula. (November 2008)

live oaks, sycamores, and other riparian trees were established within the banks of Santa Paula and Sespe creeks.

While many of these heritage trees have persisted—notably within the Santa Paula and Fillmore city limits—many were chopped down for firewood or to make way for orchards. One editorial in the *Ventura Free Press* lamented that "our native trees are rapidly disappearing under the sturdy blows of the wood chopper," advising residents to plant new trees to compensate for those lost (*Ventura Free Press* 1881). Even in the late 19th century, some valley residents recognized the value of these trees, and lamented their loss:

> Some one should protest against the cutting down of the trees in the Sespe grove. A street is being surveyed through it and some of the finest trees must be sacrificed. This grove ought to be purchased by the town and kept for a park. It seems a shame that the few accessible groves in the county should be ruthlessly cut down. (*Ventura Free Press* 1887a)

…beneath its native oaks soft glows the velvet sod of Santa Paula.

—ALEXANDER 1918

Notably, no valley oaks (*Quercus lobata*) were historically documented in the lower Santa Clara River valley, either as a riparian tree along the river or on the valley floor. We found no description of valley oaks by any of the region's travelers, botanists, or residents, despite abundant references to the presence of live oaks by these observers. This absence also holds true for the Ventura River and valley (excluding Ojai, which is not in our project area).

The absence of valley oaks is affirmed by the GLO survey notes for the region: in approximately 1,700 survey points collected over a span of 50 years by twelve separate surveyors, there is no mention of valley oaks. This stands in contrast to historical ecology studies performed elsewhere, where GLO surveyors consistently record the presence of valley oaks and differentiate between valley and live oaks (e.g., in northern California's Santa Clara Valley; cf. Grossinger et al. 2007, Beller et al. 2010, Whipple et al. 2010). This absence has also been observed on the Ventura County portion of the Santa Clara River today (Orr et al. 2011).

An exception may be the Los Angeles County portion of the Santa Clara River, at the uppermost edge of the project area. Spanish explorers Miguel Costansó and Juan Crespí, traveling together on the Portolá expedition in 1769, both made note of valley oaks near Castaic Junction: for example, Costansó noted "on the plain we saw many groves of poplars [Fremont cottonwood] and white [valley] oaks, which were very tall and large" (Costansó and Browning 1992, Crespí and Brown 2001). Valley oaks were (and still are) also found in the neighboring areas of Ojai Valley and Thousand Oaks (both just outside the project area), and in fact were emblematic of both areas. This historical distribution is coarsely consistent with the modern range map, which shows an extremely limited range for valley oaks in Ventura County (Pavlik et al. 1991, Ventura County Planning Division 2007). It is also consistent with the low salt tolerance of the species, which limits their presence in valleys opening directly to the ocean (Jepson 1923, Ogden 1979).

Wetland Habitats

Though substantial wetland riparian areas were present on the extensive bottomlands of the Santa Clara River channel (see page 94), outside of the channel there were few wetlands on the valley floor. Scattered willow groves and areas of drier willow scrub were clearly present in the vicinity of the Sespe Creek confluence, though the exact location of these groves is not well documented. These areas were described as "willow thickets" (Peyton 1915), "willow brush" (Hoffman 1868a,c), and "thick grove of willows"

Palustrine and Terrestrial Habitat

- Valley Freshwater Marsh
- Willow Thicket
- Alkali Meadow
- Grassland/Coastal Sage Scrub

Characteristic Riparian Habitat

- Other In-Channel Riparian

Hydrology

- Intermittent or Ephemeral
- Distributary
- Outer River Bank
- Spring

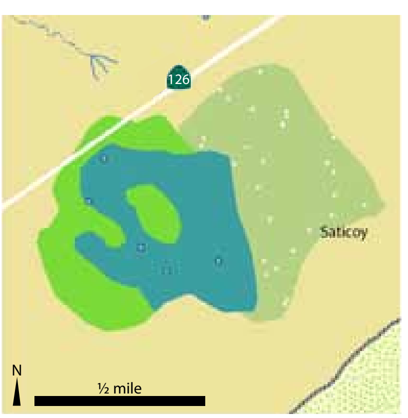


Fig. 3.10 Detail of Saticoy Springs, early 1800s. This 330 acre wetland complex was composed of springs, seasonal alkali meadows, and extensive willow groves and freshwater marsh.

(Jarrett 1983). Many features mapped as willow thickets would have included a variety of trees requiring relatively wet conditions, including alders, box elders, and cottonwoods in addition to willows.

On the south side of the Santa Clara River near Bardsdale, east of Chambersburg Road and north of Guiberson Road, an extensive willow grove served as a notable landmark for area residents. It was the site of a school, called Willow Grove, established after the 1884 flood stranded Cienega schoolhouse kids on the south side of the river (Jarrett 1983). Jarrett describes the significance of the grove:

> Another thick grove of willows grew on the south side of the Santa Clara just over the bank from Guiberson Road, so outstanding that people gave directions by saying, "go east—or west—from the willow grove."

Resident Carl Etkins (1965, in Freeman 1968) recalled that the irrigation pumping plant for the South Side Improvement Company was "fired with willow wood hauled from what was known at that time as the Grove," likely referring to this willow grove (or possibly a grove near the Cienega area north of the river). Flooding resulting from the 1928 St. Francis dam break wiped out the remains of this grove (Jarrett 1983).

A few other wetland complexes were mentioned in historical accounts, though without enough spatial accuracy to map. One of ethnographer John P. Harrington's informants described an extensive wetland in the Piru valley, a "great *cienega* that extends far up and down the creek" (Harrington 1913e). Eames (1889) described "verdant *ciénegas*" near Camulos, and Lopez (1854) notes "a *cienaga* [sic] or swamp" near Castaic. Though it is possible that these wetlands are in-channel features, they allude to the probable presence of many more wetland features — particularly in the Piru and Del Valle reaches — than were documented through our research.

SATICOY SPRINGS In contrast to the Oxnard Plain on the southern side of the Santa Clara River, the lowlands just to the north, on the opposite side of the river, contained few wetlands. This area was naturally steeper and more well drained than the south side of the river, as a result of alluvial fans emanating from the mouths of the series of canyons to the north. However, one distinctive wetland complex was found on the plain on the north side of lower Santa Clara River: Saticoy Springs. Groundwater emerged in an array of springs here, associated with a fault trace of the Country Club fault (Mann 1958), creating a series of springs, wetlands, willow thickets, and alkali meadows that were a noted source of water and wood through much of Ventura history (fig. 3.10).

This unusually large and reliable surface water source gave rise to a major Chumash village that remained at the site until the 1860s, and also served as a significant regional gathering place (Gudde and Bright 1998). One of Harrington's informants recalled that "the Saticoy Indians used to come to Saticoy springs because of the water. The last meeting of Indians was at Saticoy in 1869. Hundreds were there…" (Harrington 1986b). Crespí also

recorded the water resources and extensive village located at the Saticoy site in 1769. He described "a good-sized village of very friendly heathens having, by our count, close to twenty very well built large round houses with grass roofs, with a spring close by it, flowing a bit, and the Santa Clara River a little over a musket shot away" (Crespí and Brown 2001).

The springs were recognized widely as a major landmark and water source for later settlers in the area (fig. 3.11). Their importance was so great that the Santa Clara River was sometimes called the "Saticoy River" even into the 20th century (Hittell 1874; Bancroft 1883; *Ventura Daily Democrat* 1902, in Browne 1974; Harrington 1913e). The Saticoy Springs area served as additional pasture for Mission animals when areas closer to the Mission were no longer available: "When the pasture there is exhausted or dried up, the cattle go in search of more plentiful or better grazing elsewhere…The animals furthest from the beach make their way to a place called Saticoy" (Señan and Santa María 1804). Modern American settlement in the area began when Jefferson Crane began to farm in the area in 1861 (Triem 1985, Gudde and Bright 1998). The springs were noted as a valuable aspect of the Saticoy area, described as "magnificent springs of pure water… said to be the finest in Ventura county" (*Ventura Signal* 1872).

Prior to major water infrastructure developments (such as widespread artesian development and canals bringing water from further upstream on the Santa Clara River), Saticoy Springs and the perennial portion of lower Santa Clara River were two of the primary sources of summer water for local settlers on the northern side of the river and across the western half of the Oxnard Plain (Cooper 1887, Holmes and Mesmer 1901c, Freeman 1963, fig. 3.12). Settlers north of the Santa Clara River depended on the Saticoy area as a primary water source, and would "buy barrels and haul water from the river or Saticoy twice a week or thrice—the year round…" (*Ventura Signal* 1871b; see also Freeman 1968).

Fig. 3.11. Detail of an early map showing Saticoy Springs at the crossroads of two thoroughfares. (Norway 1867, courtesy of the Ventura County Surveyor's Office)

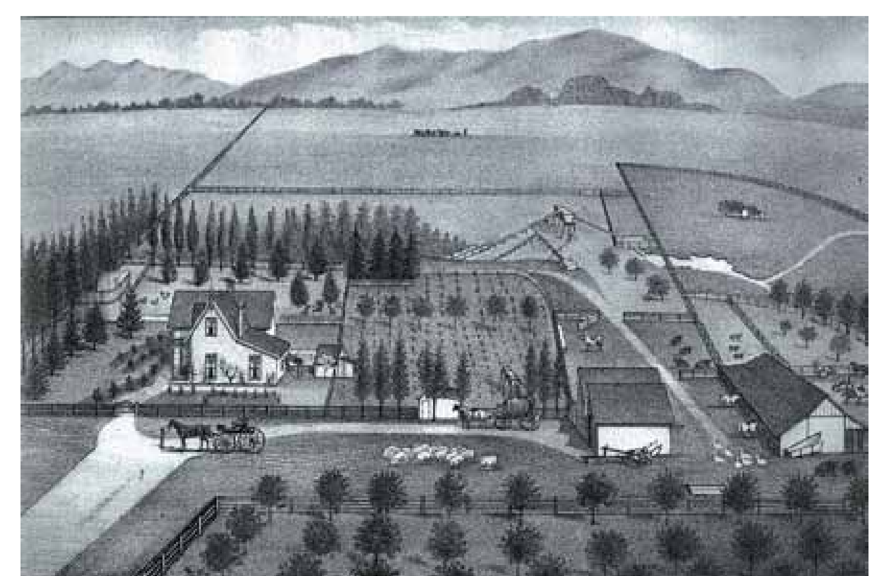


Fig. 3.12. "Residence & ranch of S.T. Wells, Saticoy," ca. 1883. This sketch shows a portion of S.T. Wells' property at Saticoy. His property included some of the springs, as can be seen at right in this image. (Thompson & West [1883]1961)

In contrast to the treeless, relatively dry grass and scrub land surrounding them, the Saticoy Springs were perennially wet, surrounded by a wetland mosaic which included 140 acres of alkali meadow as well as extensive freshwater marshes and willow groves and thickets. Cooper (1887) described the mosaic of freshwater marsh and willow thickets that he observed in 1872-73:

> At Saticoy, however, about 30 feet above the river-bed, springs issue from the edge of the 'mesa' or terrace for half a mile, constant in summer, and forming a considerable marsh, about half of which was then [1872-3] covered by willow groves, thirty or forty feet high, and uniting, the waters form a brook large enough to run a mill at all seasons, discharging within a mile, into the bed of the river.

Kimball (in Freeman 1968) described the patchwork of plant life in the Saticoy Springs area: "This extensive spring area was covered by a dense growth of willows, tules, berry vines and horse nettles. It was the finest kind of a park or playground for boys interested in birds' eggs, blackberries and licorice root." The marsh and willow groves at Saticoy also supported a variety of birds, including Bell's vireo (*Vireo bellii*, possibly least Bell's vireo), Hutton's vireo (*Vireo huttoni*), marsh wren (*Cistothorus palustris*), and yellow warbler (*Dendroica aestiva*) (Cooper 1887).

Channel Morphology

The lower Santa Clara River is a complex, dynamic, braided system. Large flood events are the major driver for morphologic change in the system and can transport substantial quantities of water and sediment over extremely short periods of time: from 1928 to 2000, the four days with the largest sediment discharge account for one quarter of the system's total discharge (Warrick 2002, Warrick et al. 2004).

In addition to natural flood events, the St. Francis Dam break (on San Francisquito Creek) created an immense flood wave that swept rapidly through the lower Santa Clara River on March 12, 1928. Peak discharges for the flood have been estimated at about 600,000 cubic feet per second (cfs) around the Ventura-Los Angeles County Line (Begnudelli and Sanders 2007), well over a 1,000 year recurrence interval flood under contemporary hydrology (Downs et al., submitted). The dam break, along with other large floods of the 19th and early 20th century (e.g., 1862, 1884, 1914), were often noted for the extensive damage caused to the infrastructure of the lower Santa Clara River valley. After each major flood, local newspapers were filled with accounts of washed out bridges, uprooted riparian trees, and eroded farmland.

These accounts pose questions about the spatial extent of erosion and deposition along the river during these storms. In particular, understanding the effects of natural floods (e.g., 1862 or 1884) and the dam break (1928) on the physical characteristics of the river is an essential component of our understanding of the historical morphology of the Santa Clara River, and how and where morphological change occurs in the system.

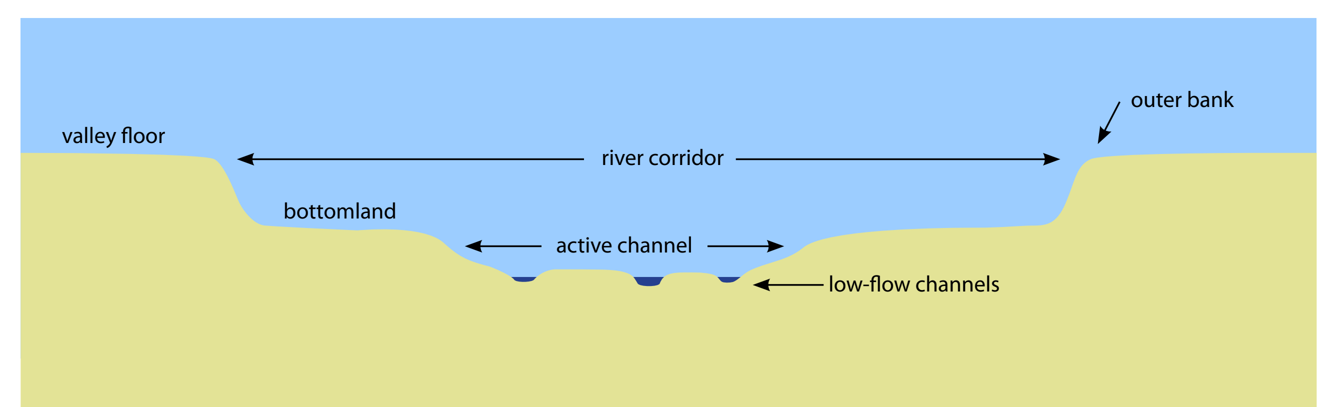
Our research suggests that while substantial change in channel morphology occurred within the outer banks of the river (on bottomlands and within the active channel), comparatively few major shifts in outer bank position occurred in the late 19th and early 20th centuries, even during major flood events. These findings, along with our methods, reach-specific examples of persistence and change, and a discussion of our results, are discussed in detail below. While we focus on plan form changes to the Santa Clara River (notably channel width), a general discussion of hydraulic geometry and channel form are also included in this section.

Hydrology and Geomorphology Terminology

A wide variety of geomorphic features are found within the outer banks of the Santa Clara River, each characterized by different hydrology (flooding frequency, depth to groundwater) and ecology (vegetation and habitat types). Concepts of bankfull discharge as defined for streams in more humid climates (i.e., formed by floods with a 1.5 to 2 year recurrence interval; Wolman and Leopold 1957) are not appropriate for this system, which is characterized by considerable extremes of flow and sediment discharge (Stillwater Sciences 2007b). To address this discrepancy, here we use terminology better suited to Santa Clara River geomorphology. For clarity and consistency, we define the terms below that will be used throughout the report. (For a visual representation of riverine terminology, see fig. 3.13.)

The *active channel* consists of the network of all low-flow channels and the sparsely vegetated or non-vegetated, often sandy bed of the river (Richard et al. 2005). This portion of the river is dynamic, and experiences significant water and sediment transport in most floods; Graf (2000) termed it the "high flow channel." It includes high disturbance areas that are scoured during high flows and have little to no vegetation, in addition to medium disturbance areas that support sparse, poorly established vegetation such as sand bars and islands (Stillwater Sciences 2007b). This is consistent with Stillwater Sciences' classification of active channel width. Nineteenth-century surveyors referred to the active channel area as the "sandy bottom" (Terrell 1861b, Thompson 1867), "sandy bed" (Hoffman 1868b, Norway 1878b, Barry 1892a), or "wash of river" (Norway 1878b).

Fig. 3.13. Generalized cross-section, showing riverine terminology used in this report. The active channel consists of the low-flow channels and sparsely vegetated riverwash. In many reaches the active channel is flanked by bottomland (floodplain) surfaces supporting riparian grassland, scrub, and trees. The entire river, from outer bank to outer bank, is referred to as the "river corridor."



Other early observers described the active channel as a "sandy and gravelly bed" (Cooper 1887) and a "sandy, shallow bed" (*Daily Alta California* 1868). Carrillo (1829, in Outland 1991) referred to the active channel as "worthless" *arenal*, or sandy area.

Above the active channel, within the outer banks of the river, *bottomland* surfaces supported scrubby to dense stands of vegetation. Though still subject to flows, these areas would have experienced minimal scour or deposition during most flood events. These areas correspond with Stillwater Sciences' low disturbance surfaces. "Bottomland" is not a common contemporary ecological term on the West Coast, though it is still widely used in the eastern United States to refer to a periodically flooded forested area (NRCS 2008). Some biogeomorphic literature also uses the term to refer to riverine surfaces above the active channel, though in a broader sense than is meant here (e.g., Scott et al. 1996, Hupp and Osterkamp 1996, Friedman and Lee 2002, Hupp and Bornette 2003, Osterkamp and Hupp 2010). In addition, the Department of Fish and Game's list of terrestrial natural communities in California recognizes "Riparian and Bottomland Habitat" as one of the primary categories of terrestrial vegetation (CDFG 2003). Early surveyors and residents commonly referred to these surfaces as "bottom" (e.g., Norris 1853, Thompson 1867, Craven 1874e), "river bottom" (*Ventura Free Press* 1876, Van Dyke 1890), or "bottom land" (Norway 1877, Hampton 2002, King 1883). (The active channel was also sometimes referred to as a bottom—though never bottomland—but was distinguished as the "sandy bottom"; e.g., Terrell 1861b, Thompson 1867, Thompson 1874.)

While portions of the bottomland certainly served as what today we would term the river's floodplain—that is, the area "overflowed during moderate flood events" (Leopold 1994)—not enough is known about flood frequency to delineate the boundaries of the floodplain. Broadly, the bottomland would have included both floodplain areas (flooded on average once every 1.5 years; Dunne and Leopold 1978) and flood-prone areas (subject to flooding). Some flood-prone portions of the bottomland would have been flooded only during relatively extreme events, such as the 1928 St. Francis Dam break or 1969 flood.

The entire river system, including the active channel and bottomlands (riparian corridor, floodplain, and flood-prone areas), is here defined as the *river corridor*. The river corridor refers to the entire width of the river between outer banks, and includes all high, medium, and low disturbance areas.

River Corridor Position and Stability

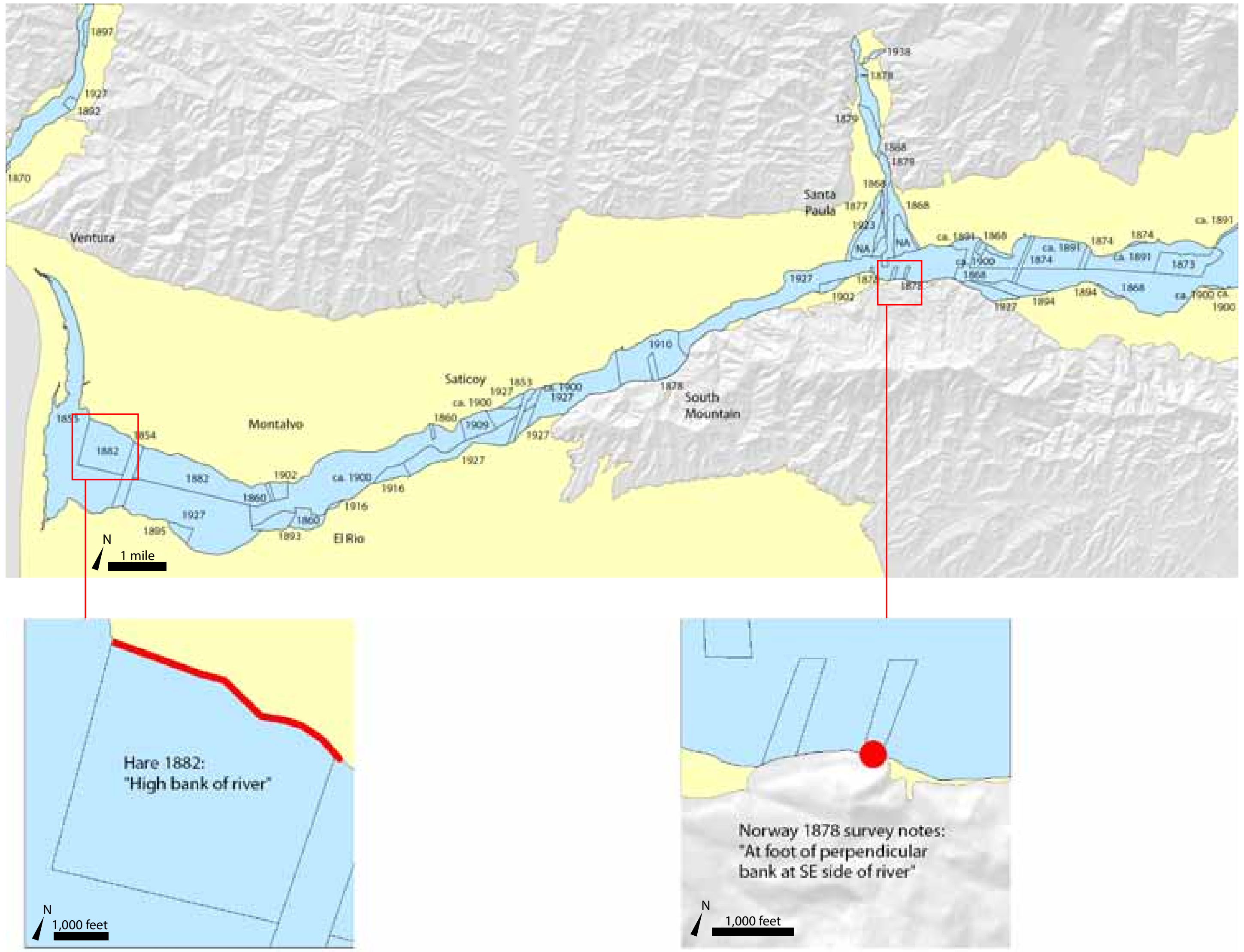
Some previous work has addressed questions of overall river corridor stability over the past two centuries. Based on historical and modern aerials, Stillwater Sciences (2007b) mapped the width of the active channel after major floods from 1938 to 2005. Their data analysis shows a substantially narrowed active channel by 2005 in many reaches, most notably in the lowest reaches of the river (due to encroachment on the channel by human modifications such as levee construction and agriculture). Overall, Stillwater Sciences found that the river corridor narrowed nearly 50% between 1938 and 2005.

Previous studies (Stillwater Sciences 2007b, 2011) have noted that the effects of the 1928 dam break are not obvious in a comparison of 1927 and 1929 aerial imagery. However, the morphology of the river before 1938 has not been established to date. To address questions of effects of pre-1938 floods, including the St. Francis Dam break, on active channel position and stability, we extended Stillwater Sciences' 1938 active channel mapping back to the earliest possible date for each length of stream. Through this process, we produced a map of outer bank position based on the earliest available source. This section describes our methods for mapping approximate 19th century outer bank position, as well as an assessment of two centuries of change.

BANK MAPPING METHODS For the Santa Clara River and main tributaries (Santa Paula, Sespe, Hopper, Piru, and Castaic), we mapped the entire river corridor (from outer bank to outer bank) in a GIS polygon layer. This area includes the sandy, active channel bed (mainstem; high disturbance) in addition to moderately vegetated areas (10-80% cover; Stillwater Sciences 2007b) that show evidence of erosion/deposition (medium disturbance) and more densely vegetated areas (>80%) that may be subject to flow during flood events, but without evidence of major erosion/deposition (low disturbance). Benches or bottomlands with evidence of flow during floods are also included. This definition of the river is consistent with research conducted by Stillwater Sciences for the period 1938-2005.

The river corridor polygon included in our historical mapping represents the earliest reliable source available for each length of stream (fig. 3.14). For the lower Santa Clara River, previous mapping of high, medium, and low disturbance areas from 1938 aerial imagery (Stillwater Sciences 2007b) was used as a starting point. This layer was then compared to earlier historical sources where available. Where earlier sources confirmed 1938 mapping, bank position was left unchanged. Where they showed a substantial change (greater than 150 feet) in bank position, the 1938 layer was modified to reflect the earlier source. In places where Stillwater Sciences was missing 1938 aerial coverage (and in Los Angeles County), we extended their mapping of the active channel. We also mapped the outer banks of the Ventura River and major tributaries of the Santa Clara River from historical aerials and other spatially accurate historical sources.

The primary sources used to complete this mapping were the historical aerial photomosaic (which includes 1927, 1938, 1945, and 1959 aerials; see fig. 1.4), historical survey maps, and General Land Office survey data. The bulk of early sources were from 1870-1900; however, relatively few early (pre-1900) sources were available for the river above the Piru Creek confluence. Over 40 historical sources were used to create the outer bank position for the Santa Clara River. Multiple additional sources were also



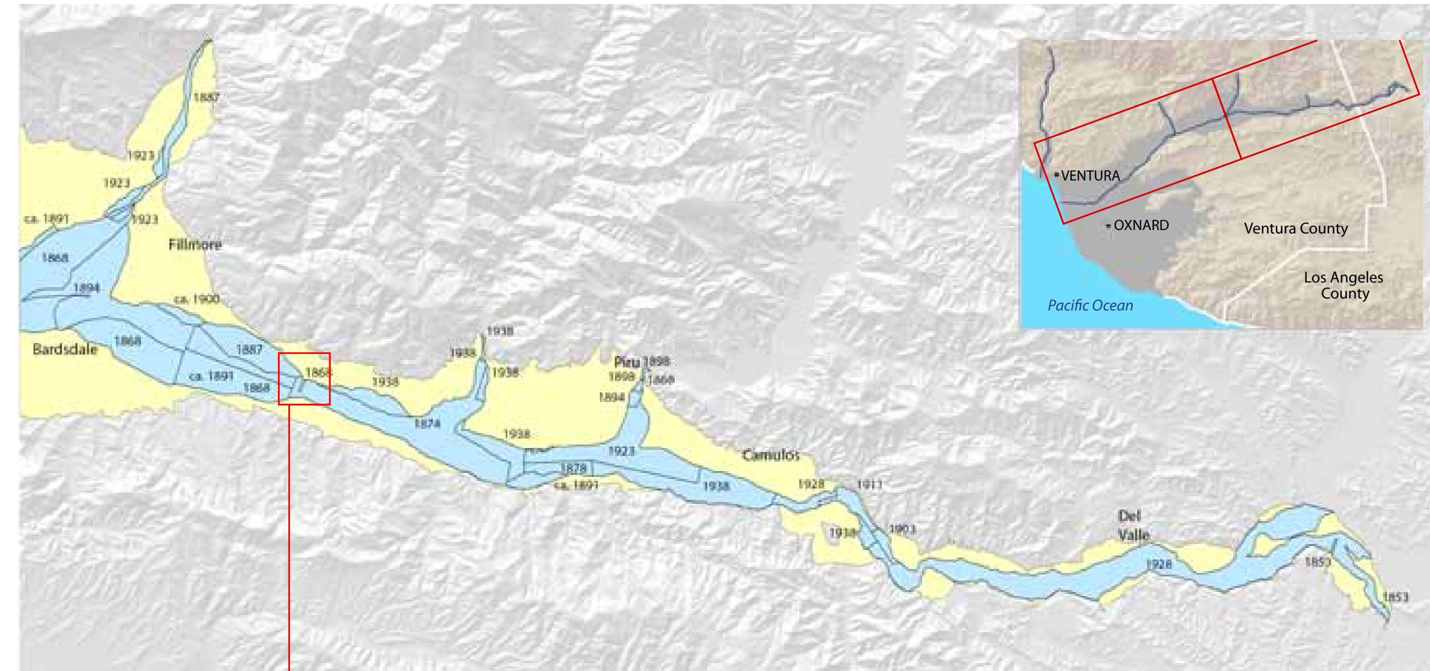


Fig. 3.14. Location of the Santa Clara River corridor by earliest available source, 1853-1938. We mapped the historical position of the outer bank, using the earliest data found for each stretch of the river. We found that while large flood events caused locally significant adjustments in outer bank position and total river corridor width, these changes were relatively small at a regional scale. Pull-out quotes provide examples of the types of sources used to map the historical river corridor.

used to delineate the historical outer bank positions of the Ventura River and major tributaries of the Santa Clara River. While 2005 LiDAR data were used to confirm the position of some portions of the bank, they were not used to map bank position where they were the only source available. This was done to avoid mapping terraces or bluffs that represent the geologic extent of the river (i.e., terraces no longer affected by floods by the 1800s) rather than the historical extent. However, this may have resulted in an underestimation of historical channel extent in some areas, as a number of scarps shown on the LiDAR were not included in our river corridor extent.

Interpretation of outer bank position from historical sources was often challenging. The outer bank was referred to as a "high bluff bank" or "bluff bank" (Thompson 1869, Norway 1878b), or simply the "high bank" (Craven 1874c,f). On some maps, both the edge of the sandy channel bed and the edge of the active channel were shown, facilitating interpretation of outer bank position. In addition, an outer bluff bank was often shown with hatch marks. However, the term "bank" was used differently by different surveyors, and could refer to either the outer bank or the boundary between the sandy channel bed and surrounding bottomlands. While auxiliary data (e.g., aerial photographs) were often used to determine the surveyor's intent, some of these data were ultimately not specific enough to be used. Through this process, we were able to develop a substantial, albeit partial, spatial dataset describing channel morphology between 1850 and 1927, including reliable mapping of the active channel area at a number of sites and times. This dataset allowed us to effectively sample the extent of change in active channel area for available locations and time sequences. While this process did not yield a comprehensive dataset of pre-1928 active channel location, it did provide confirmation in a number of places of channel position bracketing major flood events from 1862-1928.

A few areas are of known lower confidence. For example, the area east of Sespe Creek provides a conservative estimate of channel width; two GLO points at the same spot (Norris 1853, Craven 1874f) intimate that the channel extended an additional 1,400 feet to the north, but we chose not to extrapolate the entire section. For example, in cases where a map showed extensive bottomland for a portion of the river but no additional source showed the continuation of the feature upstream or downstream, we did not map the continuation of the bank. While it is likely that the outer bank continued, we had no historical data to confirm this. This resulted in a few jagged edges in our mapping where one source ends and no other shows the continuation of the feature. In addition, most of the Santa Clara River east of Piru Creek suffers from a lack of early data, and as a result is almost entirely mapped from the historical aerial. In general, this conservatism means that we may have undermapped river corridor extent in some places due to a lack of data. On the other hand, it should also be noted that in a few places (notably major tributaries to the Santa Clara River), outer bank mapping may represent multiple courses occupied by the creek but not historically occupied simultaneously, and thus may overrepresent the extent of river corridor at any given time.

It must be emphasized that this mapping is only an approximation of outer bank position for each system. A lack of data, or ambiguous data, often hindered interpretation. Futher external review and ground truthing of the mapping and comparison to modern conditions were outside the purview of this study, and will be essential before site-specific application.

RIVER CORRIDOR EXTENT While historical data support substantial changes in channel morphology within the active channel (e.g., in low-flow channel position and extent of young, in-channel riparian vegetation) on a frequent (year-to-year) basis, the position of the broader river corridor remained comparatively stable through the floods of the late 19th and early 20th centuries. Comparison with 1938 mapping shows significant changes in outer bank position in a few reaches. However, our analyses suggest that no extreme overall shifts in channel position or width occurred between the late 19th century (1870-1900) and 1938. Since many historical sources

confirm outer bank position before and after the 1884 flood (and a few before 1862), these data offer significant insight into flood effects on Santa Clara River morphology. In particular, our analyses imply that the geomorphic work of most large floods stays largely within the outer banks of the river, and that the position of these banks has until recently (1938) been broadly persistent over time.

Even the St. Francis Dam break appears to have had minimal long-term impact on the river's overall plan form configuration (fig. 3.15), despite noteworthy scour and extensive deposition at various locations along the river valley and the possibility that the gradient of the channel between the county line and Sespe Creek has been recovering ever since (Stillwater Sciences 2007b). Many riparian features persisted, as did the general width and appearance of the channel.

This conclusion is supported by recent research simulating flooding extent and discharge in the Santa Clara River valley after the dam break (Begnudelli and Sanders 2007). Modeling predicts a maximum discharge of about 1.5 million cfs at the dam and over 600,000 cfs around the county line. In the lower reaches of the river, however, modeled flow was only approximately 250,000 cfs (near Santa Paula) and about 140,000 cfs (at the river mouth). These figures imply that though the flood wave was equivalent to recurrence intervals of well over 1,000 years in the upper portion of the lower Santa Clara River, discharges attenuated rapidly downstream: by the river mouth the flood wave was calculated to be an event with only about a 20-year return period (Downs et al., submitted). These calculations validate the relative lack of documented large-scale plan form change.

Net loss in area between our earliest source mapping and 1938 conditions is 2,000 acres (fig. 3.16) or 13% of the 19th century area. (While it is possible that sediment deposition accounts for some of the

Fig. 3.15. Santa Clara River after the St. Francis dam break, 1928. This photograph was taken near Piru only five days after the failure of the St. Francis dam. (Isensee 1928a, courtesy of the Museum of Ventura County)

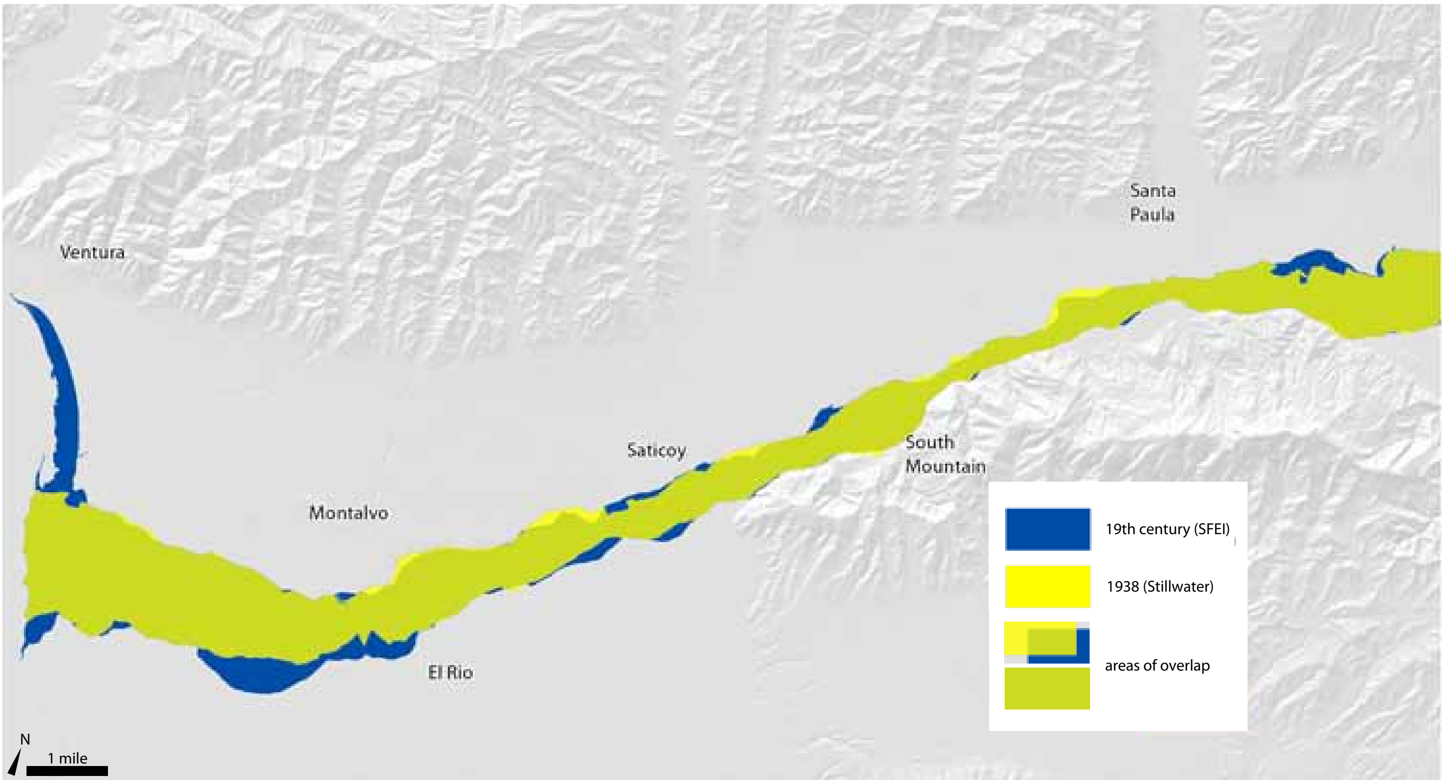


Fig. 3.16. River corridor extent and outer bank position, 19th century and 1938. By 1938, 13% (2,000 acres) of the river's former extent had been removed from the river's influence. Much of this lost river corridor was bottomland habitat near the river mouth and Sespe Creek. (1938 mapping from Stillwater Sciences 2007b)

channel narrowing by 1938, the bulk of this channel loss is from human encroachment on the river through cultivation, levee construction, etc.) While the data resolution is not sufficient to make reach-scale generalizations about stability, in many locations pre-1900s channel form coincides almost exactly with 1938 form (fig. 3.17).

In other reaches, however, comparisons between 19th century and 1938 mapping show substantial areas of channel change, on a scale of over 1,000 feet (fig. 3.18). The vegetated area south of the river in the Oxnard reach represents more than 2,300 feet of channel loss at its widest extent. The Sespe reach has been greatly constricted, especially the north bank just downstream of the Sespe confluence and in the Cienega (Fillmore Fish Hatchery) area. By 1938, bottomland areas in many portions of the Sespe reach extended 300-2,300 feet less far than they had in the 19th century.

It is important to note that while lateral migration of the Santa Clara River was relatively limited from the late 1800s to 1938, the character of many of the low-disturbance lands within the river corridor has changed dramatically over time. Many of these bottomlands were valued for agriculture (see Chapter 2 and pages 96-97), and by 1938 many were farmed. Our research suggests that much of the flooding damage occurred in these floodplain areas. While these areas may still have been hydrologically active in 1938 (i.e., subject to flow during flooding), many had lost substantial ecological value as riparian areas were replaced by farms and other uses.

Fig. 3.17. Examples of historical persistence in bank location. In many locations along the river, the position of the outer bank remained quite stable over decades, despite intervening major floods (including the St. Francis Dam break of 1928). This is illustrated here in three reaches: south of the Sespe Creek confluence (left), at South Mountain (middle), and at the Olivas Adobe near the river mouth (right). In each case, early (1854-1882) evidence also confirms the early 20th century (1927-1938) bank position. In each instance, by 2005 bank position has shifted somewhat. (USDA 2009)

The impressive stability of the SCR channel location over time, despite high intensity events such as 1862, 1884, and the St. Francis Dam break of 1928, suggests a channel with significant capacity to accommodate extreme events without significant lateral migration or changes in width. Though the channel has been significantly artificially narrowed at many spots, the largest plan form changes captured by our data set due to bank erosion were less than 1,700 feet. These types of changes, while immensely significant to local property owners, would have mostly represented very small proportions of the overall river.

By 2005, 7,600 acres of bottomland had been lost from the river corridor, nearly half of the 19th century area of about 15,500 acres (fig. 3.19). These areas had been converted to agricultural or urban uses, and were no longer regularly flooded or considered part of the river (fig. 3.20). Development

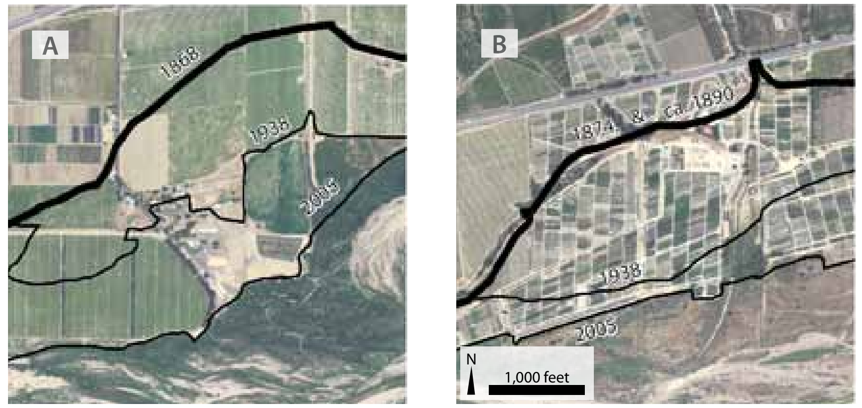


Fig. 3.18. Examples of historical change in bank location (top). In some places, bank position as documented by 19th century surveyors differed substantially from 1938 conditions, as shown here on the river west of the Sespe Creek confluence (left) and east of the Santa Paula Creek confluence (right). In each case, the river corridor had narrowed even further due to reclamation by 2009. (USDA 2009)

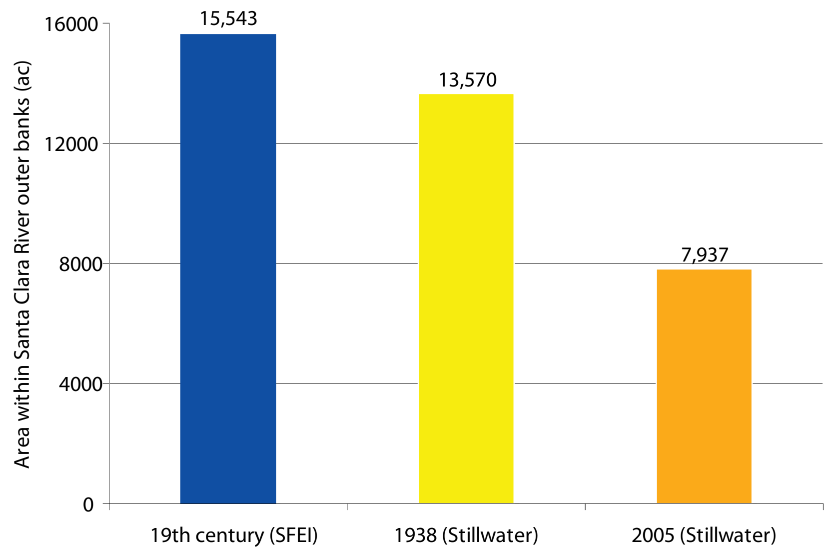


Fig. 3.19. (middle) From the 19th century to 1938, total river corridor area dropped only a little under 2,000 acres (13% loss), largely as a result of levee construction and agricultural encroachment on the channel. By 2005, over 7,600 acres had been lost, 49% of the original river corridor area. (1938 and 2005 data from Stillwater Sciences 2007b.)

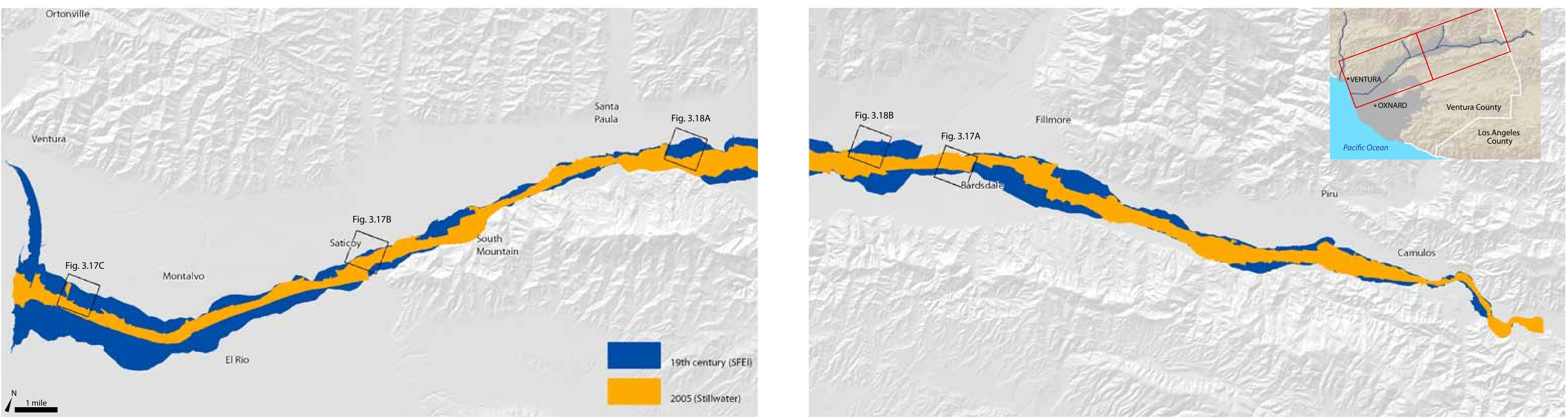


Fig. 3.20. (bottom) River corridor extent and outer bank position, 19th century and 2005. By 2005, over 7,600 acres had been lost, 49 % of the original river corridor area. Much of the lost area was bottomland habitats, leveed and reclaimed for farming and other land uses. Documented change is concentrated particularly in the Oxnard and Estuarine reaches (below Saticoy) and between Santa Paula and Sespe creeks. (2005 mapping from Stillwater Sciences 2007b)

trends over the past two centuries have resulted in a loss of floodplain bottomland, while the more regularly flooded sandy channel bed has been largely preserved. Today's river has been shaped by multiple flood events over the past centuries, in addition to more recent anthropogenic activities.

LARGE-SCALE CHANNEL CHANGE A notable exception to the overall trend of channel stability is the migration of the Santa Clara River mouth from Point Hueneme to its present location, a shift of over six miles upcoast. Geologic maps and early aerial photography of the Oxnard Plain clearly show a former course of the Santa Clara River flowing through El Rio and Oxnard before entering the ocean just south of Hueneme, about six miles south of the current mouth of the river (fig 3.21; Fairchild Aerial Surveys 1927, Clahan 2003). This inactive, meandering channel was mapped by Parsons (2004); he termed it the Saviers paleochannel and identified it as the former course of the Santa Clara River.

A few references to the old channel of the Santa Clara River are present in the historical record. An article in the *Ventura Free Press* (1878b) notes that "many years ago the waters of the Santa Clara emptied into the sea only about half a mile below the wharf," though it is unclear whether this was common knowledge at the time. At this time the expression of the old channel on the plain was likely still clearly visible in many places (Fairchild Aerial Surveys 1927), so this may have been widely accepted. A few 20th century researchers have also recognized the presence of the old route of the river (Carty 1973, Brown 1981, King 2005).

Fig. 3.21. Large-scale changes in the lower Santa Clara River course on the Oxnard Plain. Geologic, archaeological, historical, and edaphic data all support the migration of the Santa Clara River over the Oxnard Plain over geologic time. Extreme floods coupled with sediment deposition triggered channel migration on the Santa Clara River delta (Oxnard Plain) and subsequent large-scale changes in river corridor location. The dashed black lines represent paleochannels; the most recently occupied former course of the river (Saviers paleochannel, labeled a) may have been active as recently as 1812. It can also be seen here how ecological patterns of the Oxnard Plain are dictated by the channel migration history, with grassland/sage scrub on higher surfaces marking natural levees along more recently occupied routes of the river. (Nelson et al. 1917, Fairchild Aerial Surveys 1927, Clahan 2003, Parsons 2004)

It is unknown when the paleochannel was last actively occupied. Based on analysis of offshore sediments near Hueneme, geologists have estimated that abandonment of the Saviers paleochannel occurred no more than 2,000 to 3,000 years ago (Romans et al. 2009). Ethnographic accounts suggest that the shift may have happened much more recently, within at least the oral historical record of the Ventureño Chumash. One archaeological report cited Fernando Librado (a star informant for anthropologist John P. Harrington) as saying that the 1812 earthquake was the cause of the shift in channel course (Parsons 2004). While we were unable to find this (or any) document mentioning a specific year for the shift, this interpretation is not contradicted by additional ethnographic evidence. Multiple places in Harrington's (ca. 1913) field notes reference a time when the Santa Clara River mouth was near Point Mugu (Harrington 1986a,b). (Point Mugu referred to the broader Ormond Beach-Mugu section of shoreline; Parsons 2004.)

> Mugu estero used to be the mouth of the Santa Clara River. (Harrington 1986a)
>
> Ponom [Chumash name for a pond and marsh north of Oxnard]… Means (1) "que hay que cuidar," he must guard (2) for they had fear that sometime the river of Santa Clara could change its course back to Point Mugu… (Harrington 1986a)
>
> The V. river first had its mouth many years ago at the foot of hills west of V. river valley. This was long ago. Then it changed to mitsqanaqan—then in 1810 (so the old men said) in a flood to its present location. Santa Clara River ran into Migu [sic] Laguna, but more recently changed. (Harrington 1986b)

This last quote seems to imply that the Santa Clara River changed course after 1810, though this is not substantiated by other documents. Regardless, these recollections point strongly to a channel shift in the recent past (e.g., roughly 200-500 years ago). It seems probable that if the channel had changed position 2-3,000 years ago, as posited by Romans et al. (2009), the event would no longer be in the cultural memory of early 20th century Ventureño Chumash descendents as a relatively "recent" change. This interpretation is supported by the historical (19th century) presence of occasional sycamore trees on the higher alluvial sediments of the paleochannel, indicating relatively recent occupation of the channel course.

Hydraulic Geometry and Channel Form

In comparison with channel width and stability, channel geometry is relatively poorly documented. Few early sources provide site-specific accounts of bank height or thalweg depth, and all but the broadest information on channel plan form is undocumented. A brief overview of these topics is provided here.

CHANGES WITHIN THE RIVER CORRIDOR While lateral changes in river corridor location were relatively limited on a year-to-year scale, within its outer banks the Santa Clara River was quite dynamic. High flows would regularly cause shifts in mainstem position, causing the river to reoccupy former channels or cut new ones within its corridor. The width and location of the active channel, the distribution and density of in-channel vegetation, and the position and extent of bottomland would have also shifted with each major flood (fig. 3.22). Shifts in relative riparian cover and the nature of the active channel were identified by early settlers describing the Santa Clara River:

> …the land which this season might be of some value for pasture or agriculture, might next summer be a bed of naked sand, for we know how capricious these streams are when flowing through a light sandy soil. I was informed by a gentleman residing in the Buenaventura, who had resided several years upon the Rancho of Sespe that he had seen the whole bed of the river covered with sand. (Hopkins 1871)

Other accounts also describe changes to the bottomland as a result of flooding (e.g., *Ventura Free Press* 1876, *Ventura Free Press* 1891b). Much of the low-lying riparian vegetation—willows and cottonwoods in or close to the active channel—would be uprooted from the river during major flood events. A few long-time residents of communities along the Santa Clara River noted that during significant floods of the late 19th and early 20th centuries, substantial portions of the riparian vegetation in the river would grow between major flood events, then be scoured out by flood waters:

> The reason that the 1884 flood seemed to be a very large flood is that the river was very heavily loaded with cottonwoods. Some of these cottonwoods were 50 or 60 feet high and had an undergrowth about eight feet high. (War Department 1938)

> [during 1884 floods] The banks of the Santa Clara River, the Sespe and Santa Paula Creek that had been lined with great oak, sycamores, and cottonwood trees, that had stood for centuries on their banks, had been swept bare… The Santa Clara River took out hundreds of acres of good land and left stones in its place. (Hardison, in Freeman 1968)

> I think a great part of the damage done by the floods is caused by the growth which has occurred in the streams over a period of many years. In 1914 this growth was all washed up and we have had 24 years [between 1914 and the 1938 flood] in which to grow alders, willows and cottonwoods. When a big freshet comes, it takes this debris down in great quantities. (War Department 1938)

This [flooding] is all caused by the Santa Clara river, which gets very high and changes its course to first one side and then another.

—VENTURA FREE PRESS 1891B

Much later accounts describe that between floods "much of the bed is overgrown with weeds and willows" (C.E. Grunsky Company 1925) and that "during the dry period these willows encroach on that stream, so that during a major flow there is not enough open channel available" (War Department 1938). These dynamics are discussed further in the riparian vegetation section (pages 96-97).

It should be noted that some sources indicate that land use changes within the valley and tributaries altered effects of floods, making the active channel and bottomlands more susceptible to large-scale changes than previously. This effect was identified by the early 1880s: in 1886, a resident of Ventura noted that "within the last four or five years the Santa Clara River and those of its tributaries whose sources have been stripped of timber and brush, now

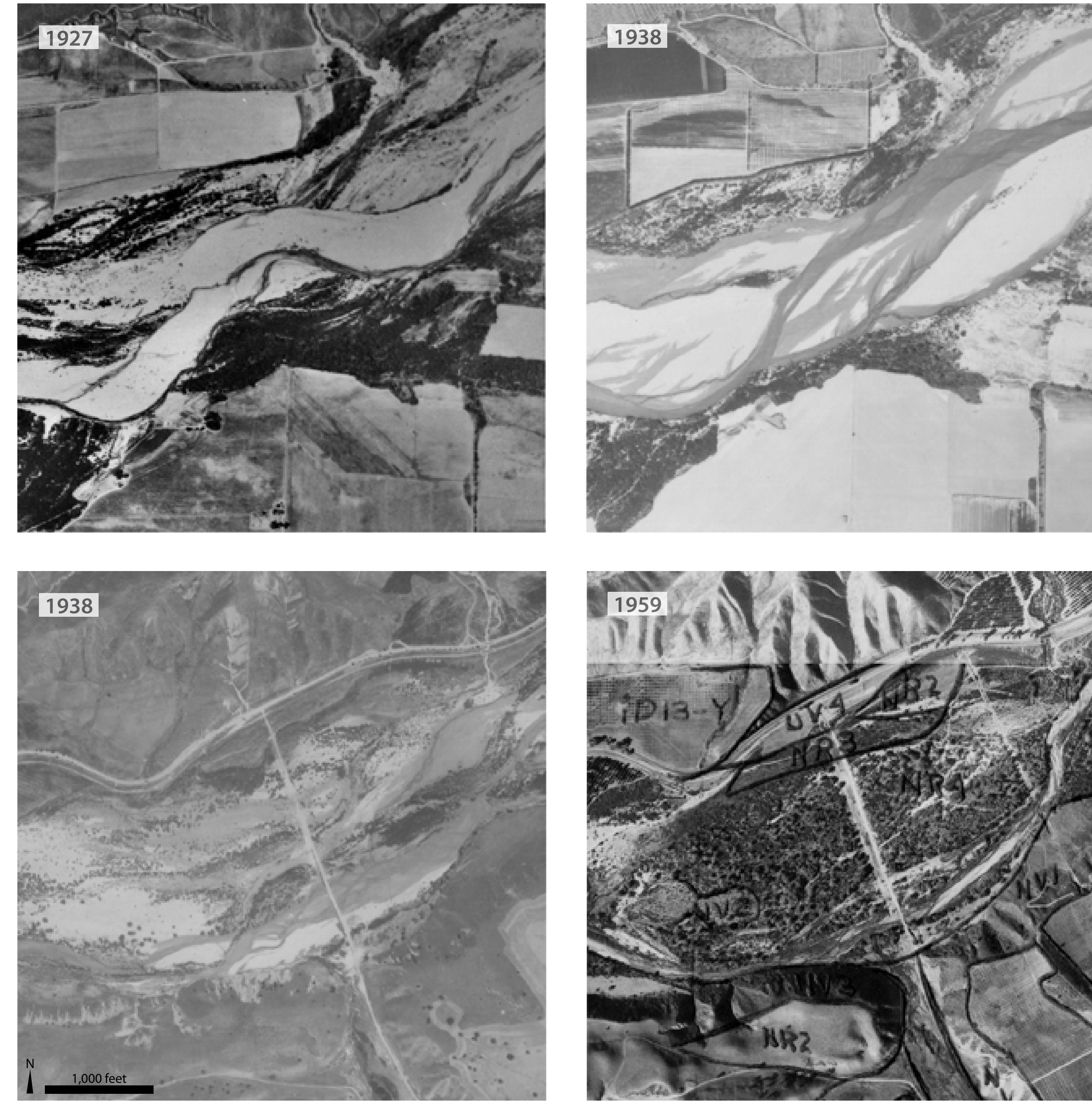


Fig. 3.22. Decadal-scale shifts in in-channel riparian vegetation and channel form. Major floods reworked the active channel and floodplain, creating new channel and vegetation patterns. Top images: Santa Clara River east of Santa Paula, 1927 and 1938. Bottom images: The river east of the Los Angeles County line, 1938 and 1959. (Fairchild Aerial Surveys 1927, courtesy of Whittier College; USDA 1938, courtesy of Ventura County; USDA 1959, California State University Northridge, Map Library)

run more violently and destructively than formerly. As a consequence, the Santa Clara Valley is being much injured by floods" (California State Board of Forestry 1886). It is possible that floods of the late 19th and early 20th century—in particular 1884, 1914, and 1938, in addition to the St. Francis Dam break—may have impacted in-channel riparian distribution and bank position stability more significantly than previous floods of record. However, these accounts are hard to interpret given the relatively short memory of these observers in comparison to longer (e.g., decadal scale) variations in climate and precipitation, and the observed effects may not be a direct result of changes in land use.

INCISION/CHANGES IN BED LEVEL Stillwater Sciences documented changes in bed elevation from 1949 to 2005 for the entire lower Santa Clara River (and back to 1929 between Santa Paula and Piru creeks), noting trends by reach in incision and aggradation. As is the case for many historical studies, however, we did not recover documents in the historical record to permit a comprehensive quantification of earlier trends in bed level. It is possible that human actions may have created local changes in bed level prior to 1929/1949. For example, changes associated with the St. Francis Dam break flood of 1928 may have caused incision of the Santa Clara River above Fillmore (Downs et al., submitted), or changes in hillslope vegetation associated with grazing and introduction of invasive species could have caused channel aggradation. However, it is also possible that regional bed level changes prior to the 20th century would have occurred primarily in response to avulsion of the lower reaches across the Oxnard Plain rather than as a response to human activity.

While no comprehensive data set detailing bed elevation exists for the period before 1929, scattered early observations provide limited evidence for changes in bed level since the 1700s. Notably, near Saticoy and Piru in 1769, Crespí noted that the active channel was quite shallow: "the bed does not lie very deep" (Piru, Crespí and Brown 2001) and "the bed must have a width of fifty varas [140 feet] of sand… very shallow and on a level with the land of this great plain" (Saticoy, in Crespí and Bolton 1927). Almost 100 years later, another traveler also described the Santa Clara River near Montalvo as having "a wide, sandy, shallow bed" and "low banks" (*Daily Alta California* 1868).

In some areas high bluff banks were (and still are) present, such as near the Olivas adobe (built 1837, enlarged in 1849) on the right (north) bank of the river near its mouth, where a bank 20 feet high (Hancock 1854) provided some protection from flooding. King (1883) also noted around Piru that "at some points the banks of the river are 20 ft high."

CONNECTIVITY TO MINOR TRIBUTARIES Prior to the widespread construction of channels connecting them to the Santa Clara River, most small creeks appear to have sunk into the coarse soils of their alluvial fans rather than maintaining a defined channel all the way to the river. In the 19th century, these small creeks would have mostly maintained a subsurface connection with the Santa Clara River, and possibly a brief seasonal surface connection through poorly defined channels in times of high water.

In contrast, in the present-day drainage network nearly every tributary is directly connected via engineered channels to the river. Even relatively small channels with limited flow are currently connected with the river's mainstem. This change is captured on numerous historical maps which show the unconnected streams disappearing on the valley floor (e.g., Holmes and Mesmer 1901b, USGS 1903a). In addition, many anthropogenic surface connections are striking on the historical (1927/1938) aerials for the river valley, which often clearly show the transitional point between the sinuous, natural upstream portion of a creek and the straight, engineered downstream portion. This systemic change has implications for the density of the drainage network of the valley and the speed at which water is delivered to the Santa Clara River. Increased drainage density has the potential to create higher flood peaks and bank erosion downstream, as well as reducing groundwater recharge (SFEI 2011).

Dry Season Flow

While some research has been conducted to determine the nature of flow on the Santa Clara River prior to significant Euro-American modifications (cf. Schwartzberg and Moore 1995, Nautilus Environmental 2005) and some researchers have speculated that perennial flow would have been present along much of or the entire river (Stillwater Sciences 2007b; see also Boughton et al. 2006 for general Southern California historical flow), little comprehensive research has been conducted to assess specific local historical conditions.

Information compiled from narrative accounts, maps, and photographs suggest that while substantial persistent, perennial reaches were present along much of the Santa Clara River, there were also extensive sections of consistently intermittent flow. From Crespí's journey in the summer of 1769 to water availability reports of the early 20th century, the historical record consistently defines certain reaches as intermittent, while others are commonly described as having water year round. These patterns in summer base flow reflect surface water-groundwater interactions, which are controlled broadly by groundwater basin location and the faults and structural variations in valley width and depth.

Crespí's River

Fortunately for current researchers, Spanish explorer Crespí's expedition traveled down the Santa Clara River from near Saugus to Saticoy in mid-August 1769, describing flow conditions in many places. Crespí observed that large portions of river maintained substantial summertime flow, while others were completely dry (fig. 3.23). Though 1769 was part of a relatively wet period, Crespí's descriptions appear representative of larger trends supported by additional sources, as discussed in detail below (Lynch 1931).

On the Santa Clara River above Camulos on August 10, 1769, Crespí recorded a "good-sized stream of running water following us ever onward," with cottonwoods, willows, grapevines, and live oaks along the channel (Crespí and Brown 2001). The river continued to have a "large flow of water" until just above Camulos the next day, where Crespí noted that

> After accompanying us with a good-sized flow of running water all during yesterday's march, the stream, shortly after we set out today, stopped flowing amid the great amounts of sand in the bed of this stream, seemingly sinking into its many sands; the bed is plainly over a hundred yards in width in spots, and must be a very full-flowing river at some seasons, as is shown by its many piles of drift and large banks of sand.

Approximately 9 miles later, around the widening of the valley east of Fillmore, Crespí noted that they "once more came across a good-sized stream of running water" that continued for "some leagues down the hollow." He made no more explicit mention of flow until around Saticoy, where he noted that the river was "not too far off to water the mounts at":

> The river bed here must be about fifty yards wide across the sand; the breadth of water flowing must have been about some eighteen yards, running very shallow—very good, pure water.

At this point Crespí ceased following the river, though he does note that the river "runs through this plain, flowing down onto it from the Santa Clara

Hollow we have just come through, southwestward, and on out over the aforesaid plain here to empty into the sea."

Supporting Evidence

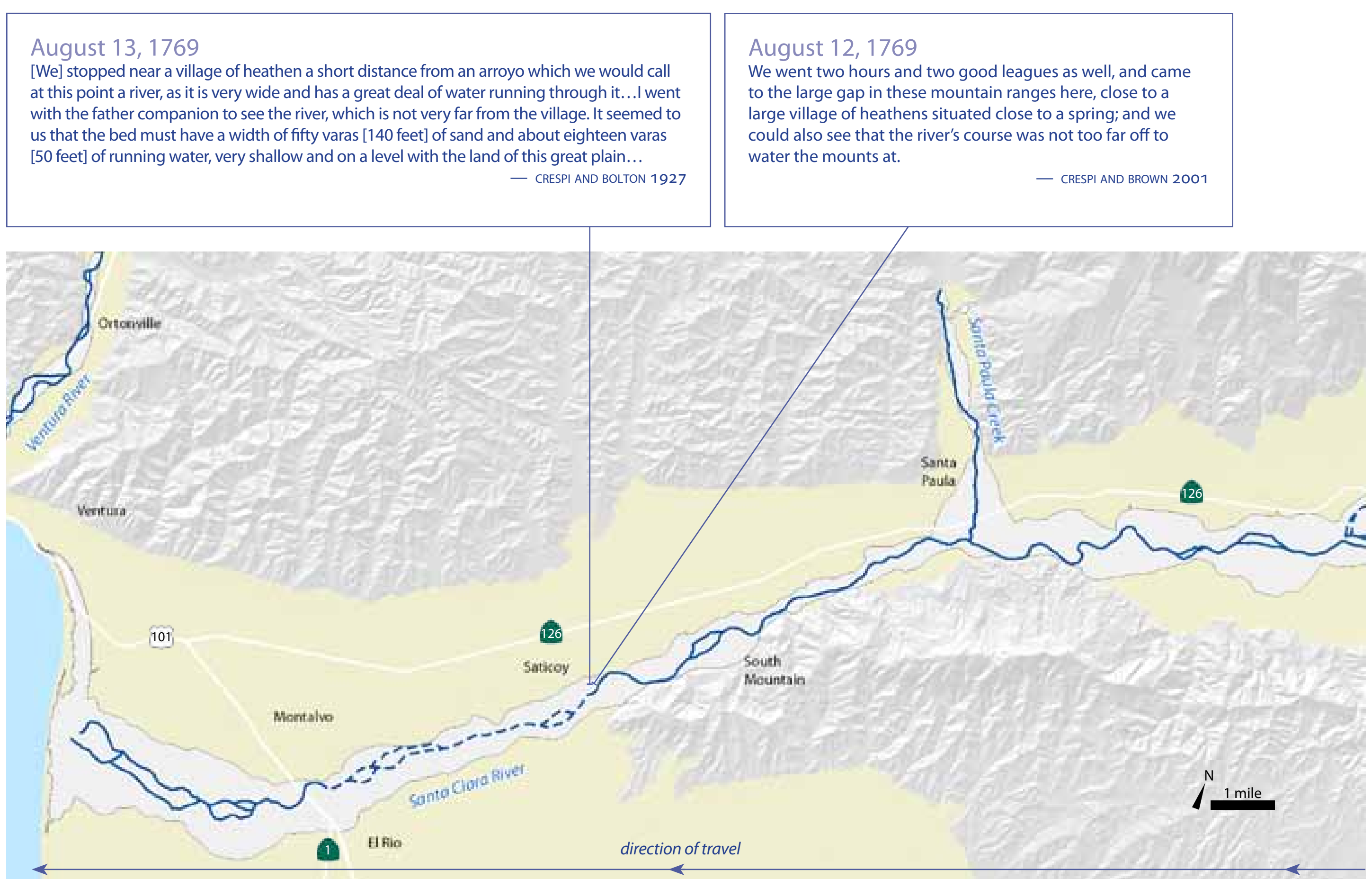
Crespí's assessment of summer flow along the Santa Clara River is largely corroborated by other, later observations of flow characteristics (table 3.2). One late 19th century source estimated that the Santa Clara River was "dry for four-sevenths of its course during a part of the year" (Porter et al. 1882), a depiction that is overstated but roughly reflective of flow conditions portrayed by more specific accounts. More than 160 years later, Freeman (1930) described similar, if somewhat diminished, flow patterns along the river (see page 82).

In particular, the disappearance of summer flow around Camulos is well documented. Above Camulos (in the Del Valle reach), Freeman (1930) noted summer surface flow, and King (1883) observed an "ample supply of nice, clear water" when traveling in mid-October. Just above Camulos, however—where Crespí observed flow disappearing into the river bed — Freeman notes that "water begins to disappear," and a September 1858 survey of Camulos Ranch notes that the "river at this time is dry" (Hancock 1858). An early *diseño* shows the river disappearing a little after Camulos, and well before reaching Piru Creek. This transition is also captured by the

The ride back to the Camulos was one of the pleasantest features of the day…Farther to the east outspread the russet fields of the Newhall Rancho, a magnificent stretch of sixteen miles of valley, with the blue artery of the Santa Clara river running its entire length.

—NINETTA EAMES, EARLY FALL 1889, AUTUMN DAYS IN VENTURA

Fig. 3.23. Crespí's River, August 1769. The Santa Clara River exhibited a pattern of alternating reaches of perennial and intermittent summer flow, as depicted below (dashed reaches are intermittent). These patterns were recorded in the observations of Spanish explorer Juan Crespí, travelling downstream along the river from August 10-13, 1769. Though Crespí's observations cannot all be placed precisely, they provide detailed, early observations of flow patterns on the river.



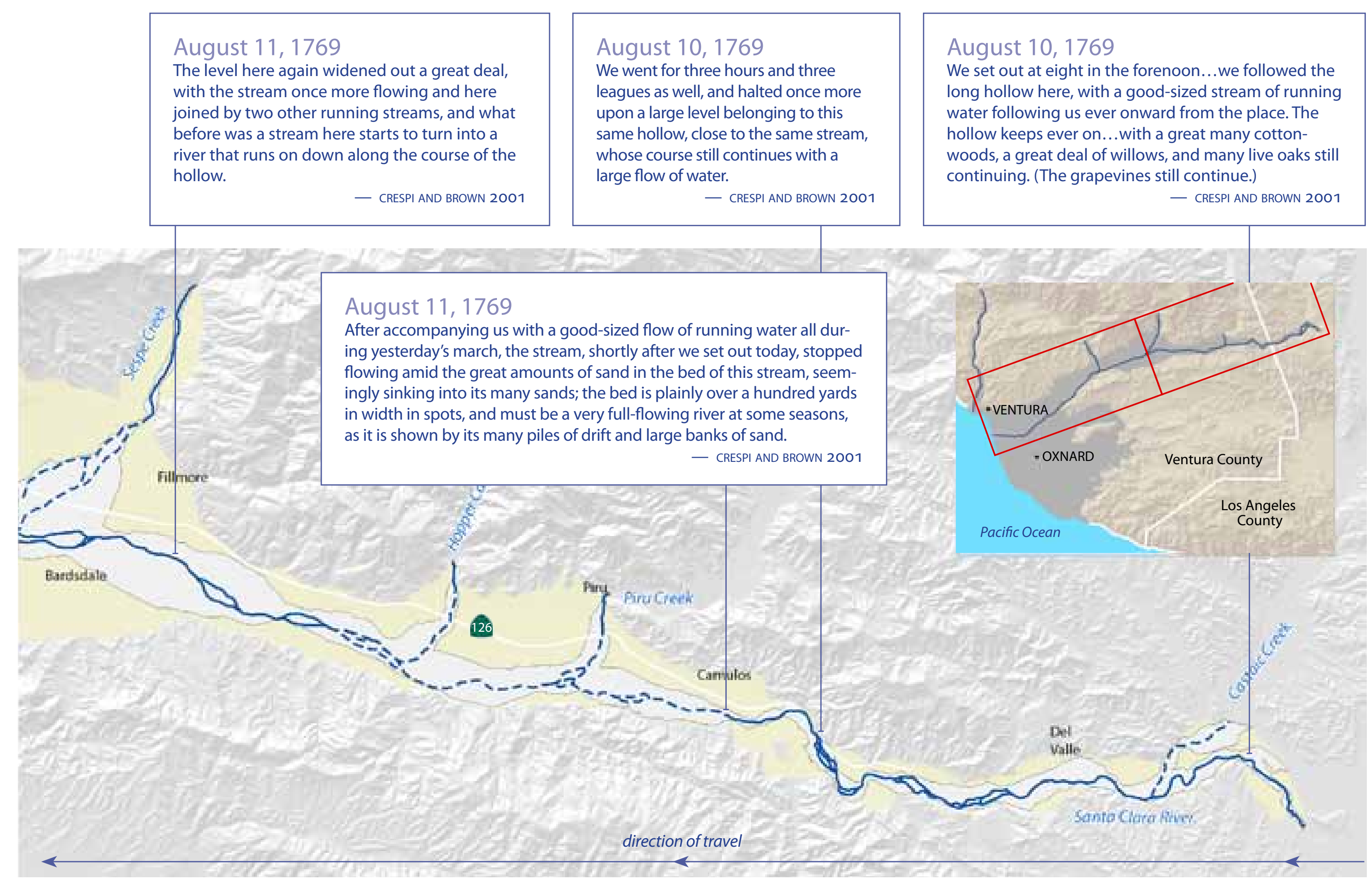


Table 3.2. Evidence of summer flow by reach on the Santa Clara River, 1769-1930.

Reach	Date	Evidence	Reference
Oxnard (river mouth)	early October 1855	"an insignificant stream, with but an inch or so of water in its channel."	Johnson 1855a
Oxnard (river mouth)	October 24, 1879	"somewhat rapid stream"	Bowers 1879, in Benson 1997
Oxnard (river mouth)	June 1, 1899	"running water"	Waud ca. 1899
Oxnard (river mouth)	September 1857	"nearly dry during the summer"	*Daily Alta California* 1857
Oxnard (101 crossing)	August 1868	"some water flowing where we crossed it, and quite a large body a few miles above"	*Daily Alta California* 1868
Oxnard (101 crossing)	June 18, 1883	"wide sandy bed where an emaciated stream reposes till revived by winter rains"	Seward [1883]1937
Oxnard (Saticoy)	Late summer/early fall 1889	"loitering along its sandy bed as if it were loth to reach the sea"	Eames 1889
Oxnard (Saticoy)	August 13, 1769	"the breadth of water flowing must have been about some eighteen yards, running very shallow"	Crespí and Brown 2001
Oxnard (Saticoy)	Summer 1872-3	"dry in summer for seven or eight miles"	Cooper 1887
Oxnard (Saticoy)	June 8, 1854	"water of Rio Santa Clara, current near 6 miles per hour and average depth 9 inches"	Hancock 1854
Santa Paula	Summer 1872-3	"Santa Clara River runs permanently"	Cooper 1887
Sespe (at Sespe Creek confluence)	October 12, 1853	"to water"	Norris 1853
Sespe (E of Fillmore)	August 11, 1769	"good-sized stream of running water"	Crespí and Brown 2001
Sespe (3 miles E of Bardsdale Bridge)	Summer	"water again comes to the surface"	Freeman 1930
Piru (~2 miles west of Piru)	October 1853	"the water of the river has sunk at this point"	Norris 1853
Piru (~1 mile west of Piru)	Oct 7-11, 1878	"dry bed of Santa Clara River"	Chillson 1878
Piru (3 miles east of Piru)	Summer	"water begins to disappear"	Freeman 1930
Piru (above Camulos)	August 11, 1769	"the stream…stopped flowing amid the great amounts of sand in the bed"	Crespí and Brown 2001
Piru	September 1, 1858	"river at this time is dry"	Hancock 1858
Del Valle	October 16, 1883	"ample supply of nice, clear water"	King 1883
Del Valle	August 10, 1769	"large flow of water"	Crespí and Brown 2001
Del Valle	Summer	"ground water…rises to flow along the surface"	Freeman 1930

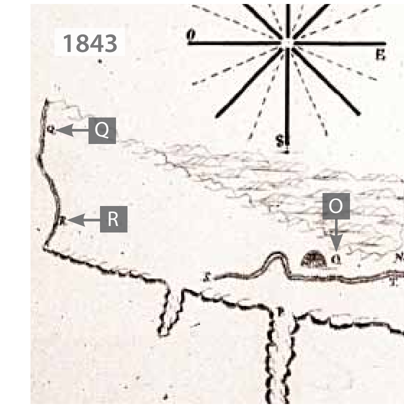
USGS topographic quad from 1903 [Santa Susana], which shows a solid blue line in the sandy bed of the Santa Clara River (the conventional USGS symbol for a permanent stream) from west of Saugus to ½ mile east of Camulos, where a forked distributary represents the stream sinking into its sandy bed (fig. 3.24).

The Santa Clara River remained dry until above the confluence with Sespe Creek (about 1.5 miles east of the fish hatchery), where surface flow resumed (Freeman 1930). Around Fillmore, Fray Señán of Mission San Buenaventura noted that substantial summer water was present above Sespe Creek : "in time of flood or after heavy rains it is impossible to cross the river for 2 or 3 days…Throughout the rest of the year the river carries no small volume of water" (Señán 1804). Historical data are not abundant in the area around the Sespe confluence, though one surveyor does note water in the channel in early October (Norris 1853) and a few survey maps show diversion dams and summer (June) flow (Barry 1892b, Unknown 1894). Definitive descriptions of flow resume above Santa Paula Creek: around Santa Paula extending east toward Fillmore, ornithologist Cooper wrote that "the Santa Clara River runs permanently and a grove of poplars [cottonwoods; *Populus* spp.] and willows lines its marshy shores for several miles" (Cooper 1887).

Evidence for dry season flow is more ambivalent in the area around Montalvo and Saticoy, though it appears that this reach was most likely intermittent as water spread and sank into the coarse gravels of the Oxnard Plain below South Mountain. Cooper (1887), who spent time near Saticoy during 1872-3, described the river as completely dry during the summer along this reach:

> The Santa Clara River runs half a mile distant, but is dry in summer for seven or eight miles along that part of its course, leaving a wide, sandy and gravelly bed, destitute of vegetation except on a few higher patches where small poplar and willow trees grow, with low shrubbery, and which become islands in the high water of winter.

While most other historical accounts do describe the presence of some summer water in this reach, almost without exception they also mention the limited amount of water present (as opposed to the Santa Paula reach, where the river had abundant summer water). Just above Saticoy, near where Crespí described watering his mounts in the "very shallow" river in 1769, Freeman (1930) remarked that surface water "begins to disappear into the gravels beneath the Oxnard Plain," and an 1889 depiction of the river late in the dry season in the same area described it "loitering along its sandy bed as if it were loth to reach the sea" (Eames 1889). Also near Saticoy, General Land Office surveyor Henry Hancock reported in June 1853 a "current near 6 miles per hour and average depth 9 inches," indicating that by late summer flow would have been extremely shallow or nonexistent. Cooper's interpretation of the Saticoy-Montalvo area as summer dry is supported by USGS (1903a) historical mapping and Crespí's earlier observations that "no trees are to be seen nearby" in the area (Crespí and Brown 2001), indicating limited summer water availability.



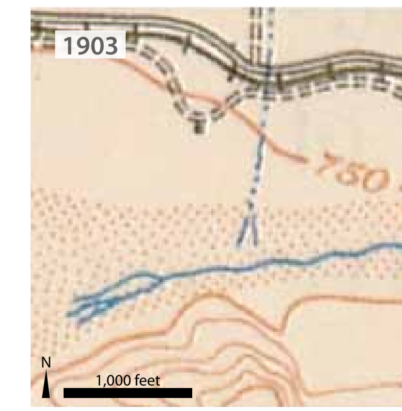


Fig. 3.24. An early *diseño* (top) shows the Santa Clara River—which it calls the "Arroyo de la Soledad"—stopping abruptly before reaching Piru Creek (labeled on the *diseño* as "Q-R"). This corresponds to the well documented location of the loss of summer surface flow in this reach, near Camulos (which is labeled with a small hut and "O" on the *diseño*). A historical USGS quad (bottom) shows the loss of flow in the same location, around sixty years later. (Unknown ca. 1843, courtesy of John Johnson and Santa Clarita Valley History; USGS 1903b, courtesy of the CSU Northridge Map Library)

TRENDS IN SANTA CLARA RIVER HYDROLOGY

The Del Valle, Sespe, and Santa Paula reaches were consistently perennial across the historical record, with abundant summer water (as evidenced by the presence of other features as well, such as freshwater wetlands, ponds, and willow-cottonwood forest; see page 94). The Piru reach, on the other hand, was consistently drier. The upper Oxnard reach (around Saticoy) also appears to have had limited, if any, summer water. In semi-arid systems in the southwestern United States, this type of system—with alternating perennial and summer-dry reaches—is called an interrupted perennial river (Stromberg et al. 2005).

Many of the same physical factors that historically controlled summer surface flow are still relevant today, and as a result many of these hydrologic trends are reflected along the Santa Clara River today (UWCD and Castaic Lake Water Agency 1996). Valley narrowing and geologic constraints force groundwater to the surface at the transitions between groundwater basins in the Del Valle, Sespe, and Santa Paula reaches, while inputs from tributaries (in particular Sespe Creek, which is still unregulated) also help maintain surface flow. On the other hand, in the Piru reach and downstream of South Mountain surface water is quickly lost in the broad, unconfined alluvium. The reach of perennial flow at the river mouth coincides with extent of the former artesian zone (Lippincott ca. 1930), the lowest portion of which is currently affected by the City of Ventura's wastewater treatment plant.

However, the presence of surface water would have been readily impacted by surface diversions, groundwater extraction, and climatic variability. Thus while broad patterns in surface water availability have persisted to the present day, the factors listed above have impacted the extent and hydrology of perennial and intermittent reaches along the river. In particular, on the Oxnard Plain (where surface flow was already often shallow), summer water availability would have been very sensitive to changes in hydrology and water management. This would have been true in dry years (e.g., Cooper (1887) described summer-dry conditions around Saticoy in 1872-3, noting that the season had been "uncommonly dry"), as well as after impacts of flow diversions and groundwater extraction of the late 19th and early 20th century.

This sensitivity is reflected in changes in flow regimes in the river in the first part of the 20th century, most notably on the Oxnard Plain. By the beginning of the 20th century, portions of the river once considered perennial were described as seasonally dry: "For the greater part of the year both the Santa Clara and Ventura rivers are dry in their lower reaches" (Holmes and Mesmer 1901c). Cooper (1967) expanded this observation to the entire river, noting that both Ventura and Santa Clara river were "dry most of the time but carrying very heavy loads during occasional floods." Tait (1912) was even more explicit (and extreme) about the cause of this drying, stating that "all of the summer discharge of Santa Clara River is taken out for irrigation and about forty pumping plants take water from wells."

Engineer Vern Freeman, writing in 1930, provides more resolution to the mid-century state of summer flow on the river. Consistent with Crespí and other accounts, Freeman recorded that the Santa Clara River was perennial until a point about three miles east of Piru, and then again for extensive sections around Fillmore and Santa Paula. However, he does record a summer-dry reach not mentioned by Crespí or 19th century sources between Santa Paula and Sespe creeks, and does not mention any summer surface flow present on the Oxnard Plain (though Mann (1958) does note that "there is little further percolation" below the Highway 101 bridge, a formerly perennial reach). Contractions in the extent of summer water in the river by 1930 could be indications of the impacts of surface diversions and groundwater extraction.

Currently (2011), flow patterns on the river appear to broadly mirror historical trends. Of course, while physically-controlled rising groundwater patterns remain generally consistent, water impoundments, diversions, and releases continue to affect extent and location of summer water, in addition to the quantity of surface water in the perennial reaches and the relative dryness of the intermittent reaches.

Below the Montalvo (Highway 101) bridge and closer to the river mouth, early descriptions also indicate that while the river was likely perennial in most years, surface water was not as abundant as in perennial reaches upstream, and flowed shallowly over the Oxnard Plain. Surface water was perennially found where the zone of artesian water intersected the river in this lower reach (Lippincott ca. 1930). Johnson (1855a) recorded that in early October, the river was "an insignificant stream, with but an inch or so of water in its channel." This sentiment was echoed by numerous observers, who described minimal surface flow from Saticoy to the ocean: what Seward ([1883]1937) called "an emaciated stream." Davidson (1864) wrote that the river was "nearly dry during the summer, and terminates in lagoons and marshes," while a traveler crossing the river near its mouth (presumably the Montalvo crossing) in late August 1868 wrote that "There was some water flowing where we crossed it, and quite a large body a few miles above" (*Daily Alta California* 1868). Bowers (1879, in Benson 1997) called the river a "somewhat rapid stream" near the mouth in late October.

The water of the river at its low stages disappears in one stretch of the river to reappear in another.

—GRUNSKY 1925

Riparian Habitats and Ecology

Riparian vegetation along the Santa Clara River was historically heterogeneous and diverse. Habitat features commonly documented along the Santa Clara River include willow scrub, alluvial scrub, herbaceous cover, cottonwood-willow forest and woodland, freshwater marshes, and mature individual sycamores and oaks. Unlike the Ventura River, much of the Santa Clara River was characterized by the absence of mature stands of riparian woodland or forest, though there were a few notable exceptions along the river. While the historical data set generally lacks the resolution to map these riparian characteristics at a fine scale, emergent patterns are evident; these define the coarse-scale variation in riparian vegetation found along the river corridor. These broad associations between landform or topographic setting, river reach, and vegetation are discussed below.

Distinct vegetation patterns characterized the outer banks, bottomlands, and active channel of the Santa Clara River (for definition of terms see morphology section, page 61). Large live oaks and sycamores (documented between two to four feet diameter) were found along portions of the outer banks, removed from the regular overflow zone. Bottomland areas were primarily dominated by riverwash, herbaceous cover, and willow/riparian scrub, though in some perennial reaches densely vegetated, mature stands of willow-cottonwood forest and wetlands (which we term "persistent wetland riparian areas" or "willow-cottonwood forested wetlands"; see page 94) were prevalent. Within the active channel, scrub colonized bar and island surfaces slightly elevated above the mostly sandy (and sometimes gravelly) river bed. The river bed itself would have been often bare in the winter and early spring, and covered in herbaceous vegetation by summer. Sloughs and side channels supported in-channel valley freshwater and alkaline marshes (fig. 3.25). GLO notes confirm the position of riparian trees on distinct geomorphic surfaces: in the Santa Paula reach, one

Fig. 3.25. This image of the Santa Clara River west of Santa Paula was taken on March 17, 1928—only five days after the St. Francis Dam break swept through the Santa Clara River valley. The recent presence of high flows is evident in the low vegetation along the river, which is bent downstream in the direction of flow. Even after such a large event, riparian patterns are evident: live oaks are seen bordering the river, while the bottomland surfaces are dominated by low scrub. The active channel is largely unvegetated, having been recently scoured by the flood. (Isensee 1928b, courtesy of the Museum of Ventura County)

survey note describes a "large live oak on high bank of Santa Clara River" (Hoffman 1868b), while nearby a 16-inch diameter cottonwood was found at the "foot of [the] perpendicular bank" (Norway 1878b).

Riparian characteristics also varied broadly by reach, with well developed trees flanking some portions of the river, and little to no riparian cover in other reaches. This reach-level variability in vegetation was observed by early explorers, travelers, and surveyors. In the lower Oxnard, Santa Paula, and Sespe reaches, for example, the active channel was narrower, and substantial bottomlands—many supporting wetlands and dense riparian forests—developed along much of the river. In the wettest portions of these reaches, GLO surveyors recorded willows and a few alders and box elders on bottomland surfaces, along with live oaks and sycamores on the high banks (Norris 1853, Hoffman 1868b, Thompson 1869). In contrast, in the historically intermittent Piru reach bottomlands were narrow and sparsely vegetated, while sandy riverwash in the active channel spread almost bank to bank. This reach stands out for its lack of riparian trees recorded by GLO surveyors (only one sycamore 14 inches in diameter, and two "no timber" points).

As a result, riparian forest along the Santa Clara River did not create a continuous corridor (fig. 3.26, 3.27). In the perennial reaches, explorer Crespí's 1769 account describes the river with "a great many cottonwoods, a great deal of willows, and many live oaks" in addition to wild grapes (Del Valle reach), or with "vast numbers of lush plants (the grapevines still continue)" (Sespe reach), or with "trees on all the river bed…sycamores, live oaks, willows and white [Fremont] cottonwoods" (Santa Paula reach; Crespí and Brown 2001). Conversely, accounts of the river outside of these wetter reaches describe more dispersed trees. In the intermittent portion of the Oxnard reach near Saticoy, for example, Crespí notes that "no trees are to be seen nearby" (though he did see "a great deal of trees" near the shore; presumably West Grove in the perennial reach near the river mouth). One article describes the river with "no gigantic trees bordering its low banks, only a group of cottonwoods; and a clump of willows, here and there" (Clifford 1872), and another "small, isolated groves of cottonwoods and willows, with here and there an occasional sycamore" (Evermann 1886). One writer even called the Piru reach a "desert" (Eames 1889).

Beautiful, indeed, is the Valley of the Santa Clara. Graceful the limpid waters of the river, fringed with willow and cottonwood…

—*DAILY ALTA CALIFORNIA* 1865

These historical patterns—differences in riparian vegetation on different geomorphic surfaces, as well as longitudinal variations between reaches—are consistent with findings in other semi-arid streams and even with present-day patterns observed along the highly modified Santa Clara River. In general, water availability is considered to often be the strongest limiting factor in determining riparian vegetation composition and distribution in semi-arid streams (Hupp and Osterkamp 1996, Tabacchi et al. 1996, Lite et al. 2005, Sandercock et al. 2007, Stillwater Sciences 2007a, Osterkamp and Hupp 2010, Orr et al. 2011). Water availability varies laterally (depth to groundwater), as well as longitudinally based on geologic and topographic

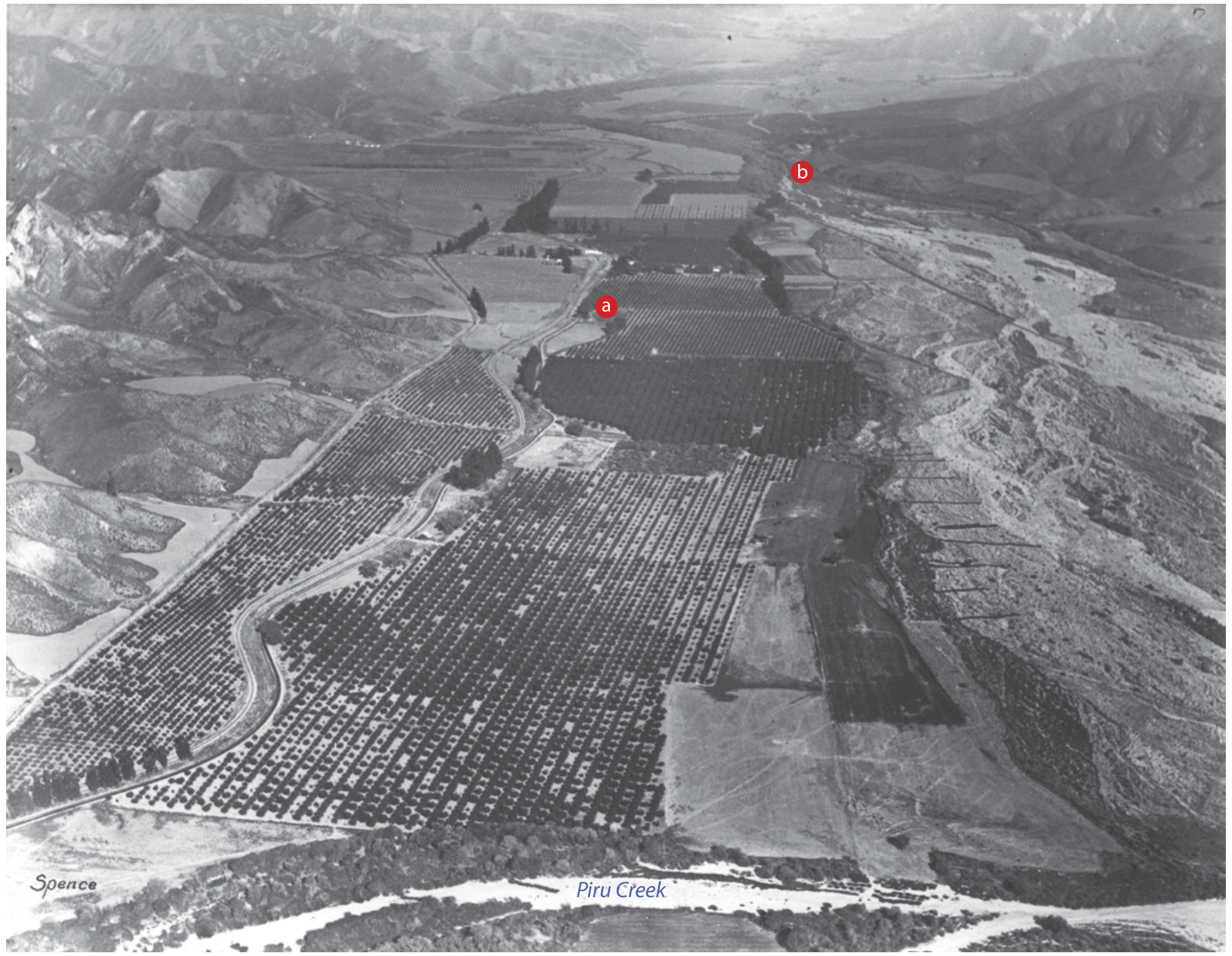


Fig. 3.26. Camulos Ranch in Piru, September 1924. Upstream of Camulos Ranch (marked a in the photograph), a continuous belt of riparian trees flanked the Santa Clara River. Downstream of the ranch, the river widened considerably; forest disappeared and was replaced by alluvial scrub and riverwash b. This ecological transition also marked a hydrologic one: the location of disappearance of summer surface water on the river. Piru Creek can be seen in the foreground. (Spence 1924, courtesy of Benjamin and Gladys Thomas Air Photo Archives, Spence and Fairchild Collections, UCLA, Department of Geography)

controls (e.g., depth to groundwater and to bedrock, depth of alluvium, and summer surface flow). As a result, variations in riparian characteristics across both gradients can be expected.

Longitudinally across different reaches of a semi-arid river, heterogeneous hydrology (in particular, presence of summer surface flow and depth to groundwater) can drive corresponding patterns of riparian vegetation (Tabacchi et al. 1996, Sandercock et al. 2007, Stillwater Sciences 2007a). This interaction between stream seasonality and vegetation can be clearly seen on the Santa Clara River, where the presence of mature willow-cottonwood riparian forest corresponds with perennial flow. This is what Sandercock et al. call "abrupt changes in patterns of riparian vegetation" along a longitudinal gradient. Similar patterns are still visible on the river today, though the extent of native riparian forest has been drastically reduced (Stillwater Sciences 2007a, Stillwater Sciences and URS Corporation 2007, Orr et al. 2011; see fig. 3.43).

Vegetation characteristics are also influenced by the lateral variations in hydrology and geomorphology across the river, though (as is the case for the Santa Clara River) patterns are often less distinct. Both groundwater availability and flood disturbance frequency, two of the primary driving

Fig. 3.27. This *diseño* captures a similar pattern of discontinuous riparian forest (shown here as closely spaced, small, circular trees) east of Piru Creek at a. Though the location of this transition is highly generalized, it is shown here east of Camulos and extending up what is likely Castaic Creek b in Los Angeles County. (U.S. District Court ca. 1840c, courtesy of The Bancroft Library, UC Berkeley)

factors in semi-arid systems, (Hupp and Osterkamp 1996, Lite et al. 2005, Stillwater Sciences 2007a), vary laterally across the river (increased depth to groundwater and decreased flood frequency with increasing distance and elevation from the active channel). As a result, the position of the bottomland surface plays a crucial role in determining the riparian vegetation able to colonize it (Bendix and Hupp 2000).

Unfortunately, however, the identification and characterization of fluvially-created bottomland surfaces in semi-arid systems can be challenging. High discharge, low recurrence floods contribute to the shape of the channel and riverine landforms. The morphology of these systems is complex and not easily characterized. Bottomland location and elevation can change quickly, and bottomland appearance may often resemble that of the active channel (Bendix and Hupp 2000, Sandercock et al. 2007). Osterkamp and Hupp (2010) refer to bottomlands as "shifting mosaics of landforms adjacent to stream channels." This morphologic complexity is matched by—and partially drives—spatially variable, heterogeneous patterns in riparian vegetation distribution seen in semi-arid streams. As a result, the interaction of vegetation with geomorphic processes in semi-arid systems is particularly complex and challenging to characterize.

The following sections describe more of the vegetation characteristics along the length of the Santa Clara River, as found in the active channel and bottomland surfaces. For the reasons detailed above, it is challenging—if not impossible—to provide much reach-level detail regarding the historical location of various in-channel habitat types. Instead, we provide broad characterizations of the suite of riparian habitats historically documented within the river corridor.

Bottomland and Active Channel Habitats

A variety of habitats were found within the active channel and bottomlands of the Santa Clara River, including willow scrub, alluvial scrub, herbaceous cover, freshwater wetlands, side channels, and sloughs (fig. 3.28). (Large persistent wetland riparian areas are discussed separately in the subsequent section; see page 94.) With the exception of the persistent wetland riparian

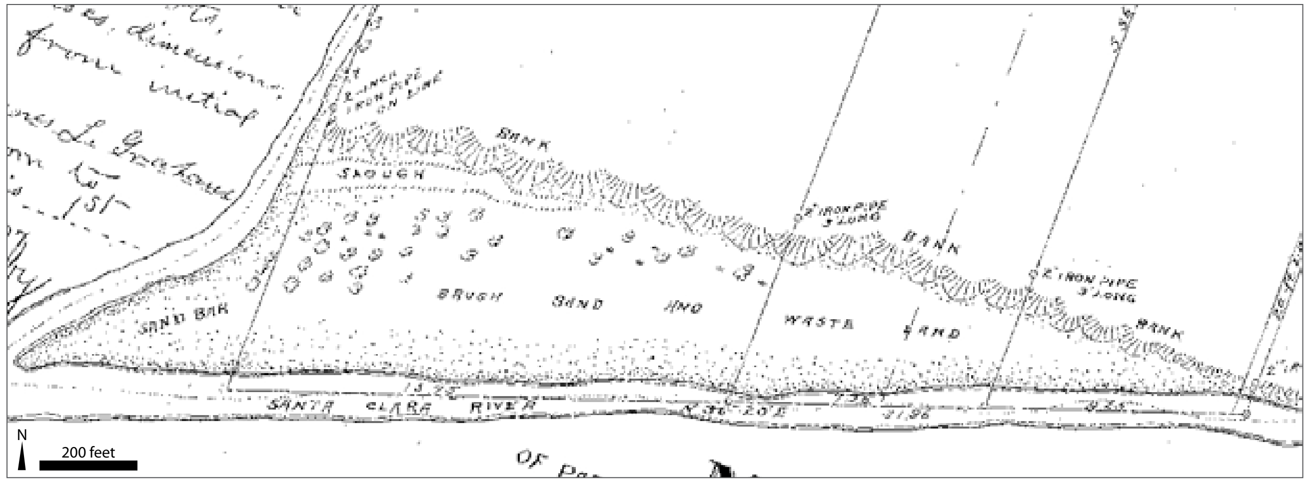


Figure 3.28. This 1897 map shows the variety of habitats found within the clearly delineated banks of the Santa Clara River, including a slough, "brush sand and waste land" with scattered willows, and a sand bar. Adams Barranca can be seen joining the river at left. (Orcutt 1897, courtesy of the Ventura County Surveyor's Office)

In this glad clime breathing is a refreshment, and the mere act of living a delight. The warm, healing winds, the glancing sunshine, the serpentine line of the river, stealing through its desert of sands…

—NINETTA EAMES, FALL 1889

areas, in-channel habitats are poorly documented in the historical record. Since the historical record rarely specifies whether a feature is in the active channel or on the bottomland (and given the challenges outlined above in characterizing bottomlands in semi-arid systems), the two are mostly undifferentiated, and we treat them together here.

Features in the active channel included the low-flow channel, as well as side channels and sloughs which carried water during floods. The channel itself is consistently described as being sandy riverwash, and almost completely unvegetated or covered in herbaceous vegetation, depending on the season (fig. 3.29). The 1917 soil survey describes the active channel of the river as composed of "sand and fine sand" (Nelson et al. 1920), and GLO quotes repeatedly characterize the river as "sandy bed" (e.g., Hoffman 1868b, Barry 1892a). One surveyor traveling through the Cienega area noted "leave swamp for sandy plain" as he entered the active channel, emphasizing the abrupt shift between moist bottomland and the active channel (Norris 1853). Near Camulos (upper Piru reach), explorer Crespí noted that the bed of the river has "piles of drift and large banks of sand" (though he also notes "large bottomlands of very good soil"; Crespí and Brown 2001). In some places, this riverwash occupied all or nearly all of the area between the outer banks, with no other recorded major habitats present in the active channel or on bottomland surfaces. Near Camulos, the soil survey shows nearly the entire width of the Santa Clara River dominated by riverwash, a swath about ½ mile wide which would likely have been treeless and vegetated with only herbaceous cover, with minimal or no bottomlands (fig. 3.30). The presence of extensive areas of riverwash and herbaceous cover clearly predates many human-induced disturbances to the river, including the St. Francis dam break.

Occupying a position in the river corridor above the active channel and thus less prone to overflow, bottomlands hosted a wide array of riparian habitats, from freshwater wetlands to alluvial scrub. Some bottomlands relatively high above the river in reaches with perennial flow supported mature cottonwood-willow forest (see page 94), while in other areas only sparse scrub would have been established.

Fig. 3.29. A view of the river corridor south of Santa Paula (top) looking south toward South Mountain, 1888. The sparsely vegetated active channel can be seen behind the town of Santa Paula, with strips of dense riparian vegetation on bottomlands along both sides of the river. (Unknown 1888; courtesy of the Santa Paula Historical Society)

Fig. 3.30. Santa Clara River east of Piru Creek, 1898 (bottom). This view of the Santa Clara River, captured during the State Mineralogist's 1898 field work, shows the broad expanses of sparsely vegetated riverwash characteristic of the Piru reach. The view is looking south east; Piru Creek can be seen coming into the Santa Clara River from the left. (Watts 1898, courtesy of the California State Archives)

In some areas, bottomlands may have closely resembled the active channel. The early soils report identifies a few slightly finer soils flanking the riverwash that correspond to bottomland habitats (e.g., Yolo sand and Yolo fine sand). Nelson notes that along the Santa Clara River, these soils "may resemble riverwash, from which they were separated, in many places, on the basis of slightly greater elevation and their growth of willow and vines," or that "in many places [Yolo fine sand] much resembles riverwash, except in its slightly higher position and its covering of brush and willow" (Nelson et al. 1920).

In other areas, the bottomland would have been clearly differentiated from the active channel, both by its position and its vegetation. While this was most evident in the persistent wetland riparian areas, bottomlands also supported an array of other habitats, including willow scrub, alluvial scrub, herbaceous cover, and wetlands and sloughs (fig. 3.31).

Willow trees and scrub were historically widespread along the Santa Clara River. Many maps show willows growing on what are apparently islands, side bars on the margin of the active channel, or higher benches within the banks of the river (e.g., Craven 1874h, Barry 1892b, Barry 1893, Stocker 1894, Barry 1898, Everett 1907, Unknown 1911). On these maps, willows are labeled as "heavy willow and cottonwood brush," "willow brush," "willow land," and simply as "willows" (Barry 1892b, Barry 1893, Stocker 1894, Waud ca. 1899, Waud 1916; fig. 3.32).

Narrative accounts also support the predominance of willow scrub (and the lack of established in-channel trees outside the wetland riparian areas) across most of the river. The historical soil survey describes riverwash in the active channel as "barren of vegetation except for small stands of sweet clover and willow over the least exposed parts" (Nelson et al. 1920). The Santa Clara River near Saticoy was described as "a wide, sandy and gravelly bed, destitute of vegetation except on a few higher patches where small poplar [black cottonwood] and willow trees grow, with low shrubbery,

QUICKSAND AND THE SANTA CLARA RIVER BED

Historical accounts consistently describe the bed of the Santa Clara River as sandy, with only scattered accounts referring to coarser substrate. In addition, a number of travelers mentioned the presence of quicksand in the active channel. Bowers (1879, in Benson 1997) described the river bed near the mouth in late October as "a mass of shifting quicksands"; more than 30 years later Chase (1913) was warned to not ford the river on the Oxnard Plain in late spring due to "possible trouble with quicksand." Sarah Eliot Blanchard, who grew up near Santa Paula in the late 19th century, recalled trouble with quicksand near Montalvo (Blanchard 1961), and Jarrett (1983) wrote that in the Bardsdale area residents layered bean straw in the active channel to preclude wagons fording the river from sinking in. Accounts like these provide insight into the nature of sediment transported by the river, as well as the availability of near-surface water on the river in these reaches during late spring to early fall.

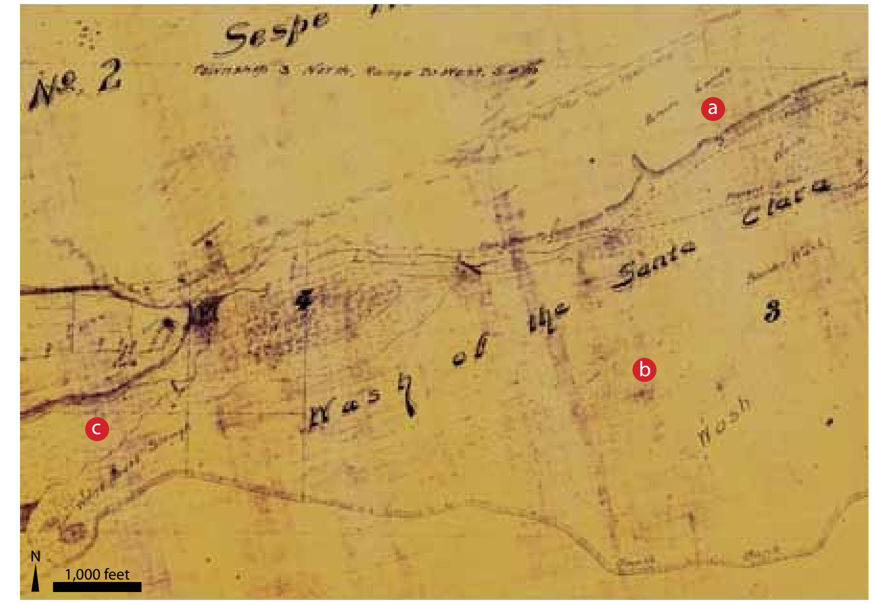


Fig. 3.31. This portion of a map showing the river immediately downstream of the confluence with the Sespe shows "Bottom Lands" (a) sitting above a break in slope, at a higher elevation than the "Wash" of the Santa Clara River (b). Ponds and a slough (the upstream end of East Grove, (c)) and willows are also noted. (Stocker 1894, courtesy of the Museum of Ventura County)

and which become islands in the high water of winter" (Cooper 1887). GLO survey notes record a "small patch of willow" downstream of Saticoy (Hancock 1854), and east of Santa Paula the channel "covered with willow brush" (Craven 1874e). The only GLO survey trees found within the bottomlands or active channel were within persistent wetland riparian areas or near the confluence of the Sespe and Santa Paula creeks with the Santa Clara River, areas with many established islands that would have protected these trees from floods. By contrast, many large, mature sycamores and live oaks grew along the outer bank of the Santa Clara River. (These habitats are not represented on the historical habitat map.)

These areas would have also supported an array of willow-scrub associated plants, including arroyo willow (*Salix lasiolepis*), narrowleaf or sandbar willow (*Salix exigua*), red willow (*Salix laevigata*), and mulefat (*Baccharis salicifolia*). These species composed the "low shrubbery" mentioned by Cooper (1887). Early court testimony describes the river near Sespe as covered with mulefat:

> As to the character of this river bed, I find that some portions of it are dry barren sand; on some portions, and perhaps the larger portion, there is a growth resembling the willow, called, as I understand by the Californians 'Guatamote,' [mulefat] generally but a few feet high. (Hopkins 1871)

In addition to willow scrub, several maps also show wetland features and sloughs in portions of perennial reaches outside of the persistent wetland riparian areas. Near the mouth of the Santa Clara River, on the north bank, maps show a marsh, sloughs, alkali land, and willows (Waud ca. 1899, San Miguel Company 1906, Nelson et al. 1917). Further upstream, a 1907 map shows a narrow strip of marsh along the Santa Clara River near Saticoy (Everett 1907), and just above the confluence of the Santa Clara River with Sespe an 1892 map shows sloughs and the low-flow channel flanked with "cienega [wetland] grass" (Barry 1892b; see also Barry and Isham 1894,

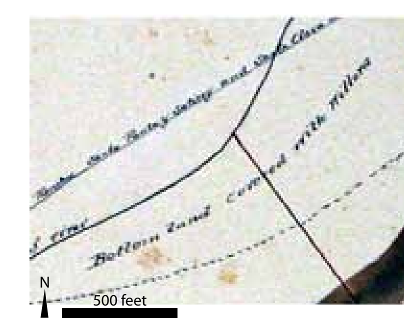


Fig. 3.32. Above the Highway 101 bridge, "bottom land covered with willows" was found on the protected bars at curves in the river. (Barry 1893, courtesy of the Ventura County Surveyor's Office)

Stocker 1894). East of Santa Paula near East Grove, two maps depict a lagoon beside a strip of either marsh or herbaceous cover (the symbol is unfortunately ambiguous in both maps; Unknown ca. 1890a, Power 1892). There were undoubtedly many more small wetlands within the banks of the Santa Clara River not documented by the historical record, for example in side channels and sloughs. These small, in-channel wetlands would have provided valuable habitat for a variety of aquatic and terrestrial wildlife species.

Alkali is present in large quantities in the lands bordering the coast and is also found in the low lands along the river.

—TAIT 1912

A likely exception to the ubiquity of willow scrub and mulefat across the Santa Clara River is the intermittent Piru reach. While few details have survived about the character of the scrub in this reach of the river, it is clear that the limited availability of summer water would have been the major factor shaping riparian characteristics in this area, and it is unlikely that the groundwater table was high enough for willow establishment or sustained growth. As a result, we hypothesize the presence of alluvial scrub in this reach. Alluvial scrub, found across Southern California systems, is typically characterized by scale broom (*Lepidospartum squamatum*), California buckwheat (*Eriogonum fasciculatum*), and mulefat (*Baccharis salicifolia*) (Hanes et al. 1989). This vegetation type is characterized on the San Gabriel River floodplain by Smith (1980) and as scalebroom scrub by Magney (1992), who notes that development of alluvial scrub in stream floodplains is encouraged by limited flooding frequency (only every 5-10 years). Analysis of vegetation patterns, flood dynamics, and other environmental factors along the Santa Clara River (Stillwater Sciences 2007a), the upper Santa Ana River (Burke et al. 2007), and various other Southern California rivers (Hanes et al. 1989) suggests there may be a general succession pattern with scale broom, California buckwheat, mulefat, and golden-aster (*Heterotheca* species) as indicators of early successional stages, and with species such as sagebrush (*Artemisia californica* or *A. tridentata*), black sage (*Salvia mellifera*), and cactus (*Opuntia* spp.) more characteristic of later successional stages.

This interpretation of historical presence of alluvial scrub is consistent with sagebrush and cactus recorded by GLO surveyors on the high bank of the river (Craven 1874f). It is also supported by modern vegetation classification and mapping (Stillwater Sciences 2007a, Stillwater Sciences and URS Corporation 2007, Orr et al. 2011), which records areas of scalebroom scrub and patches of other related vegetation types that are often considered to be components of Southern California alluvial scrub (e.g., *Artemisia tridentata*, *Atriplex lentiformis*, *Pluchea sericea*, *Salvia mellifera*, and *Yucca whipplei* vegetation alliances) in the Piru reach and along lower Sespe Creek near its confluence with the Santa Clara River. Smaller unmapped patches of sparse alluvial scrub dominated by sessileflower false goldenaster (*Heterotheca sessiliflora*) and scale broom (*Lepidospartum squamatum*) are also currently observed on bar features upstream of the Freeman Diversion Dam (Orr pers. comm.)

FISH SLOUGH

Along the Santa Clara River, the most heavily documented slough in the historical record is Fish Slough. Located in Sespe Creek at its confluence with the Santa Clara River, Fish Slough was the site of an in-channel wetland complex and (as per the name) fishing spot for steelhead trout in the early 20th century (Jarrett 1983; fig. 3.33). It was also the site of late 19th-century irrigation diversions (Crawford 1896). Large willows—up to 2 feet in diameter –grew in Fish Slough, as well as watercress (Jarrett 1983).

Fig. 3.33. Fish Slough complex, 1894. This map of the Santa Clara River-Sespe confluence shows the whole length of Fish Slough, extending about half a mile upstream on Sespe Creek. (Stocker 1894, courtesy of the Museum of Ventura County)

In addition, a number of quotes and maps also indicate the prevalence of herbaceous cover within the river corridor. In the *Overland Monthly,* Clifford (1872) described the Santa Clara River "gilding through its even, grassy fields," while another traveler wrote of "much fine meadow" along the river near the Los Angeles County line (Holton 1880). Near Camulos, an early account described "low, reed-grown banks" (Roberts 1886), while near Sespe, one observer reported that "…on the flats bordering the river we found a greensward, much of which was made up of sour grass, that a mule will eat rather than starve" (Rothrock 1876). Near Santa Paula, Crespí described the river "with a great deal of green flats along its bank" (Crespí and Brown 2001).

The river bank on each side is composed to a considerable extent of sandy plain or 'arenal'…arable and pasture land form on each side of the river a comparatively narrow strip…

—SMITH AND STUART 1871

This grass was also valuable as forage for livestock. The 1871 court case for Sespe Rancho hinged on whether the lands within the banks of the Santa Clara River were valuable, and repeated testimony described how settlers used these lands as pasture for their livestock, especially during dry periods when forage elsewhere was limited (see pages 96-97). Mission-era accounts also describe

Fig. 3.34. Detail of a "willow swamp" at the confluence of Santa Paula Creek and the Santa Clara River. Though the map is coarse, this appears to be an early representation of East Grove. The cartographer also drew a "swamp" on the Santa Clara River east of Sespe Creek (the Cienega, not shown here). (Unknown ca. 1860, courtesy of The Bancroft Library, UC Berkeley)

The river was whirling along to the sea through banks clad in long grass, wild-rose, and sweetbrier, with tangles of wild-grape overshadowed by willow, cottonwood, and sycamore, and its mica sands sparkling like flakes of gold as they rolled over in its swift waters.

—VAN DYKE 1890,
SPEAKING OF THE DEL VALLE REACH

the desirability of these lands for cattle, noting that when there was no more pasturage near the Mission and on the Oxnard Plain, cattle would "roam farther up to the meadows along the river" to graze (Senán 1804).

Persistent Wetland Riparian Areas

In addition to the array of bottomland habitats described above, large areas of freshwater wetland and willow-cottonwood riparian forest were also documented on bottomlands along the river. These habitats, which we call "persistent wetland riparian areas," were found in perennial reaches of the Santa Clara River and occupied bottomland surfaces that were less frequently disturbed by flooding than other in-channel habitats. Because of the abundance of water and timber, they were often significant cultural areas, and as a result are often well documented in the historical record (fig. 3.34).

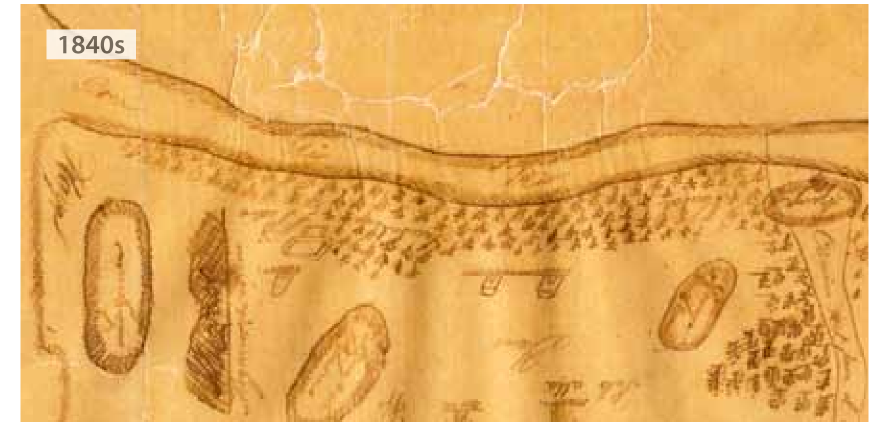
"Persistent wetland riparian areas" were unusually large (aggregate size over 200 acres) areas of wetland riparian habitat whose presence transcended significant flood events of the late 19th and early 20th centuries. While other areas of riparian forest were present inside the river corridor, they were more variable, shifting in location and extent with major flood events.

The following section characterizes the four documented persistent wetland riparian areas historically found along the lower Santa Clara River. These areas include: south of the river from the Highway 101 crossing to the mouth, east of Santa Paula, east of Fillmore, and east of Camulos. While it is possible that additional large wetland riparian features persisted elsewhere, insufficient documentation exists to confirm their presence.

WEST GROVE (SANTA CLARA RIVER MOUTH RIPARIAN FOREST) Along the south side of the Santa Clara River, a substantial, continuous strip of riparian vegetation extended from the river mouth to around the Highway 101 bridge about three miles upstream. This section of riparian forest covered about 1,200 acres. It was particularly notable to early travelers and settlers given the lack of other timber on the Oxnard Plain, and is included in many early maps of area as a prominent feature of the plain.

In 1769, Crespí noticed this grove from afar as his expedition traveled along the Santa Clara River near Saticoy: "Though no trees are to be seen nearby, a great deal of trees was visible afar off where we thought the shore must be close by" (Crespí and Brown 2001). The earliest map found that depicts the grove, drawn in the 1840s, shows a continuous willow grove (*sausal*) extending from the river mouth beyond the current location of the Highway 101 bridge (already labeled *camino,* or road, on the map) at a more or less continuous width (fig. 3.35). The map also shows willows extending along the south side of the road. While this map is clearly only a rough sketch of features on the Oxnard Plain, it does include the *sausal* as one of the key landmarks of the plain.

While they do not accurately depict the extent of the grove, other early maps confirm its presence south of the river, indicating its prominence



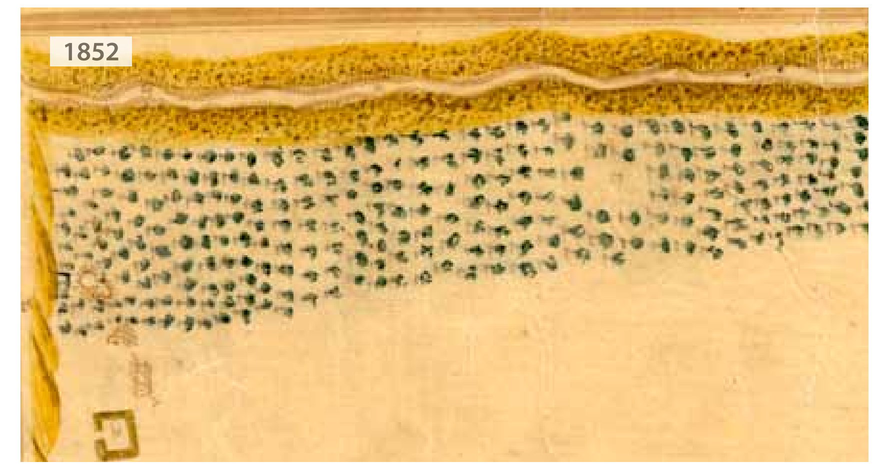


Fig. 3.35. Riparian forest (West Grove) on the lower Santa Clara River, 1840-1852. An early map (top, 1840s) shows extensive riparian willows (labeled *sausal*) along the south side of the river, extending beyond and along the camino (now Highway 101). About a decade later (1852), the grove is still a major landmark on the south side of the river (bottom). (U.S. District Court ca. 1840e, Ardisson 1852; courtesy of The Bancroft Library, UC Berkeley)

as a landmark on the Oxnard Plain (e.g., Reed ca. 1871). Another early map (Ardisson 1852) shows a continuous strip of trees of consistent width along the river (see fig. 3.35). While this map does not show the road crossing, the scale indicates that the trees are present along the river for about three miles, roughly the distance from the river mouth to about a mile downstream of the Highway 101 bridge. This estimation of the grove's extent is corroborated by Cooper (1887), who described a grove in 1872-73 beginning three to four miles west of Saticoy (either just above or just below the bridge) and extending "along the south bank of the river for three miles." Cooper called this grove West Grove (as opposed to the East Grove near Santa Paula), a name we have adopted here. The name also affirms the discontinuity of riparian forest along the river.

Later observers also made note of this riparian forest, providing more detail on species composition: a mix of willows, cottonwoods, sycamores, and live oaks. While the *diseño* labeled the grove a *sausal* (willow grove), Brewer ([1930]1974) noted "a grove of cottonwoods which came nearer to a forest than anything I have yet seen here" in March 1861. Another traveler described "a considerable body of willow, cotton-wood and some sycamore" (*Daily Alta California* 1868). Cooper (1887), describing the grove in 1872-73, noted "poplars, willows, and stunted live-oaks" (Cooper's poplars were likely black cottonwood (*Populus balsamifera ssp.*

TRANSFORMATION OF THE BOTTOMLAND

…the bed of the Santa Clara River is not entirely waste land…a large portion of said river bed affords fine pasture land, and a considerable portion has been cultivated and farmed successfully during the last season in corn and other crops…

—RANDOLPH ET AL. 1870

Differences in native vegetation and disturbance regimes along Santa Clara River bottomlands were reflected in variations in the agricultural value of the bottomlands. Persistent wetland riparian areas boasted dense vegetation, a relatively low depth to groundwater, and fertile sediments deposited during occasional flooding. In contrast, bottomlands along other parts of the river were often sandy and used primarily for grazing or hardy annual crops. Even in these less fertile regions of the river, access to water for irrigation made bottomlands attractive places to farm and pasture livestock in an otherwise largely arid valley:

> …were it not for the pasture which said river bed has afforded Mr. Moore could not have well kept his sheep alive on said Ranch the present season. I have known crops of corn and vegetables raised in said river bed this season… (Qualls 1871)

Fertile pockets of bottomland were widely recognized by early settlers, many of whom took advantage of what the river's bottomlands had to offer. South of the Santa Clara River mouth in West Grove, landholders cleared portions of the bottomlands for cultivation:

> …about 40 acres of the rich bottom is now being cleared off and will be farmed this coming season…the Santa Clara river with its fine timber and rich bottom lands form the northern boundary; in this timber wild blackberries are found in great profusion and of good quality… (*Ventura Signal* 1879, in Hampton 2002)

On the south side of the river above Highway 101 near West Grove, a newspaper columnist described a "low bottom to the left moist and good for crops of various kinds," in contrast to the scrubby, drier land on the valley floor (*Daily Alta California* 1868). Around Piru, explorer Crespí noted "large bottomlands of very good soil that could be cultivated by irrigation" (Crespí and Brown 2001). General Land Office surveyor Craven (1874f) described their value for raising corn and barley along the river between Fillmore and Piru, noting that "during the winter seasons the freshets cause the Santa Clara river to rise and overflow the old river bed and it has the effect of improving the land making it easier to cultivate and more productive."

In less fertile regions, or regions that were more regularly flooded, it appears that most agriculture took place outside of our mapped outer banks, in areas that could still benefit from the irrigation water provided by the river but were better protected from floods (Petit 1925). Within the outer banks, farming could only be practiced for portions of the year:

> In the rainy season the bed of the river is overflowed with water, consequently no one could settle on or live on the land in the river bed during the rainy season…in the summer season they can raise their crops on the lands in the bed of the Santa Clara River. (Stuart 1871)

Bottomland farms date at least to the middle of the 19th century. An early map from the 1840s shows an irrigated field on bottomland just east of Timber Canyon, on the north side of the river between Santa Paula and Sespe creeks (U.S. District Court ca. 1840d; see fig. 3.39). Early farmers planted seasonal crops, such as beans, sugar beets, alfalfa, and potatoes, which allowed them to retreat during the wet season, with orchards planted only on "better drained areas" (Nelson et al. 1920).

By the 1870s, large portions of forested bottomland were in the process of being cleared and planted to these crops (and later, even orchards in some places). One writer described "fields of deep alfalfa along the river bottom" in upper Ventura County (Van Dyke 1890), and another noted that "the orchards crowd down to the very bed of the river" (Eames 1889) in the Camulos region. These lands were often irrigated.

However, even these seasonal crops were sometimes destroyed by flooding; during the 1884 flood, one resident recalled "many small alfalfa fields and garden patches on the river bottom that could be irrigated from the river that were entirely wiped out" (Hardison, in Freeman 1968). As farmers began to establish more permanent cultivation, bottomland development remained vulnerable to these events: "The high water of two weeks ago did a good deal of damage in the river bottom, washing away fences etc." (*Ventura Free Press* 1876).

The value of these lands was at the heart of one of the most infamous land squabbles in Ventura County history, between Thomas More and other settlers in the Sespe area. In claiming the two leagues of land allocated to him by the court, More wanted to claim land on either side of the Santa Clara River while excluding the river bed itself, in order to maximize land holdings outside the river while still retaining control of the river's water and bottomlands. To justify doing so, More argued (as did Carrillo, the grant's previous owner) that the river bottom lands were worthless since they were sandy and frequently flooded and scoured by the river, and therefore should not be included in the grant (Carrillo 1829, in Outland 1991). The settlers, however, argued that these lands were extremely valuable as grazing and agricultural land, testifying that they were "fine pasture land" (Randolph et al. 1870), "equally valuable to any lands upon said Ranch of Sespe" (Herrett 1871) and were used in the dry season for cultivation (Stuart 1871). Ultimately, More's claim to the river bed was denied by the U.S. Supreme Court, and the land was opened to settlers against More's wishes. The conflict culminated in More's murder in 1877.

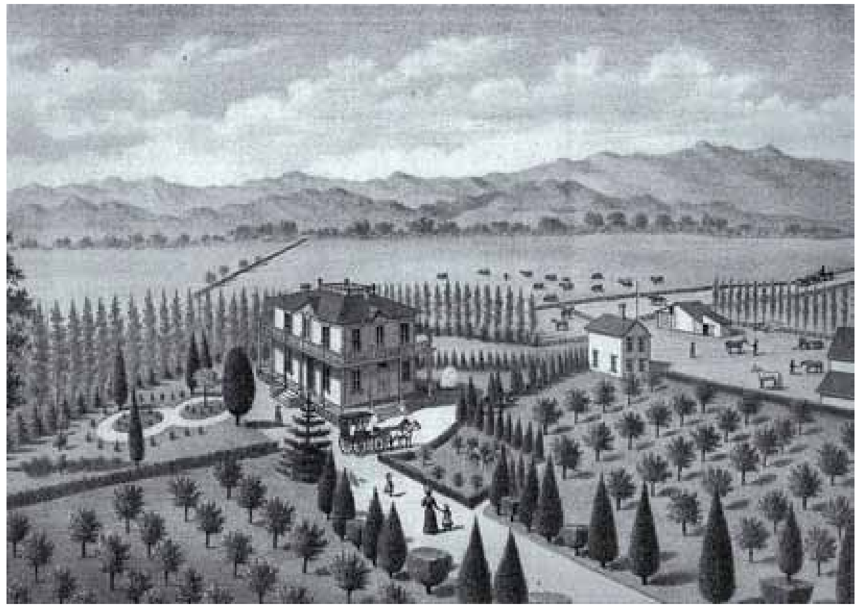
Through the 20th century, levees constructed along the lower Santa Clara River enhanced farmers' ability to cultivate in these areas (fig. 3.36). At the mouth of the Santa Clara River, levees bordering the active channel of the river have contributed to the elimination of West Grove, allowing cultivation to cover this fertile land.

During the winter seasons the freshets cause the Santa Clara river to rise and overflow the old river bed and it has the effect of improving the land making it easier to cultivate and more productive.

—CRAVEN 1874F

Fig. 3.36. This bottomland surface west of the Sespe Creek confluence remained uncultivated in the late 19th century, as shown here in this 1894 map (left). By 1938, the surface had been converted to mostly walnut, orange, and lemon orchards. The area is still farmed today (right). (Stocker 1894, courtesy of the Museum of Ventura County; USDA 2009)

Fig. 3.37. John Scarlett's ranch abutted the south bank of the Santa Clara River, just east of McGrath's oceanfront property. Scarlett's ranch included a large portion of the forested bottomland (West Grove) along the river, as can be seen in the background in this image. The *Ventura Signal* (1879, in Hampton 2002) printed that "the Santa Clara river with its fine timber and rich bottom lands form the northern boundary; in this timber wild blackberries are found in great profusion." (Thompson and West [1883]1961)



Mr. Adolf Camarillo says that the lowlands south of Ventura used to contain many sycamores. The whole country there (the lowlands south of Ventura) used to be called in Sp[anish] Monte de San Pedro. It has since that time been grubbed out. There used to be tule sloughs and willowy places.

—Adolfo Camarillo, interviewed by John F. Harrington ca. 1913 (Harrington 1986b)

trichocarpa; Stillwater Sciences 2007a, Orr et al. 2011). Henry Hancock (1854), surveying a GLO transect across the river and through the grove in 1854, noted discrete cottonwood groves and willow groves within the larger riparian zone (fig. 3.37).

In addition to riparian forest, West Grove contained a matrix of open areas, dense underbrush, and low ponds and sloughs. Cooper (1887) described the grove as "partly open and partly crowded with dense shrubbery." The early U.S. Coast Survey T-sheet captures this characteristic in the westernmost part of the grove, showing open, grassy areas between denser thickets (Johnson 1855b, c). Another source describes the presence of dense undergrowth in the grove:

> …the Santa Clara river with its fine timber and rich bottom lands form the northern boundary [of the property]; in this timber wild blackberries are found in great profusion and of good quality… (Ventura Signal 1879, in Hampton 2002)

This diverse, heterogeneous riparian area would have provided habitat for a number of wildlife species (RHJV 2004, Stillwater Sciences 2007c). Cooper (1887) called West Grove "the most productive bird-hunting locality I found in the valley," and Evermann (1886) described numerous birds found in the willow and cottonwood thickets at the mouth of the river, including Rufous hummingbird *(Selasphorus rufus)* and Wilson's warbler (*Wilsonia pusilla*). Wilson's warbler, which Evermann describes as "abundant in the willows near the mouths of the Santa Clara and San Buenaventura Rivers," is also a common species found in many western willow thickets today (Otahal 1998, Cornell Lab of Ornithology 2009).

Mapping of West Grove (see page 48) was based on a few detailed sources which depicted the location and width of parts of the grove with spatial accuracy. A USCS T-sheet (Johnson 1855c; fig. 3.38) shows dense thickets approximately 3,700 feet wide at the mouth of the river, and GLO surveyors

ARUNDO ON THE SANTA CLARA RIVER

Today, the non-native giant reed (*Arundo donax*, commonly referred to as Arundo) has colonized large portions of the Santa Clara River and Ventura River floodplains and Calleguas Creek. Arundo often forms dense, massive stands along the river, displacing native riparian vegetation and limiting bird species and other wildlife abundance in invaded areas (Stillwater Sciences 2007c).

In addition to direct habitat displacement, Arundo negatively impacts streams in a number of ways. It has the potential to cause large-scale changes in stream morphology and hydrology by lowering groundwater levels, slowing the downstream transfer of sediment, and impeding flows (Dudley 2000, Coffman et al. 2004, Coffman 2007). In addition, it has increased the susceptibility of riparian corridors to wildfires, potentially creating a positive feedback cycle wherein more frequent fires promote more intensive Arundo growth (Coffman et al. 2010).

The timing of Arundo's arrival to Ventura County is unknown. It was described as "plentiful" along the Los Angeles River by 1820, where it was used to roof houses (Robbins et al. 1951). Given its proximity to and early use by the San Buenaventura Mission, a similar introduction history is possible along the Santa Clara River. This is potentially supported by Chumash ethnographic records, which describe Arundo as "Carrizo de Castilla" (that is, large grass from the Spaniards) or "European bamboo" (Timbrook 2007; Timbrook also provides an excellent treatment of the Chumash and Spanish uses for Arundo).

However, though it is possible that Arundo was present very early in both the Ventura and Santa Clara river watersheds, no definitive evidence was found confirming its presence or absence in the 18th and 19th centuries. Although Arundo may have been present along the Santa Clara River or Ventura River by the early 1800s (if not before), its widespread expansion in riparian ecosystems appears to be relatively recent, corresponding to widespread colonization following the floods of 1969 (Bell 1997, Coffman 2007). This is consistent with the absence of Arundo in historical descriptions of riparian character, which implies either the absence or limited distribution of Arundo along the river.

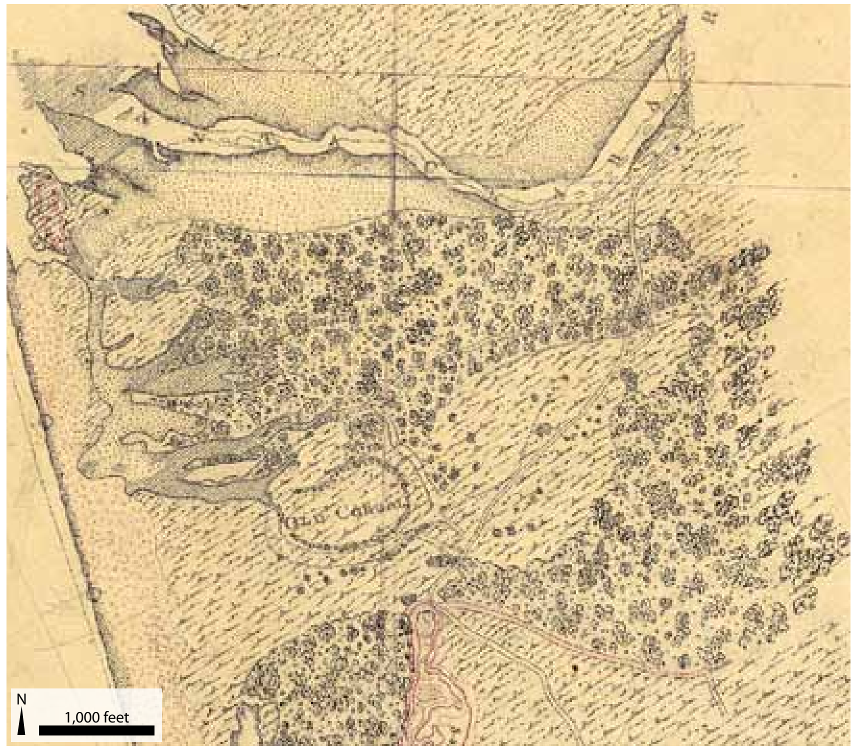
(Terrell 1861b, Thompson 1867) crossed 2,600 feet of "thick timber" at the highway bridge. These two sources provide riparian zone width on either side of the forest. County survey maps (e.g., Barry 1893) and the historical aerial mosaic were used to complete the mapping process. There is some indication that the upstream portion of the forest was wider than mapped; an earlier GLO survey (Hancock 1854) took a bearing on a tree on the "north end of the timber of Rio Santa Clara" that implies that the timber was much wider than we have mapped. Since he gives no precise location, we have not mapped this wider zone at the top of the forested area. However, this would seem to be supported by the early *diseño* which also shows vegetation extending east along the road (see fig. 3.35a).

…the first [left] bank…yet presents the original forest of willow and other trees as shown upon the diseño… -

—Reed 1871

As the above evidence shows, West Grove persisted in extent and location through the major flood events of the second half of the 19th century (e.g., 1861-62, 1867-68, and 1874-75). However, the forest is mostly absent in 20th century images of the lower river due to agricultural reclamation. The 1927 aerial imagery shows a dense (albeit narrower than in the GLO survey) stand of trees north of the Highway 101 bridge, but only scattered

Fig. 3.38. Santa Clara River mouth, 1855. This early USCS survey shows the westernmost end of West Grove as it stood in 1855. Dense stands of trees surround an open area (including an "old corral"). Auxiliary sources describe the grove as a mix of willows, cottonwoods, and sycamores. (Johnson 1855c, courtesy of the National Oceanographic and Atmospheric Administration)



patches of forest remain downstream, and the area appears to have been heavily reworked. Oblique photographs from the 1930s through 1950s show similar patterns: patches of vegetation are narrower, more scattered along the south side of the river, or are completely absent (Fairchild Aerial Surveys 1934, Spence Air Photos 1952). Interestingly, in some of these later photographs riparian trees appear to have colonized the northern side of the river (e.g., Fairchild Aerial Surveys 1934; see fig. 3.1). This shift may have been in response to infrastructure development which redirected flows southward, creating a more protected surface on the north side of the river.

While the forest had mostly disappeared by 1927, the outline of the low-disturbance bottomland is still visible on an aerial image. By 2005, nearly all traces of the forested area had disappeared into farmland, housing, a landfill, and golf course, and the area had been largely cut off from the river by a levee built by the Army Corps of Engineers in 1961 (Stillwater Sciences 2007b; see fig. 3.41).

EAST GROVE (SANTA PAULA WETLANDS) Another prominent area of mixed riparian willow-cottonwood forest occurred just east of the Santa Clara River's confluence with Santa Paula Creek. At least two large sections of forest were present, one on each side of the river, with a probable extent of 620 acres. These forests included willow and cottonwood stands and freshwater marshes within the outer banks of the river.

These forests appear to be among the most substantial and persistent sections of riparian forest/wetland along the lower river. They are depicted by a number of early cartographers as a large area with both dense trees and surface water; one map (Unknown ca. 1860) labels the area "willow swamp,"

WILDLIFE IN THE HISTORICAL LANDSCAPE

This report focuses on establishing the ecological and hydrological characteristics of the historical landscape. Interpreting this environmental setting with respect to the needs of native species of concern and other wildlife is an intensive, challenging process, and is not addressed here. A key next step is to work with experts to translate relevant findings into ecological functions and wildlife presence probabilities (e.g., Goals Project 1999, Sanderson 2009). This task involves both detailed interpretation of historical faunal records and interpretation of historical habitats and hydrology to project the probable former wildlife species support functions of the region.

It is clear that the Santa Clara River habitat mosaic supported a rich faunal community of native fish and wildlife species, which have been appreciated—and often exploited—by many generations of residents and visitors. While not covered here, based on our historical reconstruction we can speculate about the kinds of species support functions provided by the matrix of riverine habitats. For example, birds such as endangered least Bell's vireo (*Vireo bellii pusillus*), yellow-billed cuckoo (*Coccyzus americanus*), and southwestern willow flycatcher (*Empidonax traillii extimus*) would have likely utilized areas such as West Grove (river mouth) and East Grove (Santa Paula) as breeding habitat; some of these species are still supported on the river today (Stillwater Sciences 2007c, 2008). The presence of perennial ponds and sloughs in areas of rising groundwater suggests these reaches may have supported California red-legged frog (*Rana draytonii*) and western pond turtle (*Clemys marmorata*). Tidewater goby (*Ecuyclogobius newberryi*), a brackish water species indigenous to California estuaries, would have utilized the lagoon at the Santa Clara River estuary (USFWS 2005).

In addition, the Santa Clara River basin has been cited as one of the most important potential areas for southern steelhead habitat restoration today (Boughton et al. 2006). Recent research (e.g., Stoecker and Kelley 2005, Boughton et al. 2006, Pearse and Garza 2008, NOAA/NMFS 2009) supports the conclusion that the river was a historically important corridor for the federally endangered Southern California steelhead (*Oncorhynchus mykiss*). The floodplain and wetland habitats along the river and estuary would have likely been important rearing habitats for outmigrant juveniles, as has been documented on other systems (e.g., Sommer et al. 2001, Henning et al. 2006). For example, one early description stated that a type of trout, presumably adult steelhead, was found "in the scienegas [sic] and along the Santa Clara River where the watercress abounds" (Ventura Free Press 1878d), referring to the rising groundwater reaches. The use of refugia in perennial reaches, even on streams with significant summer-dry portions, is consistent with studies of intermittent stream use by anadromous steelhead for spawning and rearing (Ventura County Fish and Game Commission 1973, McEwan 2001, Boughton and Garza 2008; see also Ebersole et al. 2006, Wigington et al. 2006 for Coho salmon use of intermittent streams).

The habitat complexes associated with the seasonally closed river mouth would have provided important rearing habitat for salmonids and other fishes, as has been shown for other California estuaries (Bond 2006, Hayes et al. 2008). Though the use of river mouth estuaries by Southern California steelhead is poorly understood, even today the Santa Clara River estuary has been found to support rearing steelhead (Kelley 2008).

An understanding of the historical support functions provided by the river and its tributaries is a key component of effective restoration. There is a need for a richer and scientifically-based evaluation of former habitat support functions, and current potential for rare/listed wildlife species. Further research, along with additional interpretation of the findings presented here in the context of contemporary ecological research, may more thoroughly explore the ecological functions of these former landscape features.

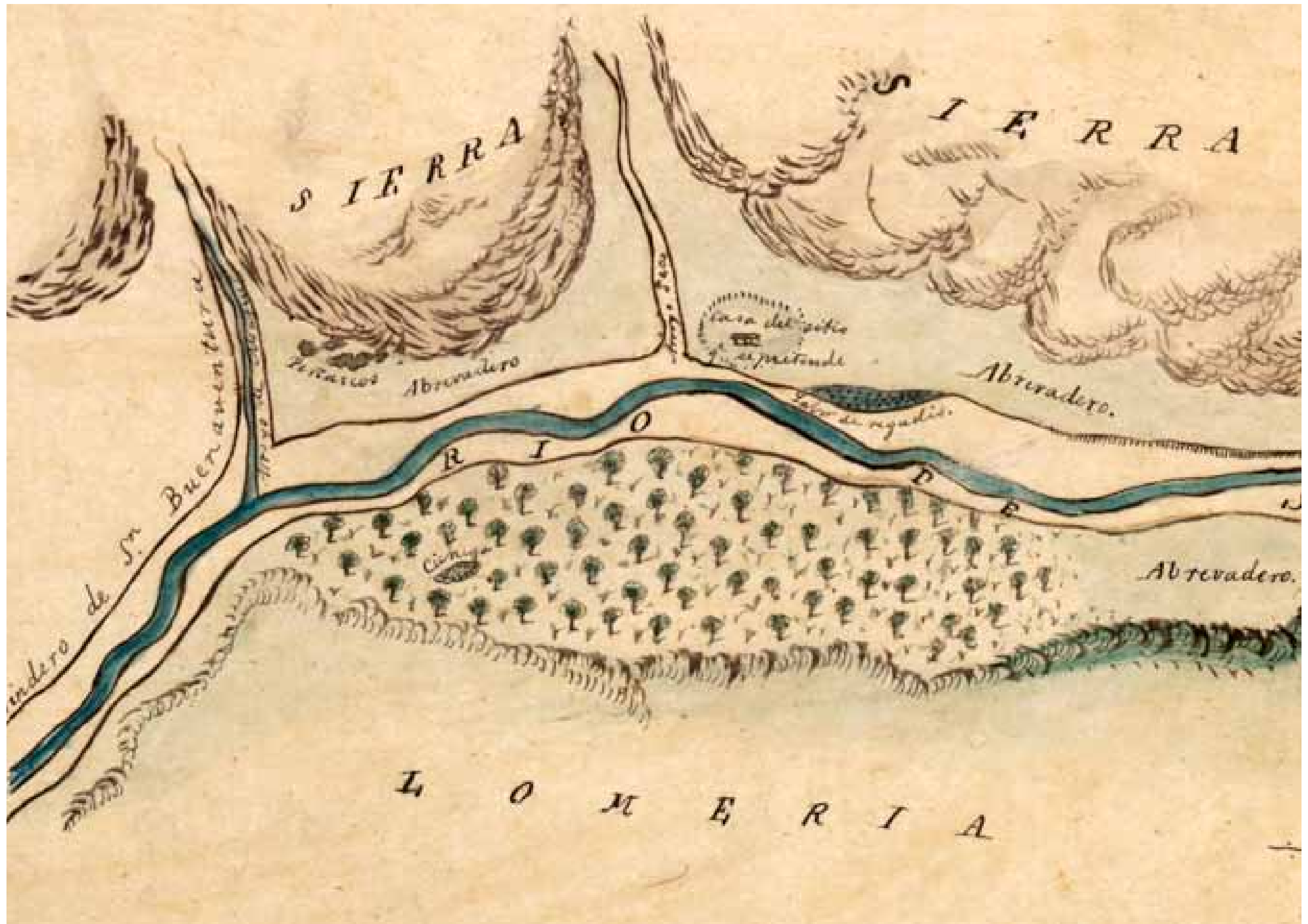


Fig. 3.39. This early map shows a number of in-channel features along the Santa Clara River, including an extensive forest south of the channel with a smaller *ciénega* (marsh) amongst the trees (East Grove, east of Santa Paula Creek/Arroyo de Mupu), and another eponymous *ciénega* (the Cienega) east of Sespe Creek/Río de Sespe. A bottomland field is shown as *labor de regadío* (irrigated field). (U.S. District Court ca. 1840d, courtesy of The Bancroft Library, UC Berkeley)

and a *diseño* (U.S. District Court ca. 1840d) shows a smaller *ciénega* within an extensive forested area south of the river (fig. 3.39). However, neither map gives detailed information on the extent or specific location of the forest-wetland complex.

Fortunately, a number of GLO survey lines also cross this area, and these surveys both support the existence of these large forest complexes and help define their historical extent. Five surveyors crossed this area when conducting surveys in 1853, 1868, 1869, 1874, and 1892. The terms they use to describe the riparian community depict a dense forest with often saturated soils and wetlands: "cottonwood and willow swamp" (Norris 1853), "willow brush" (Hoffman 1868c, Craven 1874e), "bottom land covered with willows" (Craven 1874e), or simply "swamp" (Norris 1853, Craven 1874e). Hoffman (1868a) notes "sandy and muddy" areas in the riparian area, and at one point is "in deep mud."

While the size and extent has shifted over time, riparian forest has been consistently present in this area. A surveyor in the late 1870s mapped a "dense growth of young willows" (Norway 1878c), and one survey map from the 1890s shows patches of willows between the sandy wash of the river and the cultivated bottomlands above (Stocker 1894). Other maps from this era depict wetland areas and small ponds in the river bed (Unknown ca. 1890a, Power 1892, Stocker 1894). A few ornithological records from near Santa Paula also support the presence of willows and marsh: a Traill's flycatcher (*Empidonax traillii*) was found in a "nest situated in a willow tree among the willows bordering the Santa Clara river" (Burt 1904), and a common yellowthroat (*Geothlypis trichas*) was found with a "nest of marsh grass, leaves and straws" (Badger 1919). (The recorded Traill's flycatcher was most likely a Southwestern willow flycatcher, currently a federally endangered subspecies.)

The 1938 aerial imagery shows large sections of forest, and a 1948 ornithology journal noted "a large grove of mixed willow and cottonwood trees" about three miles east of Santa Paula (Peyton 1948). Extensive riparian forest was still present in the vicinity in 2005, though the boundaries had shifted (see page 105).

FILLMORE CIENEGA An extensive freshwater wetland complex was located southeast of Fillmore, south of Highway 126 and north of the Santa Clara River and at the present site of the Fillmore Fish Hatchery. This wetland complex, known locally as the "Cienega" (Spanish for marsh), included approximately 340 acres of freshwater marsh, tules, and willow groves.

Maps and narrative accounts of the Cienega area describe a variety of habitats within the wetland complex, including mixed groves of willows,

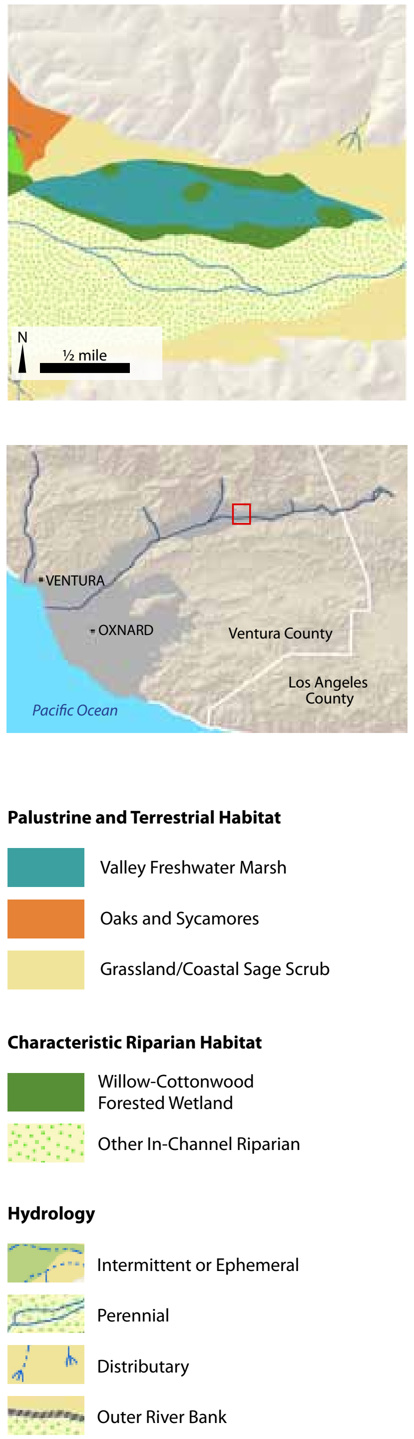


Fig. 3.40. Detail of Cienega, early 1800s. This in-channel wetland complex, located just east of the town of Fillmore, was a matrix of freshwater wetland and riparian forest.

alders, and cottonwoods (fig. 3.40). "Willow timber" was observed along the northern bank of the Santa Clara River, and "cienega and tules" further toward the middle of the marsh (Barry 1898). Jarrett (1983) recalls "2 feet in diameter" willows at Cienega. Hoffman (1868d) noted a series of box elders (*Acer negundo var. californicum*) on the slightly higher northern and western boundary of the marsh, and describes the Cienega as a "cienega and cottonwood grove" (Hoffman 1868d). The willow groves of the Cienega area likely extended west of the Cienega itself into "willow brush" between the Pole Creek fan and the Cienega (Craven 1874f,h).

Like Saticoy Springs and the Santa Paula marshes, the Cienega was a major landmark and water supply source in the otherwise relatively dry Santa Clara River Valley. A settlement at the Cienega (including post office and school, both established in the mid-1870s) predates the town of Fillmore, which was established in 1887 when the railroad was built through the area (Fillmore Historical Society 1989, Durham 2001). The Cienega corresponded with an area of rising water and perennial flow in the Santa Clara River, and was the site of a number of surface water diversions for agricultural irrigation. The South Side Improvement Company, organized in 1887, and the Cienega Water Company, established in 1910, both diverted surface water from the Santa Clara River at the Cienega and provided water to the Bardsdale and Fillmore areas on both sides of the river (Freeman 1968).

The Cienega and willow groves around Fillmore were disappearing as early as the 1880s. The *Ventura Free Press* attributed the drying of the Cienega to artesian development on Oxnard Plain: "the Scienega [sic], which was formerly a marsh, that would shake a rod from a man walking over it, is now dry enough to plow" (*Ventura Free Press* 1883b). An 1887 *Free Press* article called for protests regarding the cutting of trees in Sespe Grove (*Ventura Free Press* 1887a). By 1925, parts of the former Cienega were planted to alfalfa, a relative rarity by that time in a region dominated by oranges and lemons (Petit 1925); the 1938 aerial imagery shows the area partially planted to orchards, while a portion of the area is still densely covered with vegetation (USDA 1938). The Fillmore Fish Hatchery was established in 1940 within the original boundaries of the Cienega, an area then recognized as having high groundwater and surface flow in the Santa Clara River (Leitritz 1970). By 2005, the majority of the area was farmed, though a few patches of cottonwood-willow forest remain adjacent to the riverbed within the boundaries of the historical Cienega (Stillwater Sciences and URS Corporation 2007).

DEL VALLE RIPARIAN FOREST Above Camulos, a fourth willow-cottonwood forest flanked the Santa Clara River. Though this was a less populated area, and thus is less well documented in the historical record, it is clear that substantial riparian forest was found on this area's bottomlands. The Del Valle forest marked a reach of perennial flow in a very narrow portion of the valley.

Early travelers in the area noted lush, dense vegetation along the river. Crespí, traveling in 1769, described the bottomlands as "a good extent of soil alongside the stream; with a great many cottonwoods, a great deal of willows, and many live oaks still continuing" (Crespí and Brown 2001). He also noted wild grapes (*Vitis californica*) along the stream. This description is corroborated by another traveler more than 120 years later, who described the river in this reach with "banks clad in long grass, wild-rose, and sweetbrier, with tangles of wild-grape overshadowed by willow, cottonwood, and sycamore" (Van Dyke 1890). At the lowest end of the reach, near Camulos, one account describes "clumps of willows and groves of wide-spreading sycamores" (Parkinson 1894).

The river is generally on the south side of the valley + is very tortuous in its course + what might be termed the bottom land is apparently very rich from the rankness of its vegetation.

—KING 1883, OCTOBER 16, 1883, SPEAKING OF THE DEL VALLE REACH

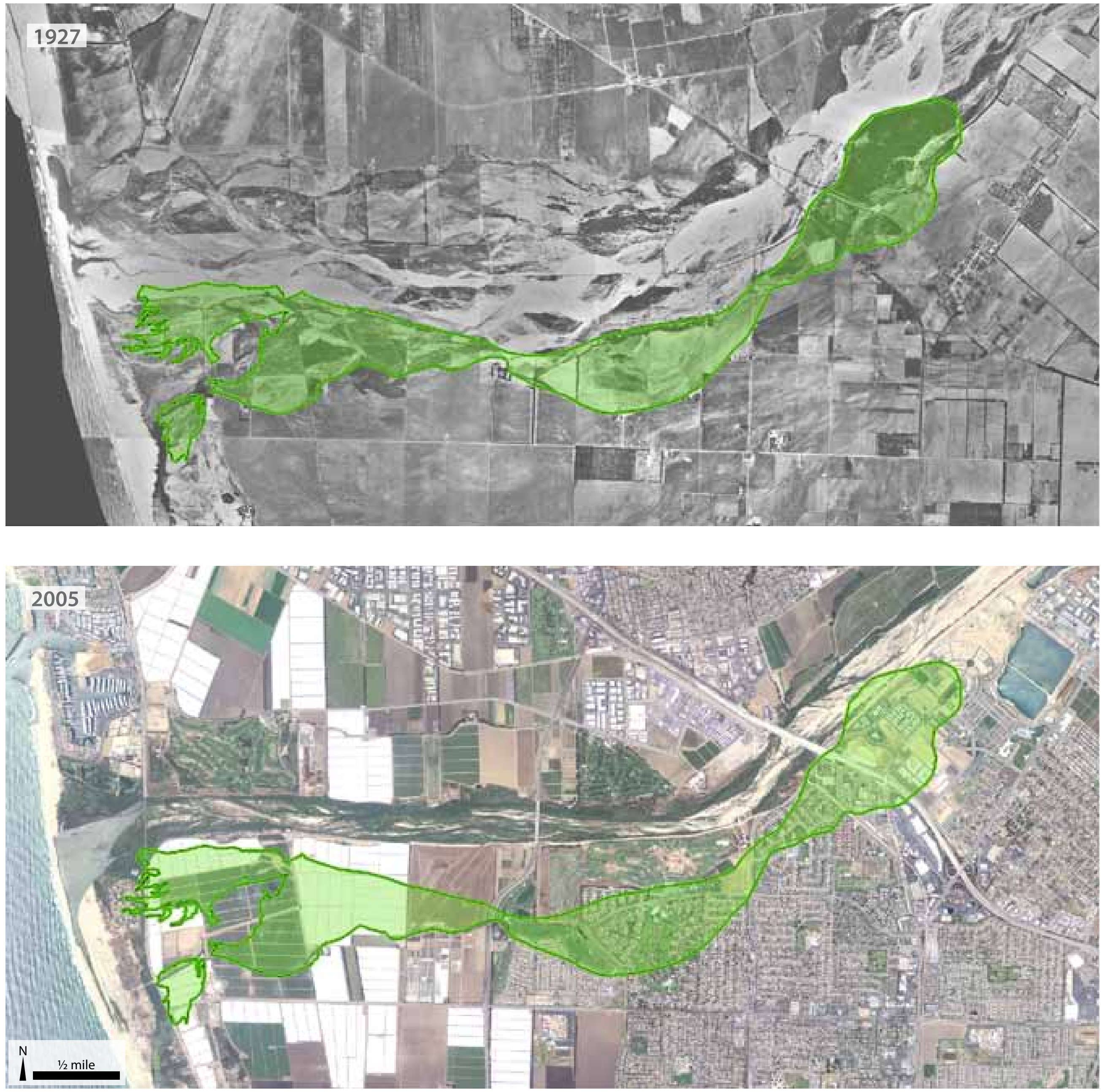
This riparian forest is still visible in early 20th century oblique photography, and is particularly notable in contrast to the intermittent, sparsely vegetated Piru reach immediately downstream (see fig. 3.26). However, the area was highly affected by the St. Francis dam break in 1928 (Isensee 1928a; see fig. 3.15). It is likely that the forest's upstream extent was much further east than we were able to map it, possibly extending well past the Los Angeles County line as it does today. Further research at Los Angeles County archives may help confirm the upstream extent of this riparian corridor.

Riparian Vegetation on the Santa Clara River Today

There has been a substantial loss of historical floodplain habitat due to the urban development and agricultural intensification of the 19th and 20th centuries. Riparian trees have been cut for fuel, cleared to make space for fertile bottomland agriculture, or killed by the lowering of the water table due to groundwater extraction. This trend is consistent with other central and southern California rivers, where similar effects have been documented (see Boughton et al. 2006).

The loss of vegetation is evident in a comparison of past and present willow-cottonwood forest below Highway 101 (near the river mouth), in the area formerly known as West Grove. This reach has been highly altered by floodplain development and constricted by levee construction, resulting in the near-complete loss of the most extensive historical grove of willow-cottonwood forest (approximately 1,200 acres; fig. 3.41). Near Fillmore, most of the 340 acre Cienega has also been converted to agriculture, though it clearly still experiences high groundwater levels (fig. 3.42). The riparian corridor is further threatened by the introduction of non-native plants, with the greatest threat currently posed by the extensive invasion of Arundo throughout the lower river.

Precise loss of riparian forest on the Santa Clara River over the past few centuries is impossible to calculate. The historical riparian mapping generated in this study is limited and coarse, and includes only prominent willow-cottonwood forest and wetland areas in four discrete nodes along the river (rather than detailed mapping of the entire corridor). In contrast,



West Grove, historical extent

Fig. 3.41. Lower Santa Clara river, 1927 (top) and 2005 (bottom). By the 20th century, the majority of the original 1,200 acres of forest along the southern side of the Santa Clara River had disappeared. (Fairchild Aerial Surveys 1927, courtesy of Whittier College; USDA 2005)

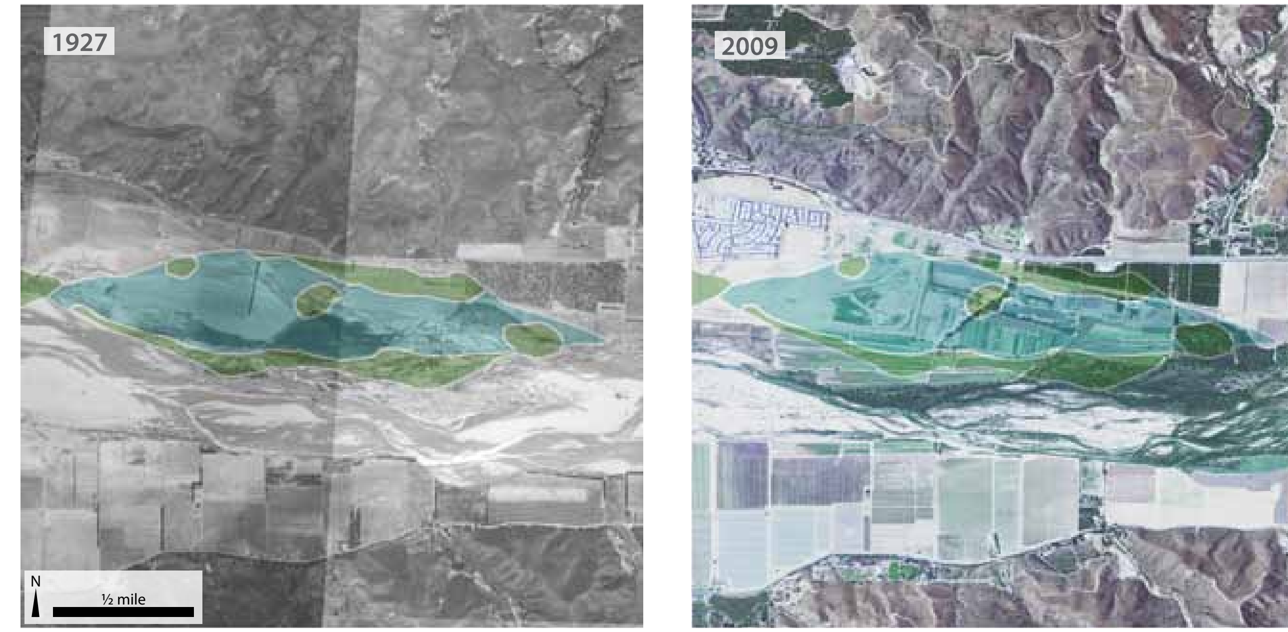


Fig. 3.42. Cienega, 1927 (left) and 2009 (right). As early as 1927, most of the original extent of the Cienega had been cleared. The former Cienega site is now the location of the Fillmore Fish Hatchery and crops tolerant of high groundwater conditions (e.g., watercress). Very little of the original Cienega extent remains, though substantial forest is found in the river corridor to the south. (Fairchild Aerial Surveys 1927, courtesy of Whittier College; USDA 2009)

Cienega, historical extent

the modern vegetation survey (Stillwater Sciences and URS Corporation 2007) was conducted at a finer spatial resolution and includes the entire river. These issues are compounded by the temporal variability of vegetation extent and distribution on the river over time, particularly associated with floods. A rough comparison is possible, however. In total, approximately 2,540 acres of willow-cottonwood forested wetland and valley freshwater marsh were present in the four persistent riparian areas in the early 19th century, compared to about 1,380 acres of mixed riparian forest and cottonwood-willow forest surveyed for the contemporary (2005) mapping (Stillwater Sciences and URS Corporation 2007; fig. 3.43). This represents a loss of 46%. The true percentage loss of riparian forest is likely far higher, since the historical figure does not account for riparian forest outside of the mapped persistent historical riparian areas.

Despite these changes, in comparison to other California lowland alluvial rivers the Santa Clara River still maintains a relatively high proportion of floodplain with native riparian vegetation and riverwash habitats (Orr et al. 2011). Valuable nodes of high quality native vegetation are still present in many reaches, reflecting the distribution of former forests. In particular, stands of willow-cottonwood forest still track gaining reaches and reaches with shallow groundwater, and occupy historical locations. Hedrick Ranch Nature Area, a reserve that supports willow-cottonwood forested wetland and occupies a portion of the former East Grove east of the Santa Paula Creek confluence. Current nodes of willow-cottonwood forest also exist southeast of Fillmore near the Fillmore Fish Hatchery (corresponding to the historical Cienega area) and between Camulos and Del Valle along the upper river (historical Del Valle area).

In addition, plant communities associated with rare Southern California alluvial scrub are still found in intermittent reaches of the river today (e.g., the Piru reach). Sagebrush (*Artemisia tridentata*), California buckwheat (*Eriogonum fasciculatum*), and chaparral yucca (*Yucca whipplei)* vegetation alliances have been observed in reaches with high depth to groundwater, where historical observations recorded cactus and sagebrush. Alluvial scrub vegetation, once common in Southern California, has been greatly reduced from its historical extent (Smith 1980, Hanes et al. 1989, Burk et al. 2007, Rundel 2007, Sawyer et al. 2009). In concert with contemporary fieldwork and analysis, it may be possible for local and regional groups to incorporate these rare vegetation types into conservation and restoration efforts for the Santa Clara River corridor.

The Santa Clara River has experienced tremendous loss in riparian floodplain habitat (particularly persistent riparian forest) in many reaches over the past few centuries. Nevertheless, comparison of historical and contemporary ecology reveals that the largest present-day patches of riparian forest today occur in areas that historically supported much larger stands of willow-cottonwood forested wetland and mixed riparian forest. Though today's nodes represent only a fraction of former riparian extent, they suggest substantial opportunity for riparian conservation and restoration in these areas. Restoration efforts at one of these nodes (Hedrick Ranch Nature Area) have been highly successful, with willow-cottonwood forest regenerating rapidly (Coffman, pers. comm.)

This research highlights that the underlying hydrologic and geomorphic processes driving the distribution of riparian forest nodes are still intact, at least in some form, today. Maintaining and enhancing the current hydrologic regime of the Santa Clara River so it remains reflective of the natural, unmodified regime may be critical for maintaining desired river and riparian-floodplain habitat, ecosystem functioning, and resilience.

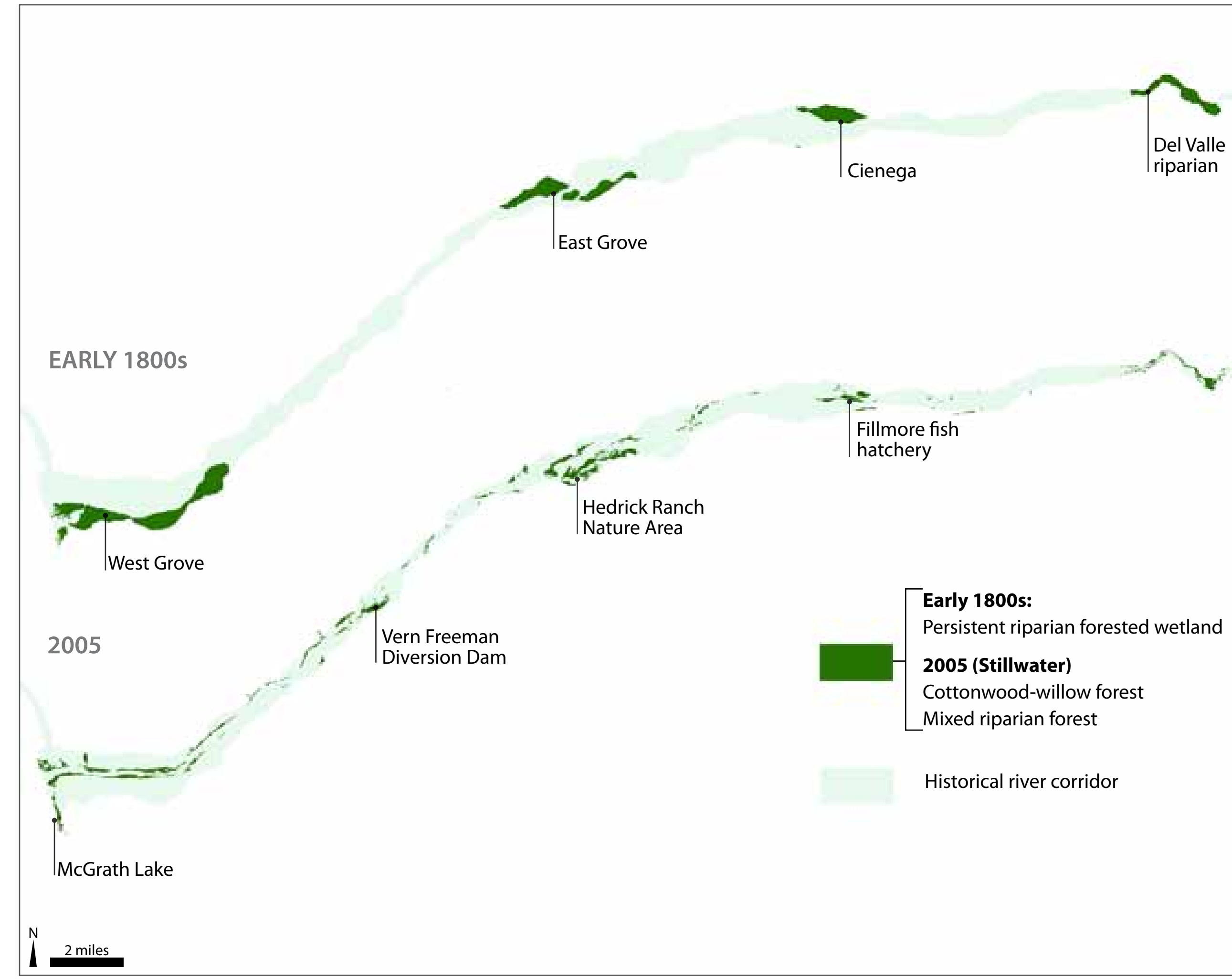


Fig. 3.43. Distribution of riparian forest on the Santa Clara River, early 1800s and 2005. The current (2005) distribution of mixed riparian and cottonwood-willow forest on the Santa Clara River closely mirrors the former distribution patterns of similar habitats in "nodes" along the river. Though the extent of these habitats has been sharply reduced, the persistence of these nodes over the past 200 years suggests relatively intact groundwater patterns and the potential for additional recovery.

Riverine transformation and synthesis

Two centuries ago, the Santa Clara River exhibited remarkable ecological, hydrologic, and geomorphic heterogeneity over the lower fifty miles of its course. In this chapter we documented this diversity, identifying patterns and characteristics of the historical river. This section synthesizes the foregoing descriptions of physical and ecological properties of the river in three sample reaches to provide a more comprehensive, integrative understanding of properties of the river both longitudinally and temporally. We also provide a summary of our Santa Clara River findings and the implications of our research for management strategies in the watershed today.

The Santa Clara River changes dramatically longitudinally, as well as throughout time. We chose three river reaches to illustrate both of these concepts in section: the river mouth, Santa Paula reach, and Piru reach (fig. 3.44). The cross-sections and accompanying plan form representations illustrate the historical hydrology, morphology, and ecology of the river in three very different locations in the mid-to-late 19th century (1853-1892). We also produced cross-sections presenting conditions in these reaches during the mid-20th century (1927-1938) and early 21st century (2005) to depict the impacts of land use changes over this time. These dates reflect data availability for each reach, in addition to a desire to juxtapose years with comparable flood dynamics (both 1938 and 2005 sets of aerial images show the active channel after large flood events on the Santa Clara River). Taken together, these reaches represent the variability in vegetation and flow characteristics along the river.

Fig. 3.44. Locations of illustrated cross sections on Santa Clara River. The easternmost reach is just downstream of the Piru confluence, and is characterized by intermittent flow and sparse, scrubby vegetation. The middle reach is just upstream of the town of Santa Paula, an area of rising groundwater historically characterized by multiple channels and marshes bounded by willow-cottonwood forests. The westernmost cross-section depicts the mouth of the river. This area has changed from a broad deltaic formation with seasonal lagoons surrounded by grasses and willow-cottonwood forest to a narrow single-thread channel with levees protecting a golf course on the north bank and agricultural operations on the south.

We used a variety of methods and sources to produce 19th century cross-sections where no historical elevational data were available. We extracted the physical form for the three cross-sections from the 2005 LiDAR data from Ventura County, using these modern data for elevations and valley width (and making adjustments, such as removing anachronistic levees, as needed for the historical renderings). We used the 2005 NAIP imagery to locate land use changes, vegetation and channel features on the modern cross sections, augmenting this interpretation with modern riparian mapping by Stillwater Sciences/URS. For the mid-20th century snapshot, we used the 1927 and 1938 aerial photos to map land use patterns and channel changes onto the cross section. Finally, in order to graphically illustrate the 19th century cross-sections, we used USCS T-sheets (for the river mouth), GLO notes from several land surveyors, and the historical habitat mapping.

Though the channel forms, vegetation and land use patterns have changed drastically since the mid- to late-19th century, historical long profile data (Stillwater Sciences 2007b) indicated that there had not been continuous or reach-wide incision or aggradation in these three locations since the mid-20th century. Stillwater Sciences' research indicates net changes in bed elevation for the two upstream cross sections between 1949 and 2005 as ranging from –2 feet to +5 feet. The cross section at the mouth experienced a general trend in downcutting of 4 feet during the time period examined; however, the scale of our cross-section was too large to effectively illustrate this. As such, we decided not to show bed elevation change as an important feature in the cross sections, since for most of the reaches depicted there was no conclusive evidence for systemic degradational or aggradational patterns.

These cross sections are only a snapshot of patterns at narrow locations and points in time within the watershed, though we believe they offer representative glimpses of temporal and spatial change in three different reaches of the Santa Clara River. Bear in mind that they are purely conceptual in nature, and are not intended to represent exact landscape patterns (e.g., tree density or marsh extent).

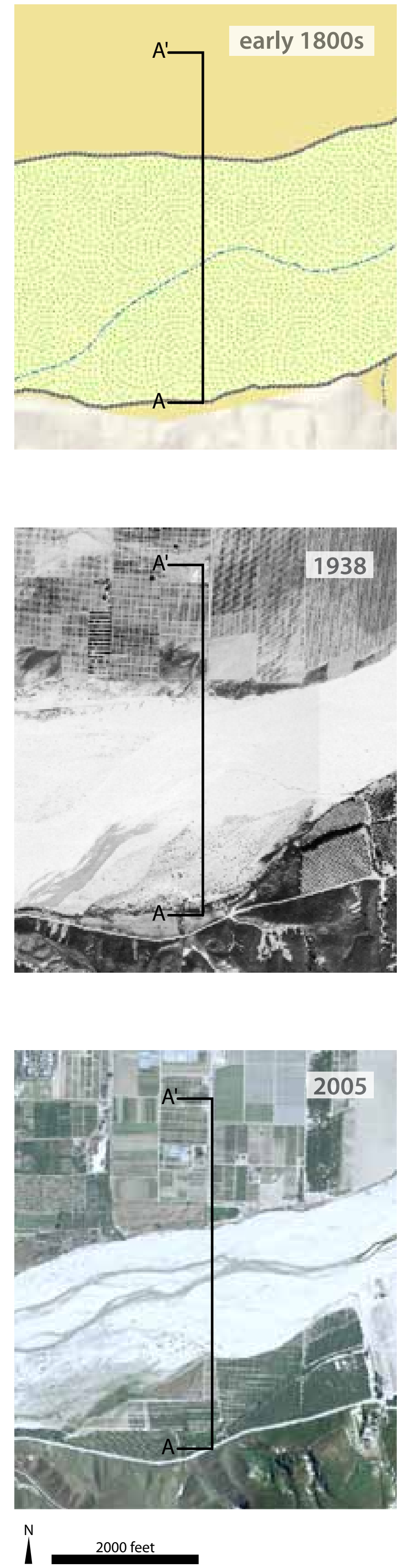
PIRU REACH

This reach of the Santa Clara River was intermittent, consistently drying out during the summer. Throughout the past 150 years, it has been characterized by a broad, sandy active channel and sparse scrub vegetation. Though its overall character has remained relatively stable over time, changes to the river corridor have occurred.

Surveyor H.S. Craven (1874f) walked north along this transect on March 12, 1874, documenting conditions along the river and valley 1.5 miles downstream of the Piru confluence. Craven noted "rocky" and sandy portions of the river bed, describing the active channel as a dry "sandy plain." He described no vegetation in the channel, but noted cactus and sagebrush growing on the northern (right) bank between the river and the agricultural fields of the valley. He also noted ploughed fields and a house not far from the north bank of the river.

Though the river corridor maintained most of its width between 1874 and 1938, aerial photography reveals several distinct changes. Most notably, the scrub recorded in Craven's 19th century survey notes had been cleared and replaced by orchard plantings, though limited xeric vegetation remained and washy arcuate patterns in the aerial image indicate that the plot was either recently ploughed or recently flooded.

Similar hydrology and vegetation persist today, though invasive giant reed (*Arundo donax* or Arundo) is now present and the river corridor has narrowed due to agricultural development on the floodplain. Between 1938 and 2005, the most drastic change was the addition of orchards on the south bank between Guiberson Road and the active channel, resulting in the constriction of river corridor width by 43% from 1874. The riverbed remains sandy and actively scoured, with some alluvial scrub and Arundo in 2005. Orchards and nurseries continue to occupy the right side of the river.



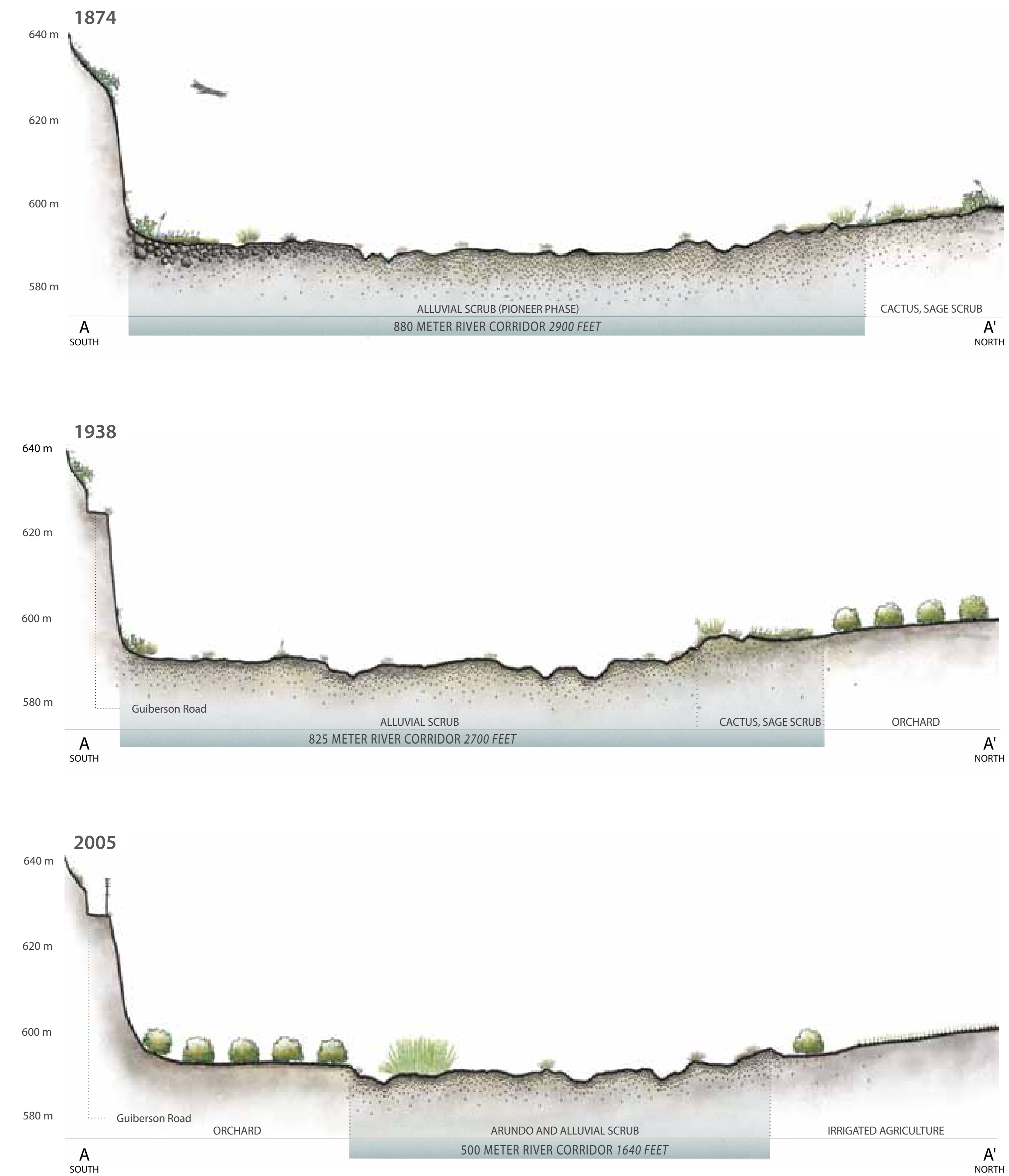


Fig. 3.45. Historical cross-sections at Piru, 1874-2005. This series shows the Santa Clara River west of Piru, between Piru Creek and Hopper Canyon. This intermittent reach was characterized by a broad active channel dominated by sand and scrub vegetation. Similar hydrology and vegetation persist today, though Arundo is now present and the river corridor has narrowed due to agricultural development on the floodplain. Cross-sections are drawn with 5x vertical exaggeration. (Craven 1874f; USDA 1938, courtesy of Ventura County; USDA 2005; Stillwater Sciences and URS Corporation 2007. Cross-sections produced by Jen Natali)

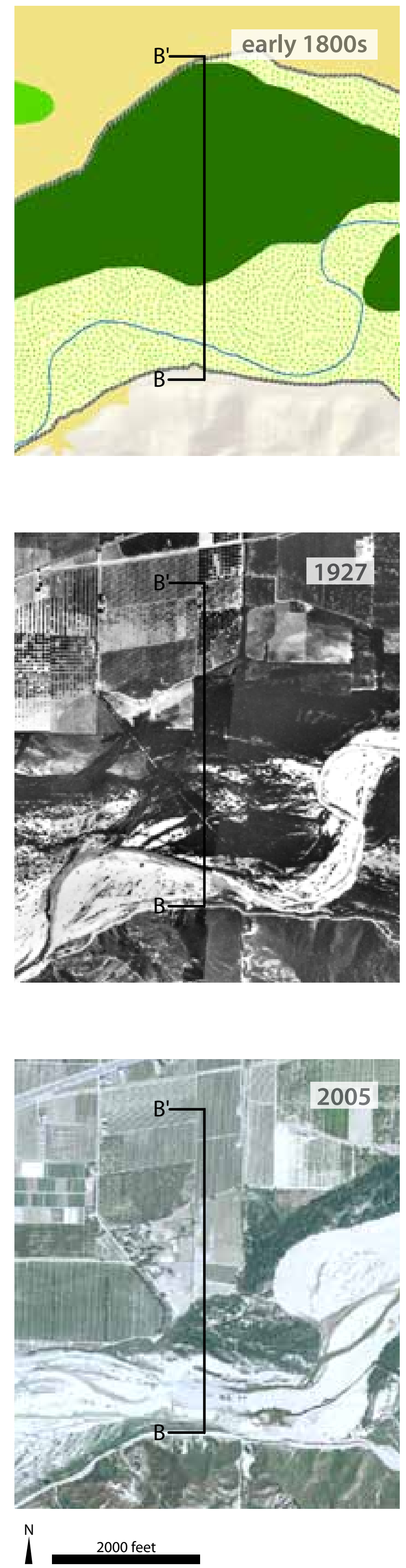
SANTA PAULA REACH

Just east of the Santa Paula Creek-Santa Clara River confluence, rising groundwater created an extensive zone of willow-cottonwood forest and freshwater wetlands situated on the river's bottomlands. Though the riparian forest in this area has been whittled away to make room for agricultural fields over the past century, substantial willow-cottonwood forest is still present in this reach, and the reach's former hydrology (gaining reach, perennial surface flow) is still intact.

Several surveyors took evocative notes along the same transect between 1853 and 1892, and their efforts are compiled in this illustrative cross-section (Norris 1853, Hoffman 1868b, Thompson 1869, Barry 1892a). Their notes record bottomland covered with willow scrub, willow-cottonwood forest, and freshwater marsh below the northern bluff bank, and an active channel with multiple shifting mainstem channels and bars. Though the surveys span 40 years, they are consistent in their descriptions of entering and exiting a "cottonwood and willow swamp" (Norris 1853), sandy and muddy substrates (including an area of "deep mud"; Hoffman 1868b), and mature timber and scrub on the north bank. This is part of East Grove (see page 100).

By the time the 1927 aerial photos were taken, some of the cottonwood and willow forest had been cleared and drained, and replaced with bottomland farms and orchards. Substantial dense riparian forest remained, though the river corridor width shrunk by just over 30%.

By 2005, the formerly 3,900 foot wide river corridor had been constrained to about 1,600 feet across, an overall loss of 58%. Orchards and other agricultural developments have replaced much of the former forest.



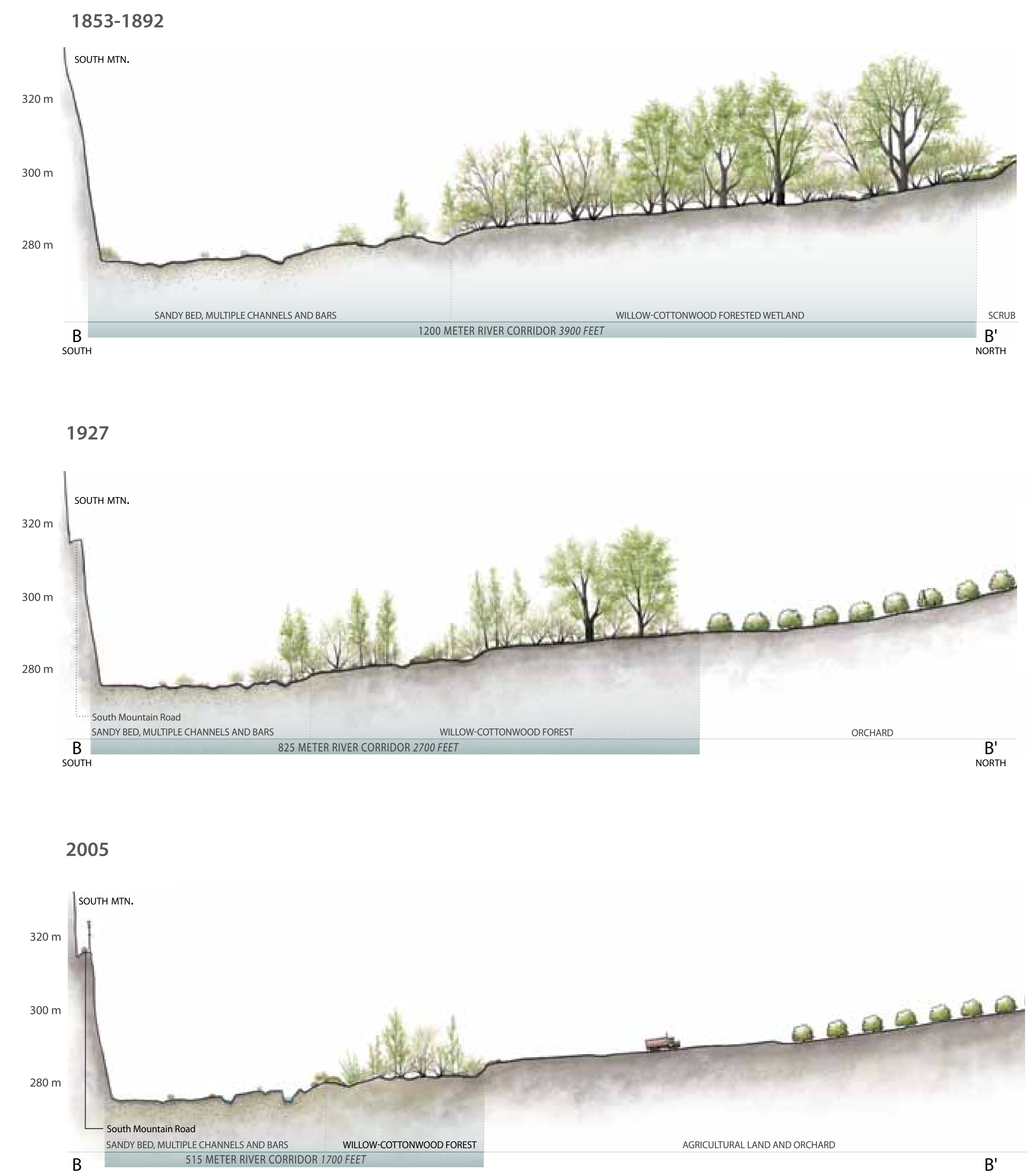


Fig. 3.46. Historical cross-sections at Santa Paula, 1853-2005. This series of cross-sections shows the Santa Clara River east of the Santa Paula Creek confluence, where the south bank of the river abuts South Mountain. The transect is in a perennial reach of rising groundwater, characterized in the 19th century by extensive willow-cottonwood forests and freshwater wetlands. Substantial willow-cottonwood forest remains in the area today, though much diminished from former extent. The earliest cross-section is derived from a composite of GLO surveys spanning the second half of the 19th century. Cross-sections are drawn with 5x vertical exaggeration. (Norris 1853; Hoffman 1868b; Thompson 1869; Barry 1892a; Fairchild Aerial Surveys 1927, courtesy of Whittier College; USDA 2005; Stillwater Sciences and URS Corporation 2007. Cross-sections produced by Jen Natali)

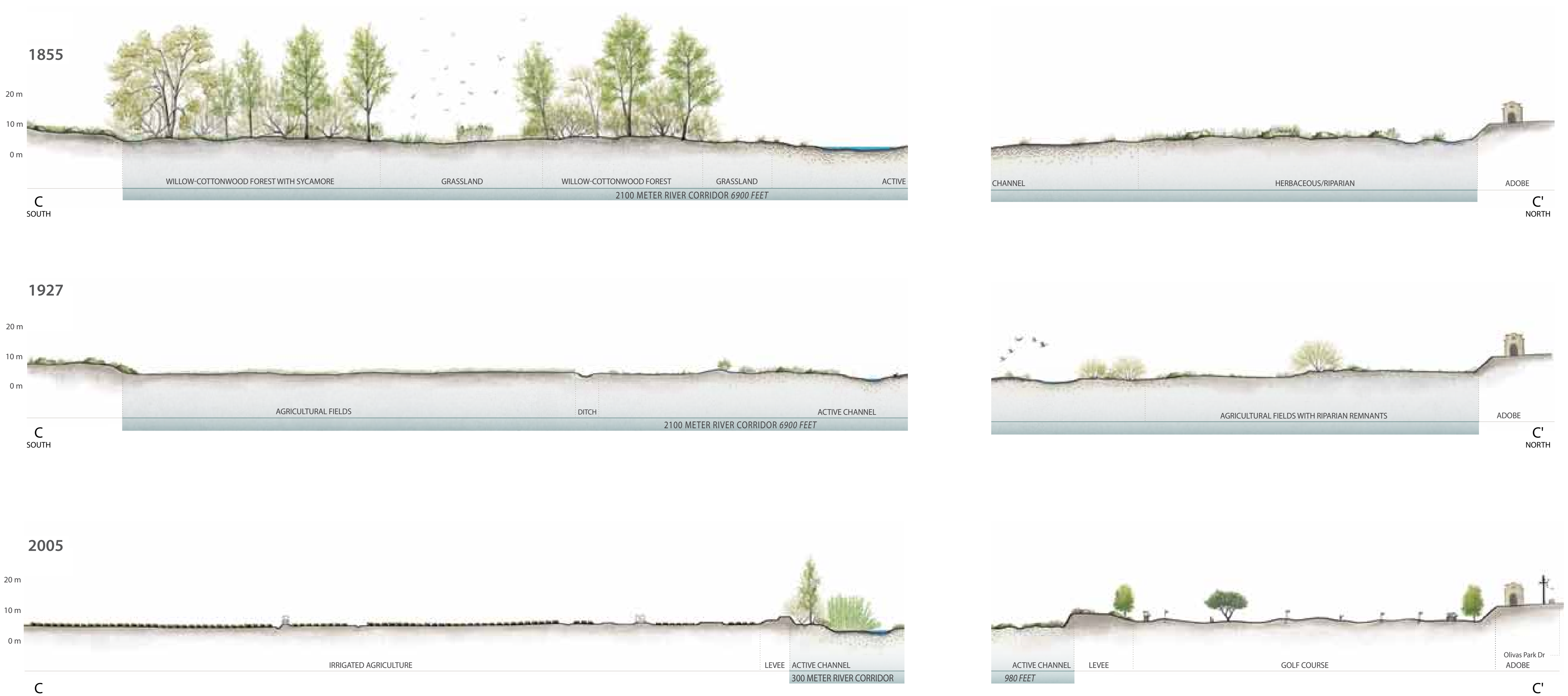
MOUTH OF SANTA CLARA RIVER (OXNARD REACH)

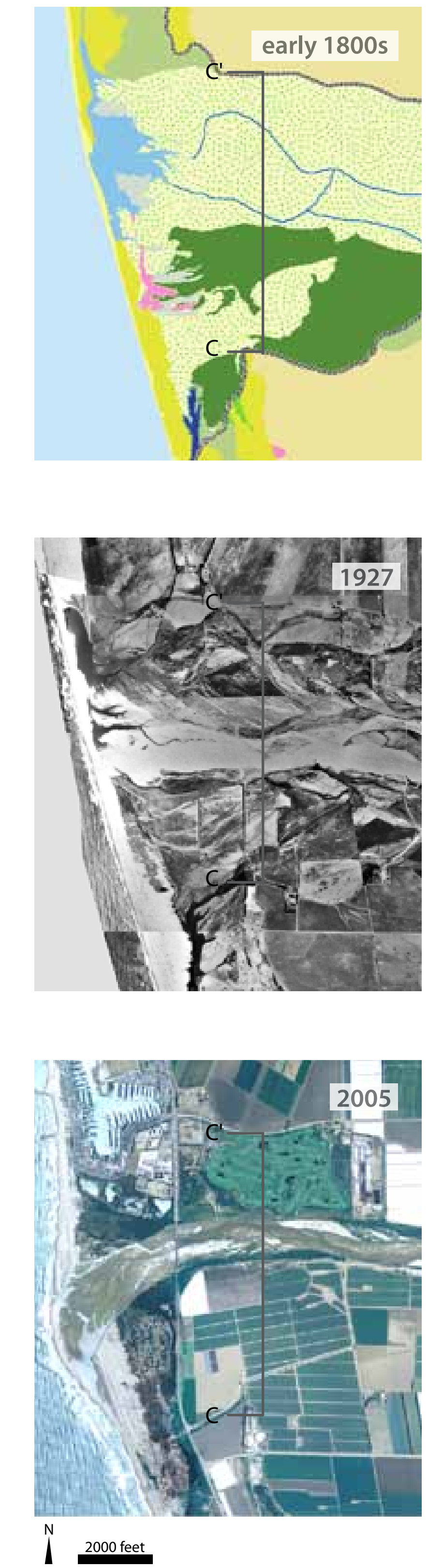
The Santa Clara River mouth south of Highway 101 has experienced dramatic changes over the 19th and 20th centuries, including the near-complete loss of West Grove and the contraction of river corridor width by over 85%. The reach has been transformed from a broad estuarine delta about 1.25 miles wide to a narrow river corridor separated by levees from intensive agricultural and recreational uses. The Olivas adobe (pictured on the right bluff bank), built in 1837 and enlarged in 1849 (OHP 2011), has stood watch over these changes.

Early surveyor's notes describe cottonwood and willow "belts" and "groves" near the mouth (Hancock 1854). These descriptions are corroborated by the 1855 T-sheet, which depicts dense willow-cottonwood forest south of the active channel, and broad distributary channels and grassland to the north. This area maintained shallow summer surface flow due to perched groundwater conditions.

Over 70 years later, in 1927, most of West Grove had been cleared for agriculture. Broad floodplain areas on both sides of the active channel were subdivided into farmland, and irrigation ditches and levees are evident. However, patterns visible on the aerial affirm that much of this area (particularly on the south side) continued to be regularly flooded. By 2005 levees bound the river, including a levee on the south side of the river originally built by the Army Corps in 1961 (Stillwater Sciences 2007b). Levees and land use constrain the formerly 6,900 foot wide river to a 1,000 foot corridor. Intensive agriculture and the Olivas Park golf course inhabit the former floodplain. Herbaceous cover, willow-cottonwood forest, and invasive *Arundo donax* flank the mainstem.

Fig. 3.47. Historical cross-sections at the Santa Clara River mouth, 1855-2005. This time series shows the Santa Clara River at its mouth, about 3.5 miles downstream from the Highway 101 bridge. A large willow-cottonwood forest and wetland complex dominated the left bank (south side) of the river from above the bridge all the way to the river mouth, a distance of over four miles. Very little of this once-expansive forest remains today. The earliest cross-section is derived from GLO notes and the mid-19th century T-sheet drawn for the river mouth by the U.S. Coast Survey. Cross-sections are drawn with 5x vertical exaggeration. (Hancock 1854; Johnson 1855c, courtesy of the National Oceanographic and Atmospheric Administration; Fairchild Aerial Surveys 1927, courtesy of Whittier College; USDA 2005; Stillwater Sciences and URS Corporation 2007. Cross-sections produced by Jen Natali)





CONCEPTUALIZING THE SANTA CLARA RIVER

Part of the challenge of developing viable restoration and conservation strategies for highly fragmented rivers is simply gaining enough perspective to think about them accurately (Montgomery 2008). Forming a clear vision of the processes at play in these systems is an instrumental part of developing restoration plans with a high likelihood of success and public acceptance (Palmer et al. 2005, Hanley et al. 2009, Greiner 2010). The historical record for the Santa Clara River provides some of the perspective necessary for thinking about its future.

From historical data, we can see that the river was neither a continuously perennial stream uniformly lined with riparian forest, nor simply a dry, scrubby wash with little established vegetation. Instead, its hydrology and vegetation were more heterogeneous than either endpoint, though it embodied aspects of both. Some seemingly barren reaches of today's river—where one might question whether two centuries of water diversions and deforestation had completely altered the river's character—are in fact remnants of historically summer-dry, scrub and riverwash-dominated reaches. Conversely, reaches with rising groundwater supported much more lush riparian and wetland vegetation than one might expect to find in semi-arid Southern California, in close proximity to drier portions of the river.

Remarkably, and despite large-scale changes to the landscape, upon close examination many of these patterns are still expressed today. Geologic controls still influence hydrology in places like the Sespe and Piru narrows, creating nodes of high groundwater across the length of the river. These areas may still be conducive to the recovery of certain groundwater-dependent riparian and aquatic habitats.

In addition to documenting historical patterns, it is also instructive to think about historical riverine dynamics. While we often focus on the episodic, variable nature of Southern California streams in this study, we found that overall ecological and hydrologic patterns along the river were historically quite stable, persisting across major flood events. More historically stable forest and bottomland habitats have been largely eliminated, leaving only the mostly sandy active channel in many places. The legacy of this transformation from a broad, topographically complex channel with the capacity to accomodate large flows to a narrower, more confined channel is a more homogeneous river with increased sensitivity to episodic events and reduced potential for the establishment of diverse and persistent floodplain habitats, particularly in the lower reaches.

SUMMARY OF FINDINGS

The following findings represent some of the significant conclusions drawn from our research and analysis. Taken together with an understanding of modern conditions, these findings can support scientists and managers working to identify restoration opportunities in the Santa Clara River valley.

1. **The historical (early 1800s) Santa Clara River valley supported a diverse array of natural habitats,** from the willow groves and wetlands of Saticoy Springs to the sycamores and oaks found on alluvial fans near Santa Paula and Fillmore. However, the valley floor was dominated by grassland and coastal sage scrub, with trees occurring singly or in stands and along creeks and rivers. Valley oaks were not documented in the Ventura County portion of the valley.

2. **Most substantial freshwater wetland complexes occurred within the river corridor of the Santa Clara River, not on the valley floor.** A rich array of aquatic habitats were found within the river corridor, including ponds, sloughs, and freshwater marshes in perennial reaches, and a suite of saline and brackish aquatic habitats associated with the estuary at the river mouth.

3. **Prior to modification, most small tributaries did not connect to the Santa Clara River.** With few exceptions, intermittent small creeks commonly sank into their alluvial fans before reaching the Santa Clara River, a characteristic common to many intermittent tributaries across California. Rather than maintaining defined channels all the way to the river, these creeks were connected hydrologically to the river through subsurface flow and poorly defined, transitory surface channels. Most of these creeks have now been connected to the Santa Clara River though constructed channels, increasing valley drainage density (that is, stream length per unit area).

4. **From the late 19th to the early 20th century, the position of the Santa Clara River corridor remained relatively laterally stable.** Inter-annual variability in the relative vegetation cover of the active channel and bottomlands is evident in the historical record, with widespread changes occurring after each major flood. However, our findings support the overall lateral stability of the river even through the St. Francis Dam break in 1928.

5. **In the relatively recent geologic past, the lower Santa Clara River shifted its outlet from near Point Hueneme to its present location.** While the date of this shift is not clear, it may have occurred in the past 200-500 years based on edaphic, ecological, and ethnographic evidence. This shift is reflected in historical alkalinity patterns on the Oxnard Plain (see page 177).

6. **The Santa Clara River was an interrupted perennial stream,** with alternating perennial and intermittent (summer dry) reaches. Only two intermittent reaches were clearly documented on the river, near Saticoy and Piru (though additional intermittent reaches may have been present). The location of perennial reaches was informed by a variety of factors, including artesian influence, tributary inputs, valley narrowing, and geologic constraints. Many of these factors continue to affect surface flow patterns today.

7. **The Santa Clara River supported a diverse mix of riparian species,** including trees such as sycamore, live oak, willow, cottonwood, box elder, and alder; scrub species such as scalebroom, buckwheat, mulefat, golden-aster, sagebrush, black sage, and cactus; and understory species such as wild grape and wild blackberry.

8. **Dense, persistent riparian forest and in-channel wetlands occurred in discrete patches along the Santa Clara River.** Rather than a continuous corridor, willow-cottonwood riparian forest was found at a few notable locations along the river, corresponding with areas of

rising or perched groundwater. Other reaches supported a different matrix of non-vegetated riverwash, willow scrub, mulefat, and alluvial scrub. This longitudinal heterogeneity tied to patterns in groundwater-surface water interactions suggests that different restoration targets are appropriate for different reaches. It suggests nodes for riparian forest restoration centered around former persistent wetland riparian areas, as well as a focus on maintaining the water resources (rising groundwater) that would support these habitats.

9. **Alluvial scrub was a likely component of the driest portions of the Santa Clara River.** While more research is needed, compiled data suggest that alluvial scrub is a more suitable riparian restoration target for drier reaches (notably the Piru reach) than riparian forest.

10. **Live oaks and sycamores occurred frequently on the Santa Clara River river outer banks.** Numerous live oaks and sycamores were documented on high banks on the edge of the river corridor. Live oaks and sycamores documented within the river corridor occurred largely in Santa Paula and Sespe creeks (likely on higher bars or islands) and as individuals within large areas of willow-cottonwood forest on the mainstem Santa Clara River.

Management Implications

- **Though the Santa Clara River has undergone substantial transformations over the past 250 years,** many of the underlying physical parameters and processes have remained intact, particularly in comparison to other Southern California rivers. These characteristics create an unusually rich array of management possibilities for the river regarding the conservation and restoration of ecological patterns and habitat value.

- **Maintaining the hydrologic heterogeneity of the Santa Clara River is an essential component of conserving ecological diversity.** Groundwater availability (and by extension, summer flow) is clearly a primary driver in the distribution and composition of riparian habitat. Disturbance from winter floods, via scour or sediment deposition, is also an important driver of riparian vegetation dynamics.

- **Riparian restoration targets should be assessed at a reach scale.** Different suites of species were supported historically in different reaches. Willow-cottonwood forest was not found continuously along the river, and is not an appropriate or feasible restoration target for the entire river. For example, alluvial scrub may be a more appropriate target in the Piru reach, and conservation activities may support the preservation of this regionally rare habitat type.

- **Reaches with rising groundwater present unique opportunities for riparian forest restoration.** Many wetland species support functions are concentrated in areas with dense riparian forest and rising groundwater. Managers may choose to prioritize restoration of willow-cottonwood forest and in-channel wetlands in these places, if contemporary assessment shows restoration to be viable. This includes former floodplain surfaces on the south side of the river near its mouth, the region east of the Santa Paula Creek confluence, and the former Cienega (Fillmore fish hatchery) area.

- **Ecological values of intermittent reaches of the river should also be protected.** Conservation of historical aspects of these reaches should be considered in project design and water management.

- **Groundwater management is an essential component of maintaining the heterogeneity of the Santa Clara River riparian corridor.** To the extent feasible, managing surface and groundwater resources to mimic historical hydrologic patterns preserves the viability of riparian restoration at the reach scale.

- **The lateral extent of the river corridor has decreased dramatically in some reaches from the 19th century to the 21st.** Different land uses have encroached on the former river corridor, claiming many of the less frequently flooded bottomland surfaces. The river currently occupies only a small portion of its former area; almost 50% of its former area has been lost. What remains is largely the much more dynamic active river channel. The removal of many of these more stable portions of the river may have influenced our perception of the river system, emphasizing its dynamic nature rather than its overall stability. This suggests a possible conservation focus on reoccupation of former floodplain areas. Riparian and river restoration projects should consider this large portion of the valley formerly part of the river. If these floodplain surfaces are still accessible in high flows, they may provide ecosystem functions and resilience and help managers design restoration strategies with increased chances of success.

4 • VENTURA RIVER AND VALLEY

For the entire distance we closely followed the Ventura River, a clear, dashing mountain stream bordered by hundreds of splendid oaks whose branches frequently met over our heads. We crossed the stream many times, fording it in a few places, and passed many lovely sylvan glades—ideal spots for picnic or camp.

— THOMAS DOWLER MURPHY 1921, TRAVELING FROM VENTURA TO OJAI

Introduction

The Ventura River drains approximately 230 square miles, emptying into the Pacific Ocean just west of the city of Ventura. The headwaters rise in the western Transverse Ranges, some of the youngest and most tectonically active mountains in North America with uplift rates as high as 0.2 to 0.3 inches/year. The resulting steep slopes and the relatively weak exposed sedimentary layers lead to high sediment production, landslide potential, and erosion rates (Scott and Williams 1978, Warrick and Mertes 2009, Cluer 2010).

The Ventura River ranges from steeper slope, step-pool formations with large boulders in the headwaters, to lower slope distributary channels emptying into the Ventura River estuary at the coast. Unlike the Santa Clara River, the Ventura River valley is narrow, and in many places the river occupies much of the valley floor. Upland portions of the watershed are predominantly covered in chaparral scrub, while riparian species occupy the river and its tributary corridors.

The Ventura River watershed experiences a Mediterranean climate, with 90% of the rain falling in the wet season between November and April. However, inter-annual variability is high and cycles of wet years and dry years often span decades. This climatic variability suggests an extremely variable hydrologic regime, similar to the Santa Clara River. Steep slopes in the upper watershed offer shorter lag time for surface water paths to channels, leading to quick flash floods which spread out in the broader portions of the watershed. These floods, common on the Ventura River, provide scour and habitat complexity, as well as flushing sediment through the system. With expanded urbanization and agricultural uses in the lower part of the watershed, levees have been built to confine flooding through urban and agricultural lands, and increased urban runoff and groundwater pollution have impacted water quality.

Together, Matilija Dam (built in 1948) and Casitas Dam/Robles Diversion (1959) block about 37% of the Ventura River watershed. They have broad effects on sediment transport, impeding over half of all sediment delivery

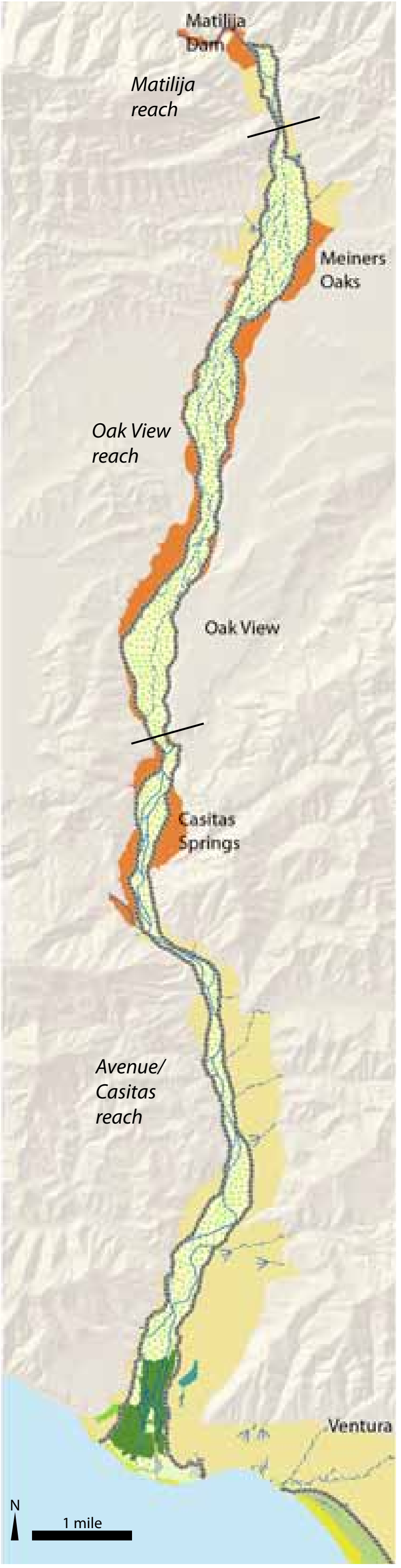


Fig. 4.2. Ventura River reach divisions. We divided the river into three reaches, based on hydrological and ecological characteristics: the uppermost Matilija Reach, the middle Oak View reach, and the lower Avenue/Casitas reach.

(Orme 2005). The Matilija Dam was originally built for flood control purposes; however, the reservoir has filled up with sediment almost completely. The dam is slated for removal, and studies have shown that it has altered flow regimes and geomorphic processes downstream, as well as acting as a barrier for migratory fish species in the watershed.

This chapter explores the historical characteristics of the Ventura River and valley prior to major urban and agricultural modifications. In particular, we focus on the pre-modification hydrology, morphology, and ecology of the river, describing each historical attribute at a reach scale. In contrast to the Santa Clara River, the Ventura River valley was lightly settled and traveled in the 19th century (with the exception of the canyon resorts of the upper Matilija canyon and the Ojai valley, both outside the purview of this report). As a result, there is much less documentation available concerning the historical character of the Ventura River.

Ventura River reach designations

We divided the Ventura River into three broadly defined reaches (fig. 4.2 and table 4.1). These reaches were defined based on the hydrology and ecological characteristics of the system. They are designed to provide meaningful units of analysis to facilitate reach-level understanding of channel dynamics and morphology.

Valley Floor Habitats

We mapped three types of habitats on the Ventura valley floor: grassland/coastal sage scrub, oaks and sycamores, and valley freshwater marsh (fig. 4.3). Grassland/coastal sage scrub was the most prevalent habitat type. In contrast to the Santa Clara River valley, which was dominated by grassland/coastal sage scrub, our mapping suggests that oaks and sycamores composed a relatively high proportion of the Ventura River valley floor. Only one freshwater marsh (17 acres) was mapped in the project area, occupying a depression to the east of the Ventura River and demarcating a former route of the river.

Broadly, grassland was most prevalent in the lower Ventura River valley, extending about six miles upvalley before transitioning to denser tree cover in the middle (Oak View) reach. Scrubland and oaks were documented north of Meiners Oaks. The following section describes these patterns and transitions in more detail.

Dryland Habitats

Unlike the Santa Clara River valley, the Ventura River valley was dominated by the natural corridor of the river. Early accounts of the river valley are filled with descriptions of its riparian vegetation, while very few sources explicitly document vegetation characteristics of the non-riparian valley floor. As a result, this section provides only coarse descriptions of regional ecological patterns. While not mapped in detail, the Ventura River corridor contained much of the valley's heterogeneity and is depicted in sources as a complex mix of oak, sycamore and scrubland (Norway 1877; Lippincott 1903). Descriptions of bottomland and other riparian characteristics are addressed in the Riparian Habitats section (see page 138).

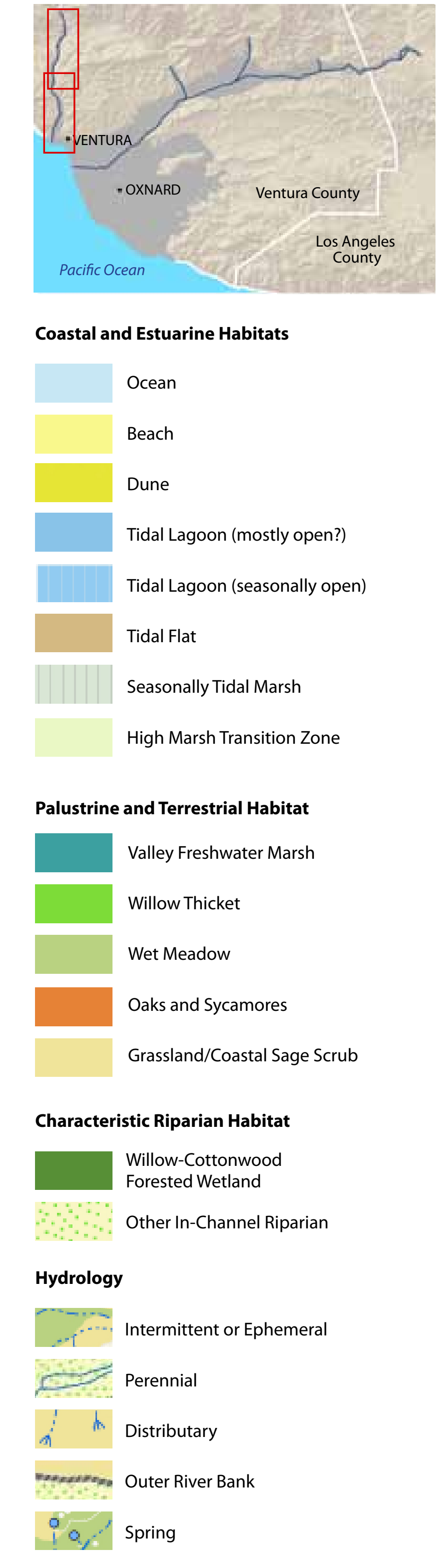
In spite of these impediments, general patterns of valley floor vegetation do emerge. Historical sources, in particular early maps and GLO survey notes, suggest that scrub-dominated cover extended downstream of the narrow, wooded Matilija canyon to the vicinity of Meiners Oaks, where oaks again became more prominent. Below Foster Park, sources indicate that the valley was dominated by herbaceous cover all the way to the river mouth. These areas are described in detail below.

Downstream from the narrow canyon just below the present Matilija dam, the valley floor in the Matilija reach appears to have been dominated by scrub. In contrast to heavy timber described in reaches to the south, GLO surveyor Norway (1878a) noted, "dense brush" on the table land east of the Santa Ynez mountains. On another line a little more than a mile further south, the same surveyor distinguished between the "brushy table land" he just passed through and the "timbered bottom"—the bottomlands of the Ventura River (Norway 1877). As supporting evidence, relatively few trees are present along this reach in the historical aerials compared to timbered areas farther south.

South of Meiners Oaks, and extending to Foster Park, live oaks (and sycamores) became more numerous. For much of this reach (Oak View), the comparatively broad river corridor encompasses almost the entire narrow valley. Observations such as "timbered tableland" (Thompson 1868) and "valley mostly timber" (Norway 1877) are a clear contrast to the descriptions of scrub farther north. Dense tree cover is evident in the historical aerial photography and, in some places where oaks have been cleared for development, earlier GLO surveys note "heavy oak timber" (Norway 1877). Sycamores also appear to have dominated the tree cover in some places (fig. 4.4; Hare 1876). In the Foster Park area, at the southern extent of mapped woodland, a notable area of sycamores and oaks has served as a gathering place since before Mission times (see Riparian Habitats section for more information on Foster Park). As in the Santa Clara River valley, the historical record contains no descriptions of valley

Table 4.1. Upstream boundaries of Ventura River reaches.

	Avenue/Casitas reach	Oak View reach	Matilija reach
Upstream end of reach:	San Antonio Creek confluence	Near Cozy Ojai Road	Matilija dam



Legend for **Fig. 4.3** (map on following page).

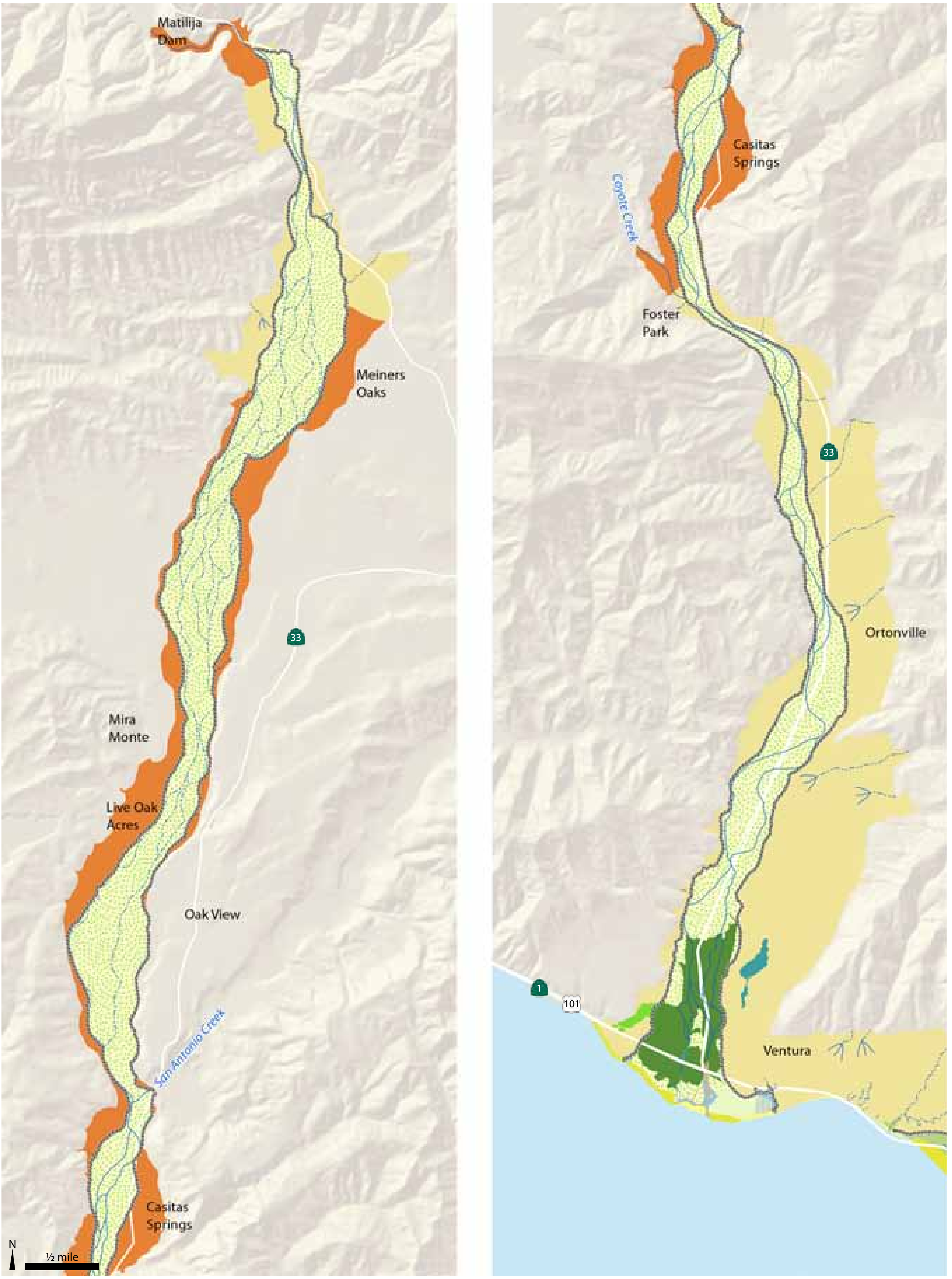


Fig. 4.3 .Historical habitats of the Ventura River valley, early 1800s. The Ventura River corridor was broad, in places occupying a large proportion of the valley floor. Live oaks, sycamores, and scrub were prevalent in the upper valley, while grassland was more common in the lower valley.

oaks in the Ventura River valley by any of the region's travelers, botanists, or residents, despite abundant references to the presence of live oaks by these observers (see page 57). (Ojai Valley, outside our project area, is a notable exception.)

Below Foster Park, historical evidence suggests relatively sparse tree cover in comparison to the wooded reach upstream. Vegetation characteristics changed notably in the Avenue area, where the Ventura River valley begins to open to the ocean. While mapped as the same general habitat type (grassland/coastal sage scrub) as the valley floor in the upper Ventura River reaches, the Avenue/Casitas area was likely more predominantly covered by grasses and forbs as opposed to scrub.

Explorer Crespí noted this distinction between the rich grasslands of the lower valley and the woodlands of the upper river valley in 1769:

> At this spot where we stopped in the hollow [Ventura River valley] close to the shore, there is a great deal of very good grass-grown level soil trending north and south, very nearly a league's worth [about 3 miles], it may be, of it, backward from the shore. Its width of smooth level soil must be about a quarter-league, and in some spots, where not so smooth, it may reach half a league, while the country opens out a great deal, further up to northward, with a great many hollows of naturally watered soil and a great amount of live-oak groves. (Crespí and Brown 2001)

The relatively early Leighton (1862) map corroborates Crespí's description of largely herbaceous cover, depicting trees along the canyons while leaving table lands mostly bare of trees. Textual sources also describe a fertile, grassy region north of the river mouth; Brewer noted that the Avenue region was a "pretty valley, green, grassy, and rich" in 1861 (Brewer [1930]1974), and Thompson and West ([1883]1961) called it an area of "unsurpassed richness." In 1856, a traveler to the Mission found the lower river valley "fine green country" with "plenty of grass" (Miller 1856, in Weber 1978). Roughly contemporary with many of these observations, the U.S. Coast Survey mapped the Ventura River mouth, also depicting herbaceous cover outside of the river corridor (Johnson 1855c; see fig. 4.20).

Overall, however, the habitat map may significantly underestimate historical oak woodland extent as a result of methods that default to grassland/coastal sage scrub in the absence of spatially explicit data. The descriptions and maps cited above suggest that, in contrast to the dominance of grass and scrub on the Santa Clara valley floor, oak and scrub may have been the dominant vegetation complex on the Ventura River valley floor above Foster Park.

Wetland Habitats

Only one freshwater wetland complex was documented on the Ventura River valley floor outside of the river corridor. (This does not include the lake at Figueroa Street on the coast, which is treated separately; see page

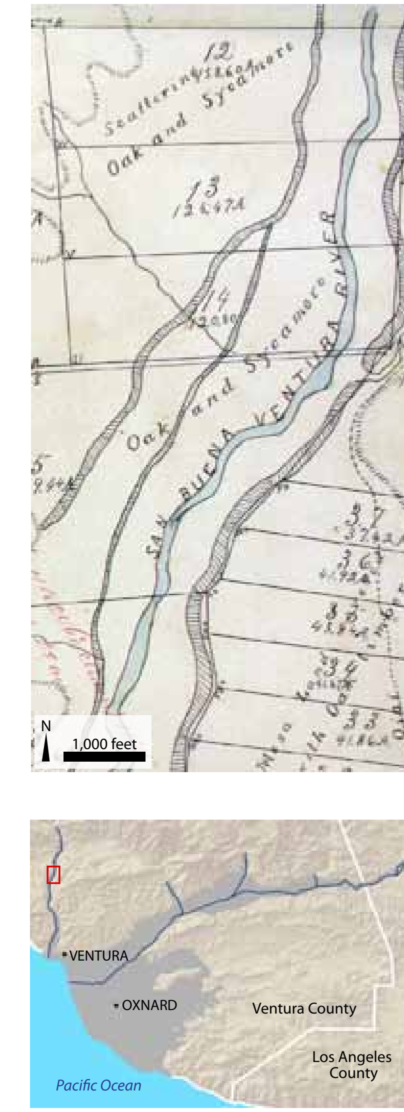


Fig. 4.4. Ventura River in the vicinity of present day Oak View, 1876. This late-1800s map depicts sycamores and oaks occupying the river corridor, as well as "scattering oak and sycamore" on the valley floor between the high bank and the scrub-covered mountains to the west. (Hare 1876, courtesy of the Ventura County Surveyor's Office)

196. It also does not include Mirror Lake, a wetland feature formerly situated east of the Ventura River between Mira Monte and Oak View, just outside the project area.)

The complex, over 16 acres in extent, occurred in a topographical low spot east of the Ventura River along modern-day Olive Street for ½ mile between West Park Row Avenue to the south and Bell Avenue to the north. It marked a portion of a former route of the Ventura River. It was documented on the 1855 T-sheet, but had disappeared by the 1870 resurvey (Johnson 1855c, Greenwell and Forney 1870; see fig. 4.20). Further research may reveal other freshwater wetlands in the Ventura valley whose presence was unrecorded by the historical documents we uncovered.

Channel Morphology

The Ventura River dominates the majority of the Ventura River valley, with multiple braided channels transporting water and sediment across its broad floodplain. Active uplift, steep slopes, and unconsolidated marine sediments give the Ventura River an extremely high sediment load, one of the highest per unit area in the United States (U.S. Army Corps 2004, Greimann 2006). These same conditions produce coarse substrate and the river's braided form, as channels shift location frequently (Keller and Capelli 1992).

In this section, we review the historical physical characteristics of the Ventura River, including lateral extent and stability, in-channel features, and changes in bed elevation. Since there are relatively few data available (especially in comparison to the Santa Clara River), these topics are only briefly reviewed below.

River Corridor Position and Stability

The overflow area of Ventura River is well-defined and includes nearly all the valley floor between the mesas and low hills on each side.

— KELTON 1940

The Ventura River corridor (including the active channel, in addition to bottomland areas susceptible to flooding) was mapped using similar methods as for the Santa Clara River, with the earliest reliable source available for each section of the river used to map outer bank position in a GIS polygon layer (fig. 4.5). Historical aerials (from 1927 and 1945) were the primary sources used to complete the mapping, though a few earlier maps were also incorporated. This methodology is described in more detail in the Santa Clara River section (see page 63).

Since no contemporary mapping of the river corridor was available, we were unable to quantify changes in extent from this mapping to the present. However, contemporary aerial imagery reveals a few places where levees have limited river corridor extent (such as along the lower river west of Ventura), and where agriculture or development has encroached into the corridor (e.g., at Live Oak Acres and along Meyers Road near Meiners Oaks). In other reaches, such as near southern Oak View, the river corridor appears relatively unchanged.

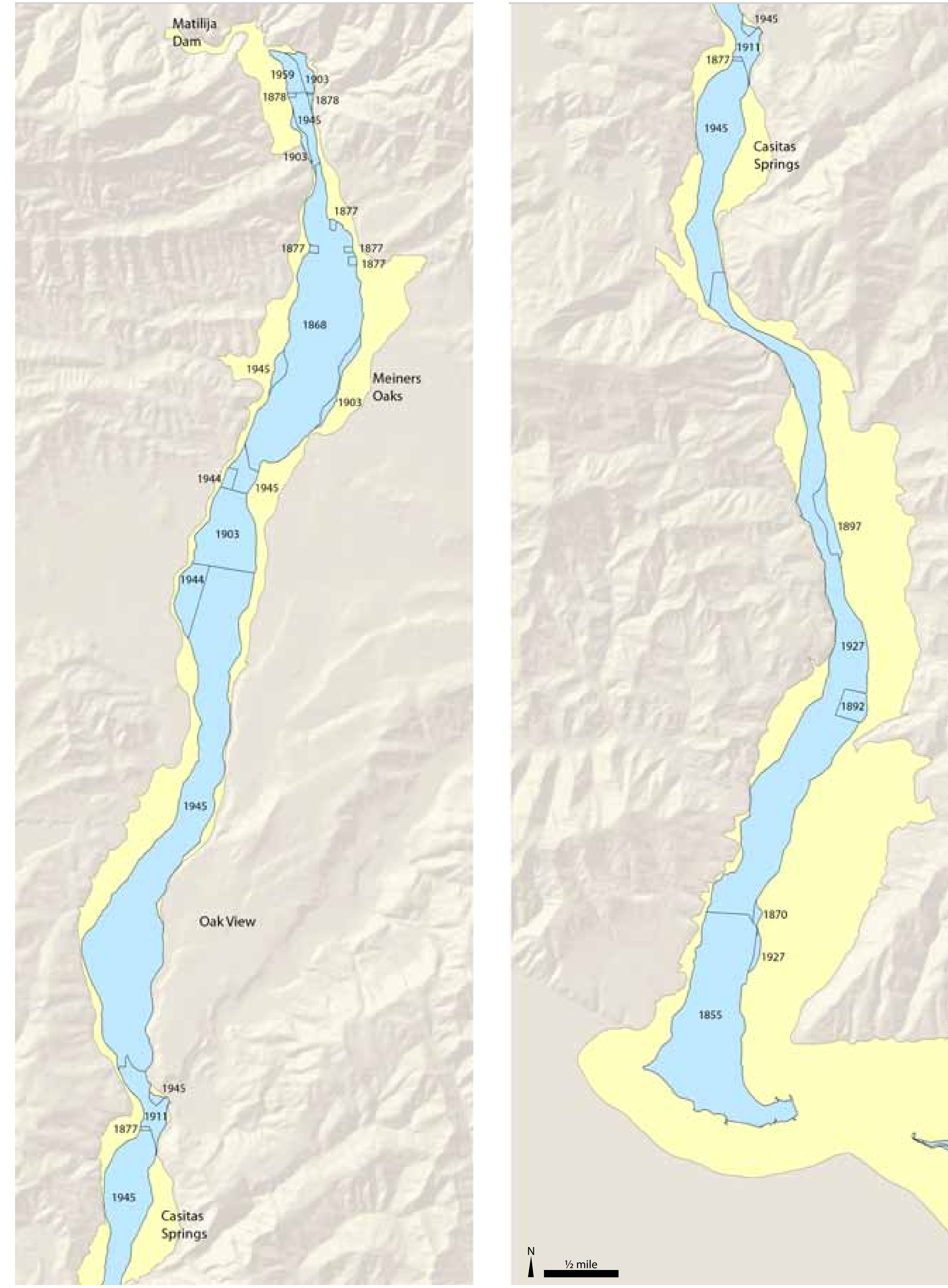


Fig. 4.5. Location of the Ventura River corridor by earliest available source, 1855-1959. We mapped the historical position of the outer bank using the earliest available data for each stretch of the river.

LARGE-SCALE CHANNEL CHANGE Within the river corridor, mainstem and distributary channel location changed frequently with flood events, as the river reoccupied old channels and formed new ones. In addition, historical sources indicate that a few major floods caused large-scale changes in the position of the Ventura River's outlet to the ocean. Interviews with long-time Chumash residents indicate a series of significant changes in the location of the river mouth over about a 1.5 mile stretch of the shoreline, from the hills west of the river mouth to Figueroa Street in Ventura. These accounts describe that the mouth of the river used to be far to the west of its present location: "The V.[entura] river first had its mouth many years ago at the foot of hills west of V. river valley. This was long ago" (Harrington 1986b). (The informant also noted that a "tule patch" at this former river mouth was formerly used to store canoes.)

Accounts state that the river mouth then shifted about 1.5 miles east, to what is now Seaside Park east of the Ventura County Fairgrounds (Sheridan 1912, Harrington 1986a, Harrington 1986b). In the 19th century, a lake here marked the former outlet of the river (see page 196). A number of statements describe the character of this former river mouth:

> The Ventura River used to empty into the ocean where the estero is now situated by the bathhouse west of the Ventura wharf, east of the present mouth of the river. The old Ventura canoe builders used to leave their canoes at that place (ancient mouth of the river)…They bent tule that was growing there on both sides over the canoe…and thus make a shade for the canoe. (Harrington 1986b)

> …in 1825 the Ventura River had its channel where now is Ventura Avenue, and that it emptied to the sea where the slough is, just east of the old racetrack grounds. It followed a course through what are now the courthouse grounds. All the land beyond to the Taylor Hills was good farming land. (Sheridan 1912)

This lake and former river mouth were also the site of a Chumash village, Mitsqanaqan. One of ethnographer John P. Harrington's informants recalled that Mitsqanaqan did not expand west of the lake because "it was said by the old Indians that the vicinity west of the lake was the mouth of the river and that the river was likely to shift its course" (Harrington 1986b).

For the first time in 12 years, Seaside Park was yesterday under water…flood waters forced campers to pack their belongings…The tennis courts, the picnic grounds and the race tracks were all under water.

— VENTURA DAILY POST, 4/8/1926, IN MOORE 1936

In the early 19th century, accounts state that the river mouth shifted from the Seaside Park location westward, closer to its current location. The date at which this shift occurred is not clear: one source states that it occurred in 1810 (Harrington 1986b), while another source inferred that it occurred later, likely during the floods of 1825 (Sheridan 1912). Many smaller changes in the river outlet location have been documented since. One source describes the shift from near Seaside Park first to the west, then slightly back toward the east:

> The mouth of the Ventura river used long ago to be at Mitsqanakan. Then it shifted to a place some distance west of its present mouth, where the little railroad bridge is west of the big railroad bridge. Then it shifted to its present location. (Harrington 1986a)

Early maps of the river mouth, in particular the T-sheets of 1855 and 1870, document the position of the river mouth in the mid-19th century. While locations differ slightly, they are within about 500 feet of each other, in contrast to the earlier large-scale changes. A later map shows the river mouth in the same location as the 1855 T-sheet (Barry 1894).

Later channel changes due to flooding often mirrored the extent or location of these former mouths. During the 1867 floods, the river reoccupied its former outlet near Mitsqanaqan, and "all of what is now Seaside Park became a lake" (Sheridan, in Moore 1936). The river similarly reoccupied this course during the extreme floods of 1884; in addition, the *Ventura Signal* reported that to the west "the river formed a new channel on the Taylor Ranch, over near the mountain by cutting through the great body of land which of recent years has been cleared of its thick growth" (*Ventura Signal* 1884 and Sol Sheridan, in Moore 1936). In 1909, the *Ventura Free Press* reported that the "mouth of the river is at the extreme western point of the lake, a quarter of a mile further to the westward than it has ever been known to be…almost as far west as the big sandhills between the Taylor ranch pasture and the ocean" (*Ventura Free Press* 1909b). A February 1992 flood also reoccupied a former distributary channel (Keller and Capelli 1992, Capelli 1993).

Hydraulic Geometry and Channel Form

PATTERNS IN THE RIVER CORRIDOR A variety of different features were documented in the historical record within the outer banks of the Ventura River. In-channel characteristics such as bottomlands, islands and bars, substrate, mainstem channel patterns, and pool locations were all noted, and are described below.

Within the flood plain of the Ventura River the main stream meanders widely, and the immense amount of debris carried by floods causes rapid and destructive shifts of the current. The stream channels generally are too ill-defined, limited in capacity, and unstable in character to give a definite indication of future flood stages.

— KELTON 1940

Some reaches of the river were relatively narrow (e.g., in Matilija Canyon or below Foster Park); these areas were often characterized by a relatively narrow active channel flanked by dense mixed riparian forest. In other reaches, however, multiple mainstem channels surrounded by riverwash threaded around established vegetated bars and islands. A few early maps capture this complex in-channel pattern, depicting networks of washy, broad channels and islands (Barry 1894, Barry 1897, Waud 1903, Everett n.d.; fig. 4.6). The size and quantity of sediment entering the river helped form the multiple braided channels that would often shift location within the river corridor in a major flood. A 1940 flood control report stated that mainstem channels were "ill-defined" and "unstable" (Kelton 1940).

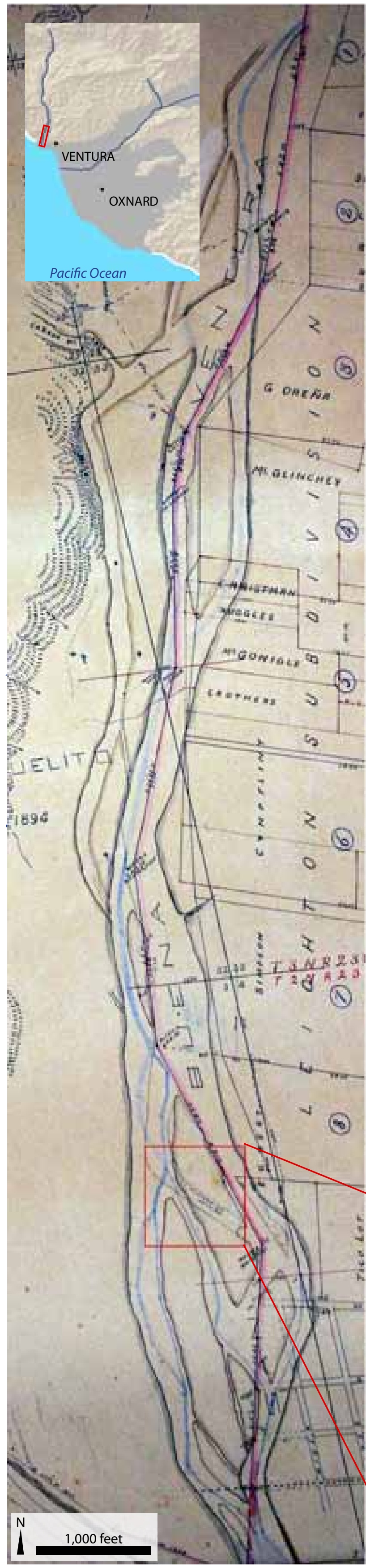
The most notable aspect of these maps is the presence of large, well defined islands; on these maps coarse depictions of the area of individual islands ranges from less than one to over 35 acres. Other sources also describe islands in the river: a *Ventura Free Press* article refers to "rocky islets" near the mouth, and an early soils map shows gravelly and bouldery islands west of Ojai (fig. 4.7). One long-time resident described camping in the early 20th century on an island at the confluence of Coyote Creek and the Ventura River:

> The parks became very popular. On what became known as the "Island," between Coyote Creek and the Ventura River, many Ventura people established camps and spent the summer there. The same was allowed east of the river. Each summer we built a temporary dam in the river to make a swimming pool. (Percy 1957)

The likely location of this island is documented in early 20th century maps of the area (Everett 1908, Unknown ca. 1910e).

In addition to islands, the presence of bottomland surfaces similar to those documented on the Santa Clara River is consistently recorded on the Ventura River. GLO surveyors crossing the river note the "river bottom" or "bottom lands" as they enter the floodplain (Thompson 1868, Norway 1877, 1878a). In many places this land, slightly higher than the washy active channel, was used for pasture, or cleared and cultivated for annual crops such as alfalfa (Lippincott 1903).

One notable difference between the Santa Clara River and Ventura River was the size of substrate in the channel, a characteristic shaped by the Ventura River's steeper channel gradient. Gravel, cobbles, and boulders were commonly found in all reaches of the Ventura River; in contrast the Santa Clara River was dominated by sand. (This is still the case today: intertidal cobble substrate, a notable and relatively rare feature along the California coast, is found at the Ventura River delta and supports a variety of marine plants and invertebrates; Ferren et al 1990, Capelli 2010.) At the river mouth in August 1769, Crespí wrote that the river "gave us some trouble on account of the stones and the large amount of water which ran above them" (Crespí and Bolton 1927). An article during the 1884 floods described a new channel at the river mouth "cut through a solid bed of boulders packed in sand" (*Ventura Signal* 1884, in Moore 1936), and a T-sheet resurvey noted "gravel and boulders" (Kelsh 1933a). Further upstream, an 1887 account describes the head of the intermittent reach, where "gravel spreads far over the desolate bottom" (Hassard 1887). Many historical landscape photographs of the river show coarse substrate on the river bed (fig. 4.8). While some of these photographs were taken after floods and thus may somewhat overemphasize the relative proportion of cobbles and boulders to finer substrate, they still reveal an overall trend toward coarse bed material.



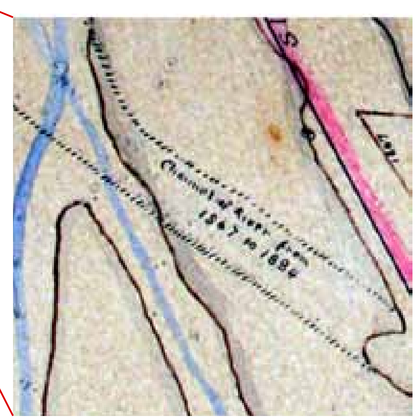


Fig. 4.6. Islands in the Ventura River channel, 1894. This 1894 map shows continuous islands, some over 20 acres in extent, stretching up the first three miles of the river from its mouth. The documented extent of islands extends at least another two miles upstream (Barry 1897). The detail at left shows channel change as a result of the 1884 floods as captured by the surveyor. (Barry 1894, courtesy of the Ventura County Surveyor's Office)

Favorite childhood swimming holes were recalled by long-time residents along the Ventura River mainstem (another feature not well represented on the Santa Clara River, at least by the historical record). J.H. Morrison, who was born in 1887 and grew up on the lower Ventura River, described his favorite swimming holes in the 1890s:

> The shallow mill pond [from the Rose Flour Mill] furnished a fine swimming-hole which we small boys shared with Mrs. Orton's ducks until we graduated to Big Rock, Mays, Dumond's or any one of several deep pools along the river. (Morrison 1959)

Additional swimming holes on the lower Ventura River (below Foster Park) were described by current Ventura residents as part of the Lower Ventura River Parkway vision plan (606 Studio 2008).

INCISION/CHANGES IN BED LEVEL Only fragmentary evidence was uncovered regarding historical trends in bed elevation on the Ventura River. As for the Santa Clara River, there may be additional elevational data (such as cross-sections, surveys for bridge construction, and as-builts) available to study incision rates over time. Obtaining and analyzing these data, though outside the scope of this study, would futher the discussion about historical changes in bed level.

Before the construction of Matilija Dam in 1947, high sediment loads and large, episodic flood events created cyclical changes in bed level, as elevation increased with sediment delivery and deposition only to be scoured out during large floods. This dynamic was captured by descriptions of large floods of the late 19th and early 20th centuries. A 1909 flood was reported to "have washed out the bed of the entire stream to an unparalleled depth below the old bed" near the river mouth (*Ventura Free Press* 1909b). The *Ventura Free Press* (1885) reported that flooding in 1885 did not extend as far as the flooding of 1884, "owing to the deepening and widening of channels by previous floods." A similar process contributed to the minor effects of the 1916 floods following the heavy floods of 1914, since "the flood of 1914 had divested an exceptionally wide channel of all brush and trees and at the same time had deepened the same course so that the waters [of 1916] met with a minimum of diverting resistance" (Moore 1936). Scouring during the flooding of 1914 was so extensive that as late as 1937, it was reported that "the high waters in 1914 cut the channel so deep that since that time it has given you no trouble" (Moore 1937). One witness quantified this incision at Foster Park, testifying that a channel eight to nine feet below the "ordinary stream bed" was created during the 1914 floods (Moore 1937). General trends were also described in the same document:

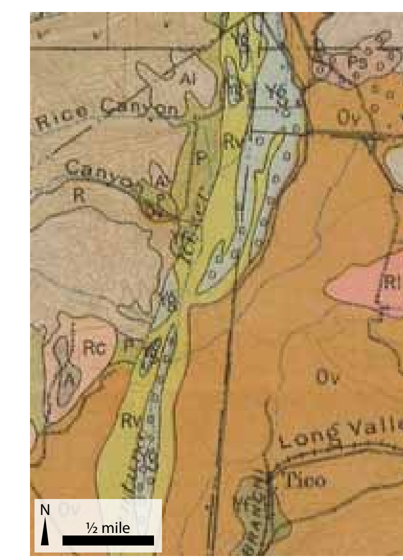


Fig. 4.7. Islands in the Ventura River, 1917. The 1917 soil map shows islands surrounded by riverwash (Rv) over a three mile stretch west of the Ojai Valley. The islands are composed of coarse Yolo gravelly and bouldery fine sandy loam (Yg), a soil type documented to support live oaks and sycamores on alluvial fans in the Santa Clara River valley. (Nelson 1917)

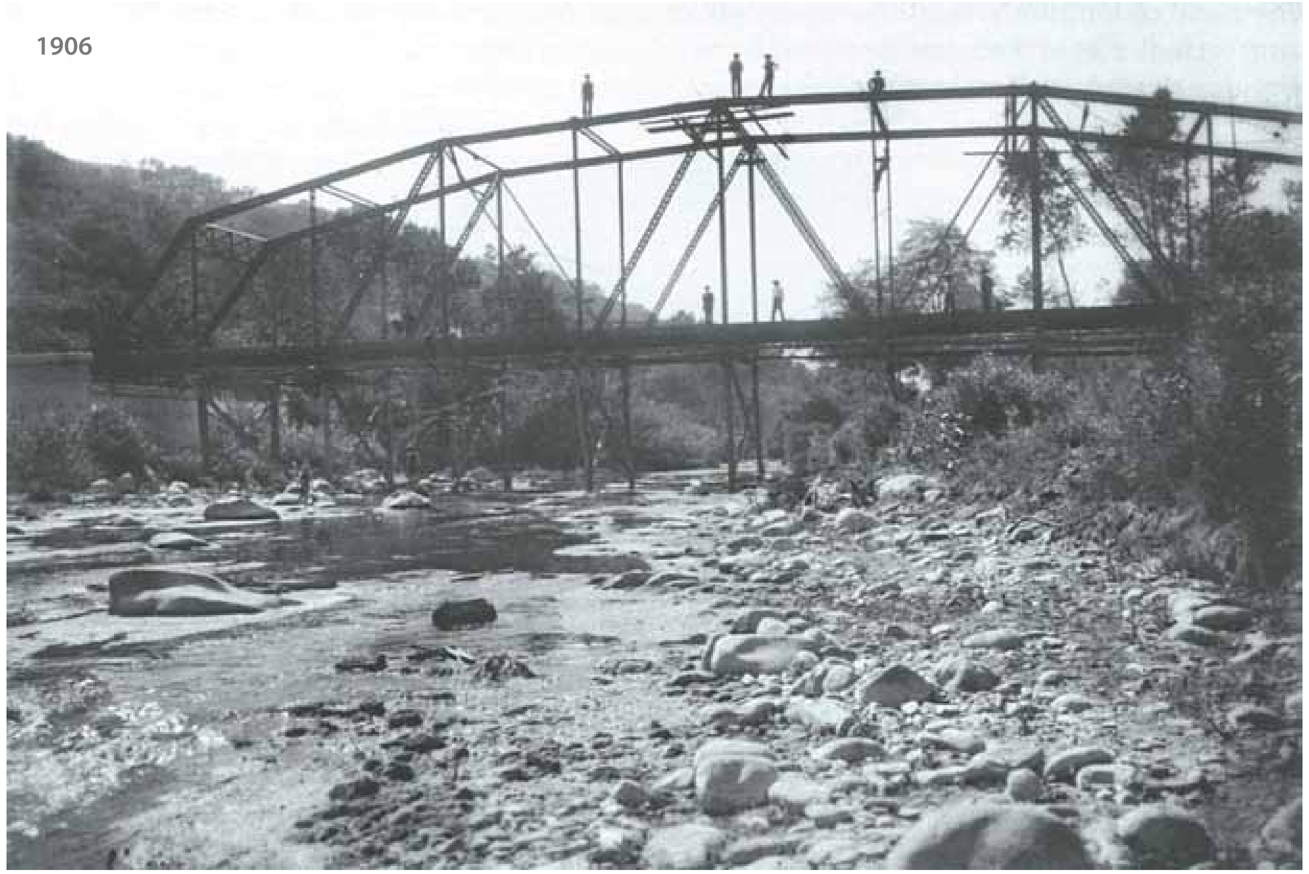


Fig. 4.8. These images of the Ventura River at Foster Park (top, ca. 1906) and at Main Street in Ventura (bottom, 1916) show the abundant cobbles and boulders characteristic of the river bed even nearly at the estuary. (Unknown ca. 1906, courtesy of Craig Held; Unknown 1916, courtesy of the Museum of Ventura County)

Chairman Cruse: "Generally speaking is the Ventura River a scouring river or a flooding river, that is to say, do floods scour the river bed, or is the river bed spread out over large areas?"

Mr. Ryan: "I notice the elevation at Casitas Pass has been lowered and I believe in all these California rivers they are, and I know there is a deposit in the center of the Ventura River at the lower end which is filled up, and in the main channel down several miles they are inclined to scour, that is what we found last year." (Moore 1937)

Dry Season Flow

Unlike the Santa Clara River, there is little early (pre-1900), reach-specific evidence for summer flow conditions on the Ventura River. Early explorers only described conditions at the river mouth, while other observers made comments about the river's water supply that provide only a general picture of early conditions. In August 1769, Crespí noted an "abundance of water" and a stony river bed near the ocean (Crespí and Bolton 1927). Mission Father Señán (1817) also described an "abundance of water from the San Buenaventura River." One eager writer described the river as "a clear brawling stream singing down in the summer months by way of a succession of pools and rapids where the trout lie hidden" (Unknown ca. 1909).

Other early generalizations on flow conditions emphasize the aridity of the region and the lack of water in the river. One article asserts that the Santa Clara and Ventura rivers "sink during the summer, before they reach the ocean" (*Daily Alta California* 1864). Holmes and Mesmer (1901c) also describe both rivers as "dry in their lower reaches," retaining only a "small summer supply for irrigation." Though these statements do not reflect average conditions as described by more reliable sources on the lower Ventura (or Santa Clara) River, they do illustrate the general presence of dry reaches on the river.

Both descriptions of the Ventura River—as an abundant source of water, and as an arid stream—have some element of truth. Documentation of flow conditions on the Ventura River consistently depicts three reaches with distinct summer flow regimes within the study area. These reaches are depicted on the historical topographic quad for the river (USGS 1903c; fig. 4.9). The first perennial reach extends from beyond the northern edge of the study area (Matilija Hot Springs) downstream to around the Cozy Dell Canyon (Matilija reach). Below this, the Ventura River valley begins to open up into the head of the Ojai Valley, and the river is intermittent until below

Fig. 4.9. Intermittent and perennial reaches on the Ventura River, 1903. The early USGS topographic quadrangle depicts summer flow conditions on the Ventura River. A solid line indicates perennial flow, while a dashed line signals an intermittent reach. The quad shows the river as about half perennial and half intermittent. (USGS 1903c, courtesy of the Los Angeles Central Library)

Oak View and the river's confluence with San Antonio Creek (Oak View reach). Last, perennial flow is shown from just above the San Antonio Creek confluence downstream to the ocean (Avenue/Casitas reach). However, the precise extent and location of summer water would have fluctuated in response to annual variations in rainfall and runoff. During wet years or series of wet years, reaches with perennial flow would have extended both spatially and temporally, while during dry years intermittent reaches may have been more extensive and would have lost surface flow earlier in the season.

This representation of Ventura River summer flow is supported by numerous additional early sources. Early photographs from the Matilija Hot Springs area show shallow riffles running over a cobble and boulder-strewn river (see fig. 4.10). Ditches brought water downstream from the perennial Matilija reach to irrigate bottomland alfalfa and orange orchards located in the intermittent reach of the river below (Waud 1903, Lippincott 1903). A GLO surveyor noted water in the river in late September 1878, south of the current intersection of Camino Cielo and Rice Road (Norway 1878a).

Shortly after leaving the confined lower reaches of Matilija Canyon, the river spread out into the broad alluvial plains of the Ojai and Santa Ana valleys. This marked a transition between the lush, perennial Matilija Canyon and the scrubby, drier upper Ventura River, as one traveler observed in early June, 1887:

> …we found ourselves at the mouth of…the Matilija Cañon…A rapid brook runs down the canon, shrinking into the deserted bed of what must once have been a broad river, and here and there the gravel spreads far over the desolate bottom. But soon after entering the ravine, the eye is relieved by patches of wood and verdure which at short intervals break in upon the sand. (Hassard 1887)

Storke (1891) also noted that in comparison to the upper Ventura River, the river "flows more tranquilly when it reaches the table-like lands of the Ojai and Santa Ana ranchos" (the intermittent reach) until it "gathers volume from the water of the San Antonio and Coyote creeks" (the beginning of the lower perennial reach).

Below its confluence with perennial San Antonio Creek, the Ventura River flowed year-round once more. About 500 feet below its confluence with San Antonio Creek in August 1877, GLO surveyor Norway (1877) noted that the Ventura River had substantial water present—16 feet wide. (This was one of the driest years on record, so the presence of summer water is particularly meaningful; see fig. 2.10.) The river around the Coyote Creek confluence was a popular area for summer camping and swimming trips (Percy 1957). In "Autumn Days in Ventura," the author described the river below the San Antonio Creek confluence in early fall:

> Before we had reached the wooded cañon of the San Antonio creek, a full moon gave a magical unreality to our surroundings. The stately trees were roofed with wild grapevines from root to crown. They were sentinel towers along the path, and the argent flash of water here and there among them was the blazoned shield of many a silent guard! A dozen times or more we forded the rushing stream. (Eames 1890)

Steady summer flow continued further downstream toward the town of Ventura. (One possible exception is a short reach, less than a mile long, around Casitas Springs, which is mapped on the historical quad as perennial but appears to be scrubby and sparsely vegetated in 1940s aerial imagery.) At Casitas (Foster Park), shallow water flowed over the river's gravel/boulder bottom. One man who grew up on the lower river around the turn of the century described abundant water in swimming holes and other pools along the river when he was young (Morrison 1959). Near the river mouth in mid-August 1769, Crespí described the river as a "very large stream or river where there is a vast amount of fresh water" (Crespí and Brown 2001), though Roberts (1886) noted that the river was often "shallow and easily forded." An alternate version of Crespí's manuscript provides additional detail about summer (August) flow near the ocean:

> They have informed me that this is a river that is split into two branches; that there is not a great deal of water running where we saw it; that the other branch, which is running to the westwards, must have a bed with about eight or ten yards' width of running water that came up to the hocks of the mounts when they went into it to drink. (Crespí and Brown 2001)

The San Buenaventura Mission stone aqueduct brought water from around the San Antonio Creek confluence to Ventura for domestic and irrigation purposes until it was destroyed during the floods of 1861-62 (Triem 1985). This may indicate more abundant or reliable water up near the San Antonio confluence, rather than further down toward the Mission.

God has provided this Mission with an abundance of water from the San Buenaventura River and the streams that flow into it.

— FRAY JOSÉ SEÑÁN 1817

Similar patterns are noted in the mid-20th century, though many accounts indicate an extension in the length of the intermittent reach. A 1937 report described the river as "absolutely dry during at least six months of the year" between Kennedy Canyon and the Coyote Creek confluence (Moore 1937). While this is slightly longer than the intermittent reach as depicted on the 1903 USGS map, it demonstrates that these reaches were largely still preserved into the late 1930s. Cooper (1967) noted more extreme conditions, describing the Ventura River as "dry most of the time," and long-time residents' fond recollections of formerly abundant flow also indicate drier conditions by the late 1950s than were historically present in the river:

> That was in the days when the Ventura River and Coyote Creek flowed water all year. (Percy 1957)

> …it is hoped that any who read this will be convinced that at one time there was water and plenty of it, in the Ventura River. (Morrison 1959)

Residents in the 1970s confirmed the presence of the Oak View summer-dry reach, stating that the reach often had "little or no surface water in the river-bed during the summer" (Ventura County Fish and

[T]he Ventura River…is the southernmost stream of California not muddy and alkaline at its mouth.

— GILL 1881

Game Commission 1973). However, the same report also noted that impoundments, diversions, and wells had contributed to the drying of reaches which had historically maintained surface flow during the summer. Anthropogenic changes in the stream hydrograph, in addition to climatic conditions (see pages 44-45), may have exacerbated the aridity of this intermittent reach beyond earlier conditions. These observations are consistent with the development of major water infrastructure on the river, such as Matilija dam (completed in 1948) and the Los Robles diversion dam and Lake Casitas (completed in 1959). The trend would have been compounded by a mid-century period of low rainfall (see fig. 2.10).

Riparian Habitats and Ecology

In contrast to the Santa Clara River, visitors to the Ventura River commented consistently on the abundance of trees found along the river. In a letter written in 1770, Juan Crespí described that along the Ventura River "there are large groves of willows, cottonwoods, and alders, plenty of oaks for firewood, and plenty of stone for building" (Crespí and Bolton 1927). A 1921 booster article boasted the Ventura River was "bordered by hundreds of splendid oaks whose branches frequently met over our heads" and had "many lovely sylvan glades—ideal spots for picnic or camp" (Murphy 1921).

Portions of the Ventura River were characterized by the presence of large stands of live oaks and sycamores in addition to the ubiquitous scrub—not just on the outer bank (as was largely the case on the Santa Clara River), but also on established islands within the river corridor. This, along with extensive sections of dense willow-cottonwood forest along some portions of the river, formed a riparian corridor that in many ways contrasted with patterns documented along the Santa Clara River.

The outer river banks, bottomlands, and active channel of the Ventura River exhibited distinct vegetation patterns (for definition of terms see page 61). While lone sycamores and live oaks on the outer bank of the Santa Clara River were often notable features in the sparsely forested valley, many of the riparian trees on the Ventura River merged into the surrounding upland live oaks and sycamores. Bottomland areas on the Ventura River were colonized by dense mixed riparian and willow-cottonwood forest in many portions of perennial reaches, while oaks, sycamores and alluvial/willow scrub composed bottomland vegetation in the intermittent reach. The active channel itself formed a largely non-vegetated matrix of scrub, boulders, cobbles, gravel, and sand, similar to the Santa Clara River active channel though with coarser substrate. In many portions of the river, well developed islands above the active channel supported vegetation similar to that found on bottomland surfaces.

As on the Santa Clara River, riparian vegetation varied both laterally and longitudinally, as expected for a semi-arid stream (see page 85). Riparian habitats along the Ventura River were broadly divided into three reaches, reflecting shifts in hydrology (summer flow, depth to groundwater) and variations in geomorphology (surface elevation, flood frequency). Directly below the present-day Matilija Dam, a short (about two mile) perennial reach was presumably flanked by mixed riparian forest in Matilija canyon, which transitioned to scrubbier cover as the canyon opened up somewhat below the Camino Cielo Road crossing (Matilija reach). As the canyon opened onto the broad flats at the head of the Ojai Valley and the river sank into its bed, riparian vegetation transitioned to a mix of sycamores, live oaks, and scrub (Oak View reach). Beginning at the confluence of San Antonio Creek with the Ventura River, a second perennial reach stretched eight miles to the ocean, and was characterized primarily by mixed riparian forest with patches of scrub and a large, persistent area of willow-cottonwood forest and in-channel wetlands at the mouth of the river (Avenue/Casitas reach). These coarse reach-scale differences in riparian habitat are described in detail below.

Of course, the morphologic complexity created by islands, side channels, and bottomlands would have created many small-scale variations in vegetation distribution, character, and density along the length of the river complicating—and presumably sometimes contradicting—the broad patterns discussed above. In particular, there may have been additional persistent wetland riparian areas historically present on the river but not documented, and at the sub-reach level there were likely short intermittent stretches along the perennial reaches of the river (or vice versa). The descriptions below do not preclude these finer-scale patterns.

In addition, though described patterns appear consistent between 19th century accounts and 20th century photographs, the Ventura River was a dynamic system, and the proportion and distribution of scrub and trees would have shifted from year to year, perhaps changing dramatically during major flood events. This was recalled in relation to the flooding of 1825, when "trees and villages were washed away" around Ortonville (Jones 1938, in Freeman 1968). It was also documented for the 1914 flood:

> If you go up the river now [1937], every tree in that river bed is 23 years of age, just exactly. There wasn't a tree left in the entire river bottom following the flood of 1914 from Foster Park in the main channel clear up to Live Oak Acres. There is a heavy growth of willow, sycamore, cottonwood and alder trees. An alder tree is a very short lived tree so the alder trees suddenly die; when they get 8 or 10 inches in diameter, they all fall and become debris in the channel. (Hollingsworth, in Moore 1937)

Matilija Reach

Extending downstream of the present-day Matilija Dam through the Matilija Canyon and down to the head of the Ojai Valley, the uppermost portion of this reach was confined (in contrast to the more broad, braided pattern at the downstream end of the reach). In the narrow canyon, the riverbed was "a mass of fallen rock and bowlders" (Roberts 1886), without the broad bottomlands found elsewhere along the Ventura River. Another account describes seeing, upon entering Matilija Canyon, "patches of wood and verdure which at short intervals break in upon the sand" (Hassard 1887). A number of sandbar willows (*Salix exigua*) were recorded in Matilija Canyon just upstream of the study area (Bracelin 1932). Early images of the canyon corroborate these descriptions of the confined portion of the river (fig. 4.10).

Less is known about the character of downstream portion of the Matilija reach, after the river exits the most confined portion of the canyon. Historical aerials (Ventura County 1945) show prevalent scrub in the broader channel.

Oak View Reach

For six miles along the Ventura River—from the top of the Ojai Valley near Meiners Oaks, past Oak View and Live Oak Acres, to the confluence of the river with San Antonio Creek above Casitas Springs—the river corridor supported abundant scrub, in addition to substantial areas of live oaks and sycamores colonizing islands and other bottomland surfaces within the river's banks. Riparian patterns in this intermittent reach were notably different from those found on the Santa Clara River mainstem, where substantial in-channel tree cover was not documented (apart from the persistent wetland areas).

The presence of scrub and trees (overwhelmingly live oaks and sycamores) in this reach is described by a number of narrative and textual accounts. The upper portion of the reach, at the transition to a broad, washy river from Matilija Canyon, was especially commented upon (fig. 4.11). Sheridan (1886) described that the "river rushes out across a broad sycamore dotted flat" from the canyon, and Roberts (1886) described the river here as "overgrown with brush, sycamores, and oaks." The early presence of oaks and sycamores is corroborated by GLO survey notes, which describe a "timbered bottom" and "bottom land with heavy oak & sycamore timber" (Norway 1877). The few GLO bearing trees documented in this reach also generally support this description (two live oaks 10 and 48 inches in diameter, and one sycamore 20 inches in diameter; Norway 1877).

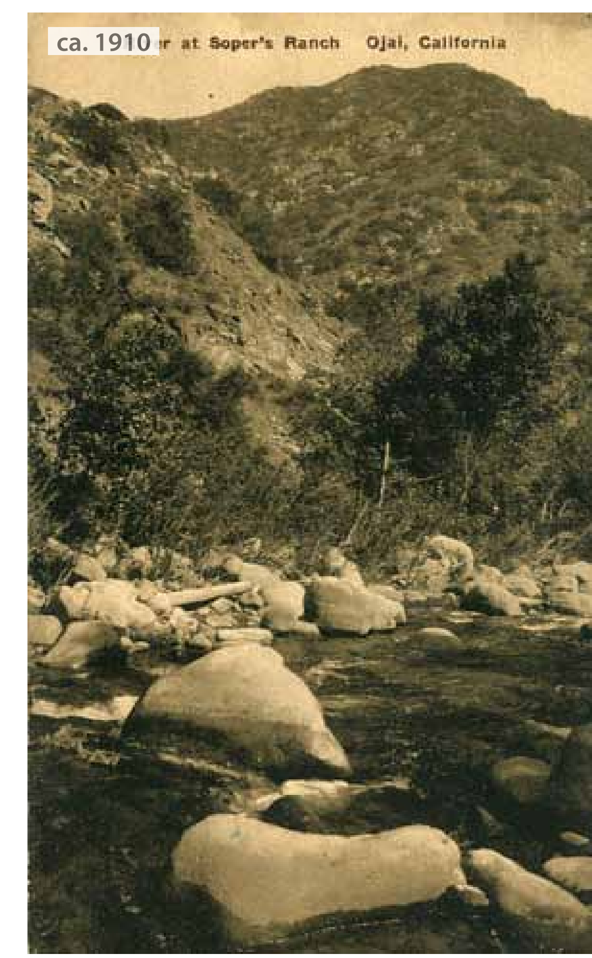
Leave riverwash, enter bottom land with heavy oak & sycamore timber…

— NORWAY 1877, BETWEEN OAK VIEW AND CASITAS SPRINGS

Early maps of the reach also show a mixture of scrubland, oaks, and sycamore. An 1876 map marks "oak and sycamore" near Live Oak Acres toward the bottom of the intermittent reach (Hare 1876). Upstream near Meiners Oaks, a map along two miles of the river shows a combination of oaks, scrub, and grasses present in the river corridor between patches of cultivation, labeling bottomlands "oaks and brush," "oaks, brush & grasses," "oaks (12" to 18" diam)," and simply "brush" (Lippincott 1903; fig. 4.12). Aerial images from the 1940s also show oaks and scrub.

Species data provide additional details on scrub composition in the Oak View reach in the mid-20th century. Chaparral whitethorn (*Ceanothus leucodermis*) was collected in a "wash" of the Ventura River below Meiners

Fig. 4.10. Two views of the upper Ventura River, ca. 1910. These two postcards, both dating from the first years of the 20th century, show the boulder-filled channel of the river in lower Matilija Canyon. The photograph at top was taken at Matilija Hot Springs, just below Matilija dam. The photograph at right was taken less than a half mile downstream. Note the narrow fringe of mulefat, willow scrub, and trees (likely alder, cottonwood, and sycamore). (Unknown ca. 1910b, d)



Oaks (Hoffmann 1932b), and slender woolly buckwheat (*Eriogonum gracile*) and chaparral yucca (*Hesperoyucca whipplei*) were collected in the river near Oak View (Pollard 1963a, 1969). Mulefat was also documented (*Baccharis salicifolia*; Pollard 1944). These records imply the presence of alluvial scrub; it is likely that a mixture of willow and alluvial scrub was present through this reach (fig. 4.13).

Avenue/Casitas Reach

Below Oak View and near its confluence with San Antonio Creek the Ventura River became perennial again, with an accompanying shift in vegetation. This reach was characterized by a matrix of often dense mixed riparian forest, riverwash, and scrub. (One possible exception is a short one mile reach at Casitas Springs, which looks much more like the intermittent reach described above on the 1945 aerial imagery.)

Strongly supporting the concept of dense riparian forest in this reach, an 1840s *diseño* of the Cañada Larga ranch shows a continuous riparian corridor stretching the three miles from near Foster Park to Gosnell Hill/Cañada de San Joaquin (fig. 4.14). The riparian corridor is shown of variable width, including a short reach of oaks south of Cañada Larga and a lot of other trees (interpreted as willow-cottonwood forest). This map is supported by

Fig. 4.11. "Looking west across Ventura River, mouth of Matilija Canyon," February 1930. This photograph, part of the Wieslander Vegetation Type Mapping Project of the late 1920s and early 1930s, shows low scrub flanking riverwash along a shallow, broad channel in the intermittent reach of the river. It was taken approximately one mile below the mouth of Matilija canyon, looking west toward the site of the current Robles Diversion Dam (Capelli pers. comm.). (Clar 1930, courtesy of the Marian Koshland Bioscience and Natural Resources Library, UC Berkeley)

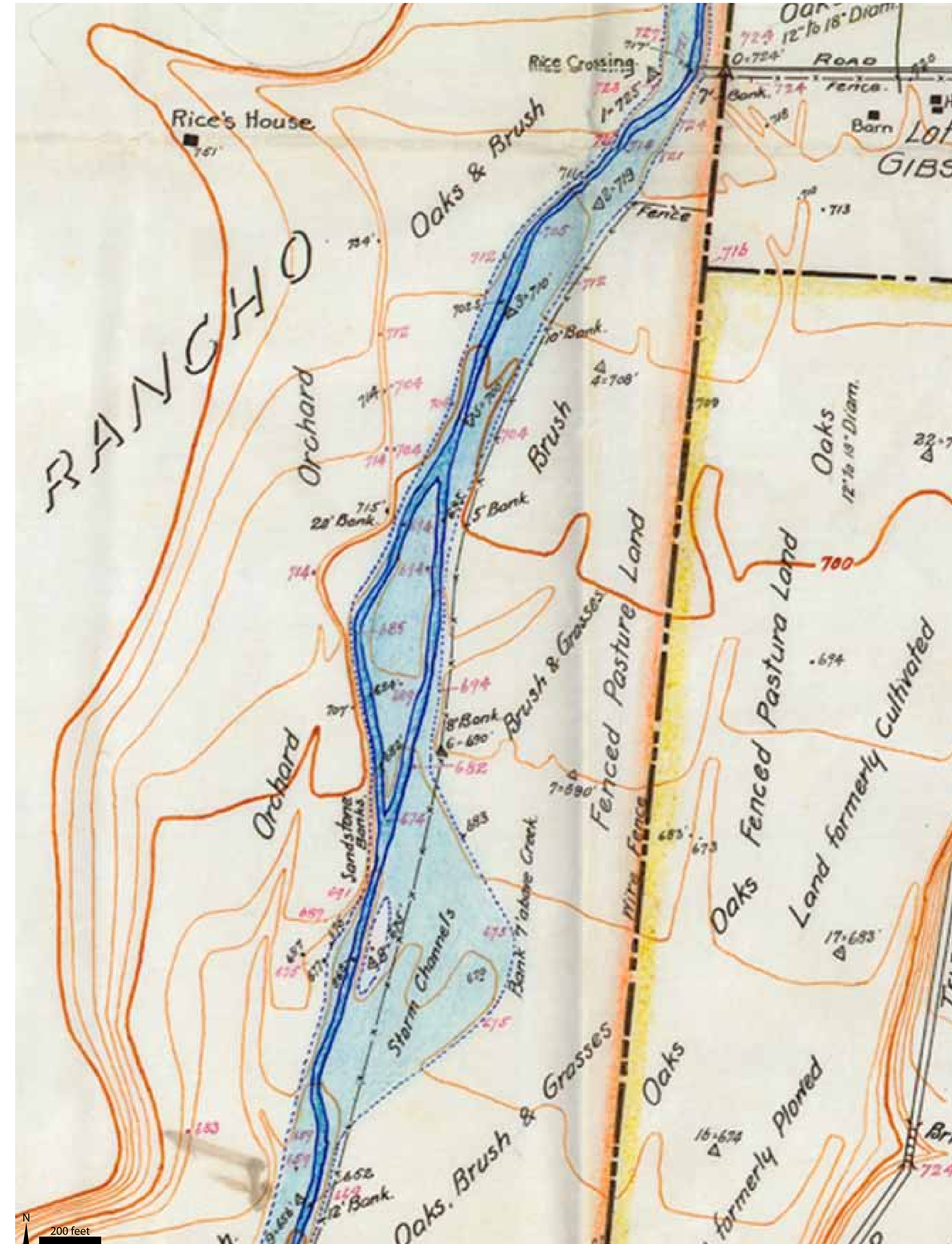


Figure 4.12. Vegetation in the Ventura River, 1903. This map of the river in the intermittent reach near Meiners Oaks shows local-scale variation of riparian vegetation, including oaks, sycamore, and brush, within its outer banks. It is evident from this map that many portions of the bottomland had already been cleared or fenced for pasture. (Lippincott 1903, courtesy of the Museum of Ventura County)

Fig. 4.13. Ventura River at Live Oak Acres. The oblique aerial photograph (top), taken in June 1938, shows characteristic riparian patterns in the Oak View reach. Sparsely vegetated riverwash composes the active channel, flanked by dense scrub on bottomlands. Further away from the active channel, more mature live oaks colonized higher river surfaces. Seven years later, the aerial photograph of the same place in 1945 (left) shows similar patterns of riverwash, scrub, and trees. (Spence Air Photos 1938, courtesy of the Benjamin and Gladys Thomas Air Photo Archives, UCLA Department of Geography; Ventura County 1945, courtesy of UCSB Map and Imagery Library)

Fig. 4.14. Dense riparian corridor along the Ventura River, ca. 1840. An early depiction of the Ventura River for three miles below Foster Park shows continuous riparian forest flanking the river, of variable—and in many places, substantial—width. A small area of oaks is shown along one portion of the river (below the "I"); the small check marks that line the river are interpreted as mixed riparian forest. (U.S. District Court ca. 1840b, courtesy of The Bancroft Library, UC Berkeley)

FOSTER PARK

Within the lower perennial reach of the Ventura River, Foster Park was particularly noted and admired for its riparian trees. The park, created in 1908, is the site of many of the historical data describing the Ventura River, including photographs, specimen records, and textual descriptions. According to one historian, the Foster Park area had been used by both Chumash and Mission fathers (Sheridan 1926). Images of this area show thick stands of trees and scrub growing over cobbles along the river, similar to today (figs. 4.15, 4.16).

Between 1932 and 1972, many plant specimens were collected at Foster Park. While most of these records are too late to be considered unambiguously historically relevant, they do provide a general sense of the wetland character of the reach. Species archived from this location indicate the presence of a diverse willow woodland with three species of willow (*Salix exigua, S. lucida,* and *S. laevigata)*, along with mulefat (Pollard 1946, 1960, 1968, 1972). Obligate wetland species are also recorded, including stream orchid (*Epipactis gigantea*; Canterbury 1939), seep monkey flower (*Mimulus guttatus*, Pollard 1964), least duckweed (*Lemna minuta*, recorded in a "pool in willow thicket"; Pollard 1962, 1965), and water speedwell (*Veronica anagallis-aquatica*, Broughton 1967), indicating presence of surface water through large portions of the year. These plants are described as being in a "willow thicket" or in "shaded pools under willows." Other records document the presence of an alluvial scrub community in portions of the floodplain (e.g., *Eastern Mojave buckwheat/Eriogonum fasciculatum var. foliolosum*; Pollard 1963a).

The diversity of species present in the Foster Park area is further illustrated by a number of ornithological records, which note both the bird collected and the nature of the locality where the bird was found. Records from the early 20th century describe many Allen's hummingbirds (*Selasphorus alleni*) in addition to black-headed grosbeak (*Pheucticus melanocephalus*), yellow-breasted chat (*Icteria virens longicauda*), and warbling vireo (*Vireo gilvus*) (Canfield 1919, 1920; Canfield and King 1919, King and Huey 1919, Huey 1920). Many of these species had nest sites recorded in "thickets" of wild rose, wild grape, or blackberry. One hummingbird was found in a blackberry thicket "completely shaded by grove of tall cottonwoods," while another was found on "an elder bush in dense willow woods" (Canfield 1920, Huey 1920).

Fig. 4.15. Ventura River at Foster Park looking north from the bridge, July 2008. Cottonwoods and willows flank the river, and willows, mulefat, and Arundo colonize coarse bars and islands.

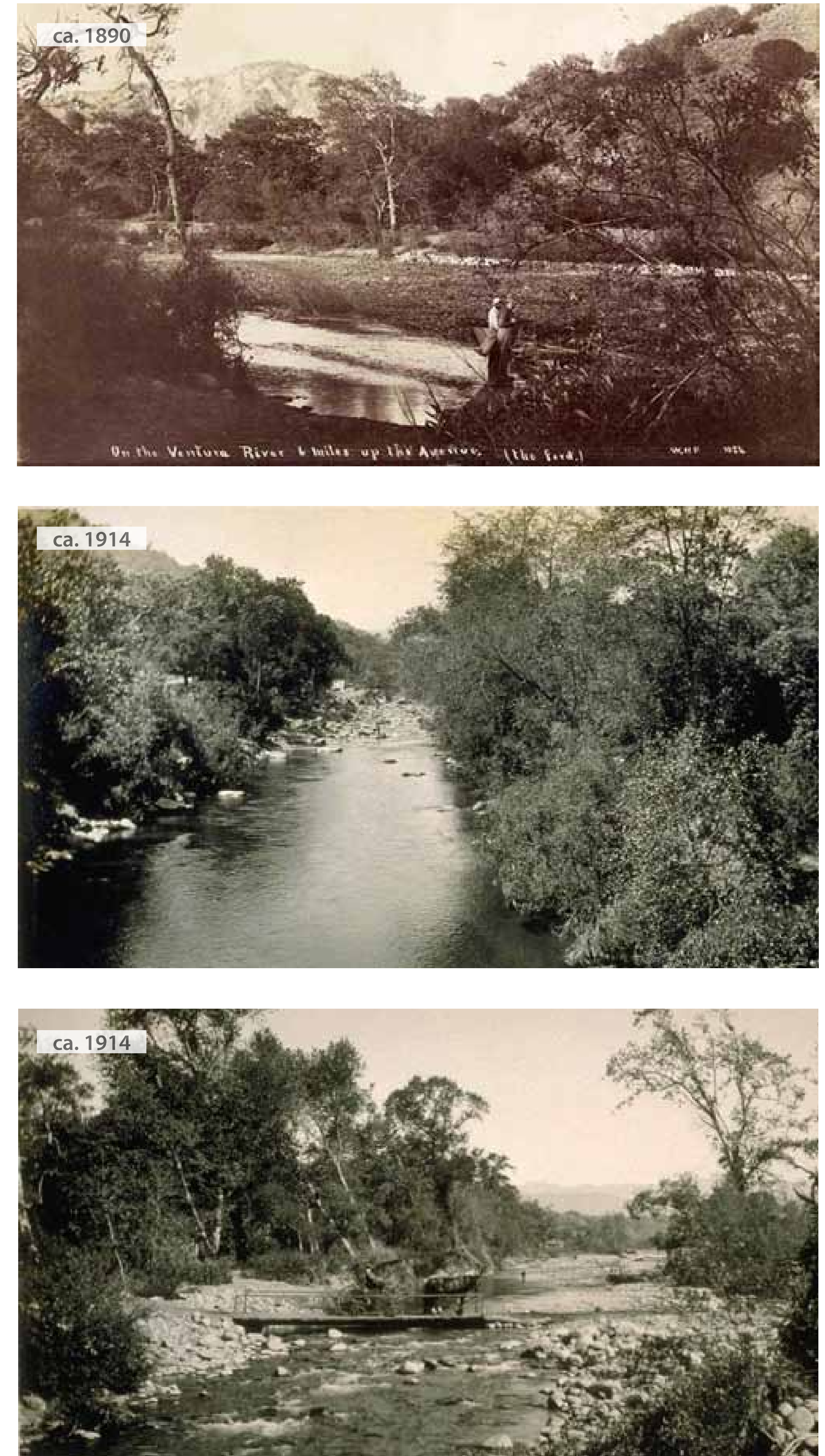


Figure 4.16. Three images of riparian vegetation near Foster Park/Casitas, ca. 1890-1914. Top: "On the Ventura River 6 miles up the Avenue (the ford)," ca. 1890. Middle: "Looking up Ventura River from the Bridge," ca. 1914. Bottom: "Casitas – View of Ventura River Crossing," ca. 1914. These images show three versions of the riparian corridor in the vicinity of Foster Park, including sycamore, live oak, willow, cottonwood, and alder. (Fletcher ca. 1890, courtesy of the California State Library; Unknown ca. 1914a and 1914b, courtesy of The Bancroft Library, UC Berkeley)

…the good Padres gathered their neophytes under the trees of the present Foster Park, and called them to their daily prayers and their daily tasks beneath the whispering leaves of the sturdy sycamores and live oaks.

— SHERIDAN 1926

Fig. 4.17. A section of riparian corridor 1.5 miles south of Foster Park. Broad, dense riparian forest present in 1927 (left) and 1945 (middle) has been converted to agriculture by 2009 (right). (Fairchild Aerial Surveys 1927, courtesy of Whittier College; Ventura County 1945, courtesy of UC Santa Barbara Map and Imagery Library; USDA 2009)

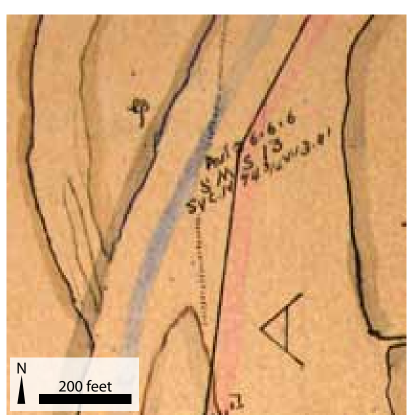


Fig. 4.18. Sycamore on island in the Ventura River, 1894. West of lower Ventura Avenue (and just above the persistent wetland riparian area at the river mouth), this small depiction shows a 24 inch diameter sycamore above the active channel of the river. (Barry 1894, courtesy of the Ventura County Surveyor's Office)

aerial imagery from 100 years later, which still shows many stretches of dense mixed riparian corridor (fig. 4.17). Photographs of this reach show a corridor of dense trees and scrub, particularly in the Foster Park area (see spread, pages 146-147).

A variety of species were documented within the mixed riparian forest. Bottomland trees in this reach included willows, sycamores, alders, box elders, cottonwoods, oaks, and walnuts, in addition to wild grapes and blackberries. A traveler in fall 1890 described "stately trees…roofed with wild grapevines" (Eames 1890), and a newspaper account from 1874 waxed poetic on the beauty of this stretch of the Ventura River:

> Our way for miles was through a shaded canyon, down which coursed a clear stream, bordered by willows and sycamores, whose light-green foliage contrasted well with the dark green of the wild walnut, by which they were thickly interspersed. Wild grape vines trailed in the greatest profusion over every place that offered a support for their clinging tendrils… (*Ventura Signal* 1874b)

This is corroborated by a 20th cenutry specimen of wild grape (*Vitis girdiana*) collected in a "poplar [cottonwood] grove" at the Ventura River-San Antonio Creek confluence (Pollard 1969).

Seven sycamores from eight inches to three feet diameter were used as bearing trees by early surveyors, in addition to a cottonwood tree (30 inches in diameter) and live oaks (20-24 inches in diameter) (Barry 1897, Unknown ca. 1910c). Some sycamores (up to 24 inches in diameter) were found within the channel, suggesting relative stability of islands or other bottomland surfaces (fig. 4.18). In 1937, the channel south of the Casitas bridge was "heavily wooded with cottonwood trees and other growths

STEELHEAD ON THE VENTURA RIVER

The historical habitats of the Ventura River undoubtedly supported a wide variety of aquatic and terrestrial wildlife species, including some that currently have special status designations or are considered locally extirpated. This aspect of the region's historical ecology is not covered in the report (see box on the Santa Clara River, page 101, for more information).

However, given the regional importance of the Ventura River's historical steelhead and trout fishery, it must at least be noted here. Prior to the protracted drought of the late 1940s and the construction of Matilija Dam in 1948, the Ventura River system supported one of the most consistent, abundant runs of the federally endangered Southern California steelhead in the region (Ventura County Fish and Game Commission 1973, Capelli 1974, Capelli 2004, Boughton et al. 2006, Titus et al. 2010). Up to that time, the river supported an important recreational steelhead and trout fishery. In addition to the mainstem river, the estuary would have been important for rearing steelhead and providing habitat for other native fishes.

Numerous early accounts describe large quantities of steelhead and trout in the river. One of the Ventureño Chumash residents interviewed by John P. Harrington recalled in 1913 that formerly "the salmon were very numerous in the Ventura river," while traveler Alfred Robinson wrote that around 1829 "salmon of excellent quality are sometimes taken in the river" (Robinson [1846]1947, Harrington 1986b). Chase (1913) noted that "from May to October the breakfast tables of Ventura need never go troutless."

of that character" (Moore 1937). Additionally, the presence of scrub is documented by much later plant collections, in which two varieties of buckwheat (*Eriogonum fasciculatum* var. *foliolosum* and *E. cinereum*) were documented near Ortonville (Pollard 1961).

River Mouth

We mapped one persistent wetland riparian area on the Ventura River, at the river mouth. This area supported dense willow-cottonwood riparian forest, valley freshwater marsh, and tidal lagoons and marshes. It could be considered a subset of the broader Avenue/Casitas reach designation, highlighting a large area whose persistence is well documented by early sources. Like similar persistent wetland riparian areas on the Santa Clara River, it is large (over 200 acres), broad, and is documented to have persisted over time. Since portions of this grove were adjacent to the city of Ventura and visible to travelers passing through Ventura on their way up- or downcoast, there are multiple descriptions characterizing it. It is mentioned by explorer Crespí, who described in 1769 that "a great many trees are to be seen on this river bed, willows, cottonwoods, and live oaks (sycamores). There are vast numbers of rose bushes at this hollow" and six months later, in 1770: "a vast amount of willow trees, cottonwoods, and a few sycamores and live oaks" (Crespí and Brown 2001). Over 70 years later, GLO surveyor Norris (1853) noted a "willow swamp" in the area. Many other 19th and early 20th century accounts also refer to the willows at the river mouth, describing a river with "willow-fringed banks" (Darmoore 1873) and "willows festooned by wild grape vines and clematis" (Francis and Hobson 1912) that "creeps

Fig. 4.19. Willows on the Ventura River, 1877 (above). A subset of the forest depicted on the T-sheets is shown in this bird's-eye view lithograph. The view is looking northwest across the river and Main Street in the city of Ventura, drawn seven years after the T-sheet re-survey. It further confirms the presence of trees, although the area appears reduced from the initial T-sheet depictions. (Glover 1877**,** courtesy of the California Historical Society)

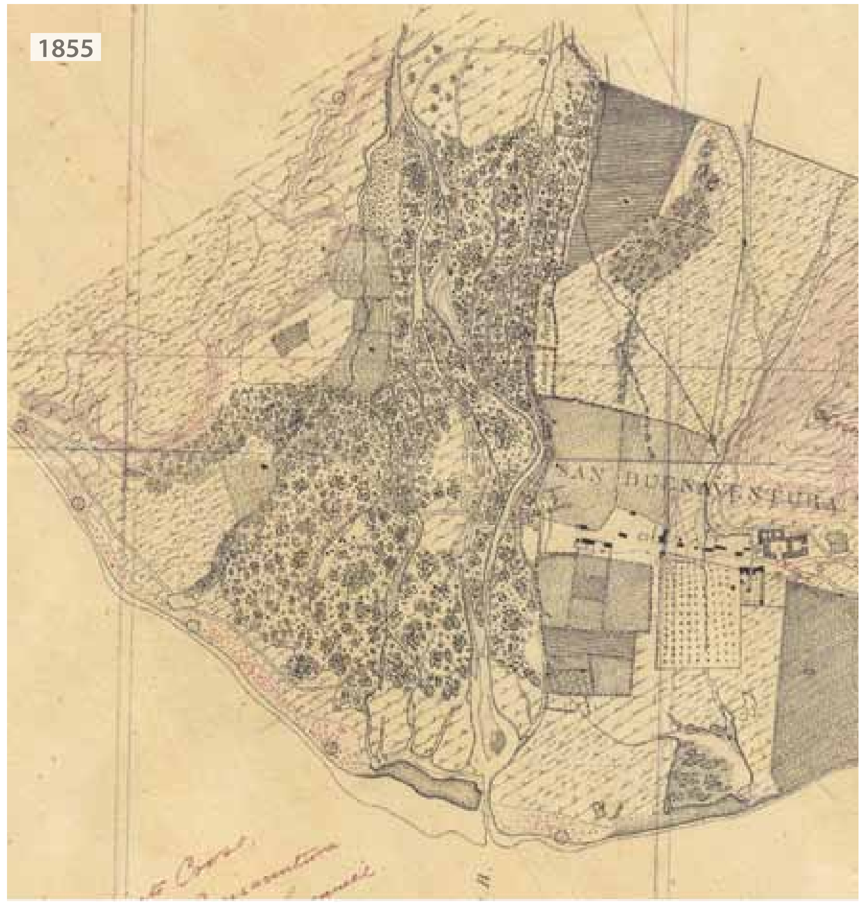


Fig. 4.20. **Riparian forest at the mouth of the Ventura River,** 1855 and 1870. While the initial survey of the Ventura River mouth by the U.S. Coast Survey (top right) provides evidence of the extent of willow-cottonwood forest at the mouth of the river, the re-survey 15 years later (bottom right) shows that, alhtough trees have been scoured near the main channel, the feature transcended the floods of 1861-2. Dense trees near the mouth of the river taper towards the northern edge of the map. (The freshwater wetland marking a former river route can be seen on the earlier map just north of the nascent city of San Buenaventura; it was almost completely gone by 1870.) (Johnson 1855c, Greenwell and Forney 1870; courtesy of NOAA)

lazily out from the grove of alders and willows" (Holder 1906). Early maps also show willows in the area (Leighton 1862, Everett n.d.).

The most persuasive evidence, however, comes from an early T-sheet and resurvey depicting vegetation at the river mouth (Johnson 1855c, Greenwell and Forney 1870; figs. 4.19, 4.20). Since these maps bracket the huge floods of 1861-2, they offer significant evidence of the feature's resilience over time. For a detailed discussion of more recent ecological characteristics of the Ventura River mouth and estuary, see Ferren et al. (1990).

Riverine transformation and synthesis

The Ventura River historically exhibited a diverse suite of ecological, hydrologic, and geomorphic characteristics. This section synthesizes the patterns documented in this chapter to provide a more integrative, visual understanding of riverine properties both longitudinally and through time (fig. 4.22). We also provide a summary of our findings and the implications of our research for management strategies in the watershed today.

We focus here on three sample reaches chosen to illustrate these concepts in cross-section: an upstream reach at Meiners Oaks (fig. 4.23), an intermediate reach at Casitas (fig. 4.24), and a lower reach near the river mouth (fig. 4.25). The transects and accompanying plan form representations illustrate the historical hydrology, morphology, and ecology of the river in these three very different locations in the 19th and early 20th centuries (1853-1903). We also produced cross-sections presenting conditions in these reaches during the mid-20th century (1927-1945) and early 21st century (2005) to depict the impacts of changing land use over this time. Taken together, these reaches represent a broad variability in vegetation and flow characteristics along the river.

We used a variety of historical sources to develop these cross-sections. Our own historical mapping, General Land Office survey notes, a U.S. Coast Survey T-sheet, and a county surveyor's map formed the backbone of our historical transects, and aerial imagery (from 1927, 1945, and 2005) were used to interpret land use changes, vegetation, and channel features on the intermediate and modern cross sections.

In the absence of historical elevational data, we used modern (2005) LiDAR data as the starting point for historical elevations and valley width, making adjustments as needed for the historical renderings (e.g., removing anachronistic road cuts and levees). As a result, the following cross-sections necessarily focus more on changes in floodplain extent and character than on changes in bed elevation.

While these cross sections are only a snapshot of patterns at narrow locations and points in time within the watershed, we believe they offer representative glimpses of temporal and spatial change in three different parts of the Ventura River. Bear in mind that they are purely conceptual in nature, and are not intended to represent exact landscape patterns (e.g., tree density or marsh extent).

Fig. 4.21. Looking over the Ventura River from the Main Street bridge near its mouth, February 2011.

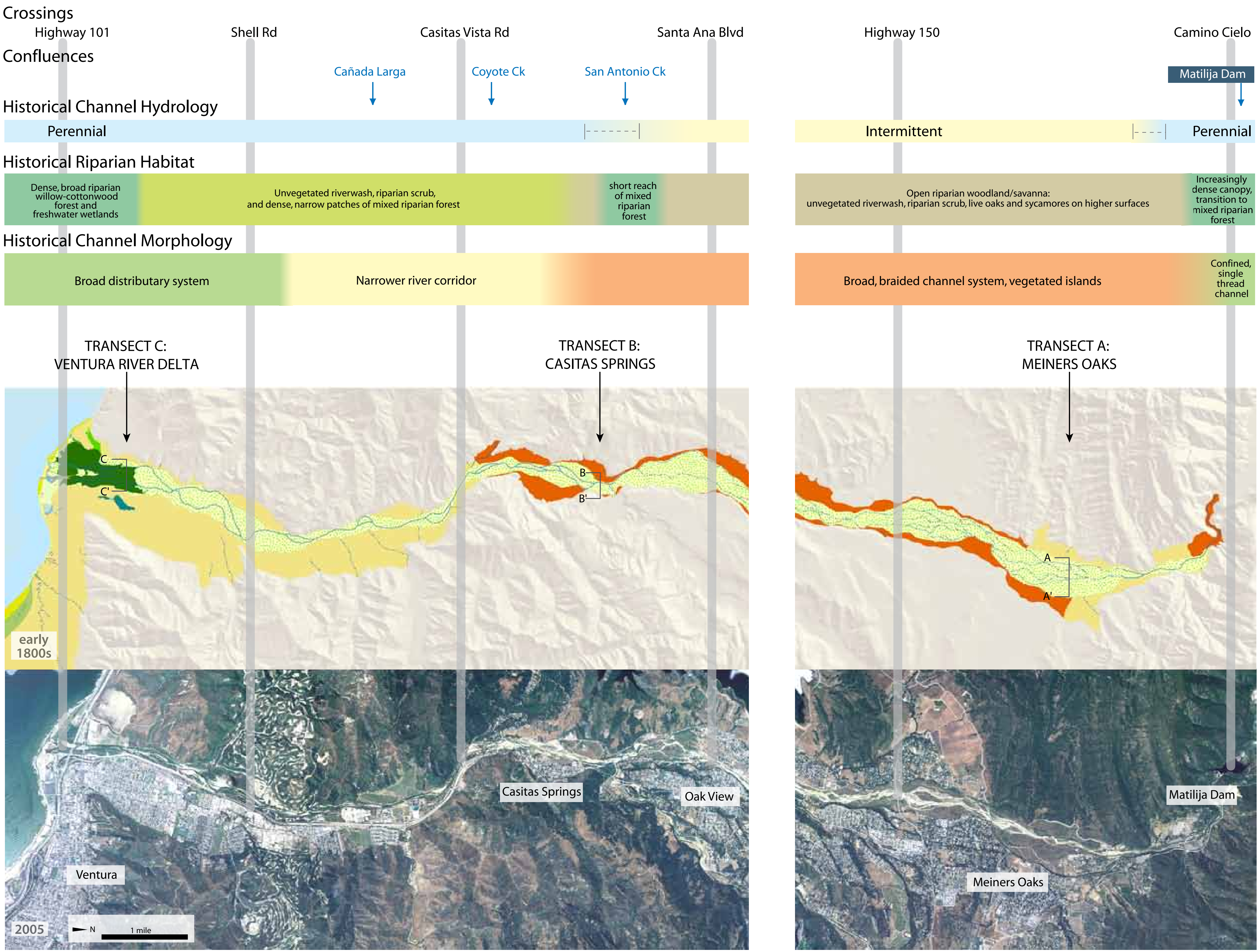


Figure 4.22. Historical characteristics of the Ventura River by reach. This diagram shows how fundamental attributes of the Ventura River varied by reach. The close relationships evident in this diagram between riverine hydrology, ecology, and morphology indicate the interrelated nature of these characteristics. Transitions between reaches were gradual, with variable locations through time. The locations of the three transects (following pages) are also indicated here.

MEINERS OAKS REACH

This reach is located near the town of Meiners Oaks, downstream from where the river exits its canyon and spreads out across the upper Ventura River valley. The area was historically characterized by a broad, braided channel with intermittent flow. Two maps from the turn of the century (1903) record the detailed vegetation (oaks, scrub, and grasses), topography, and braided channel patterns for this reach. At this time there were already multiple early uses of the river; the surveyors recorded orchards and cattle fences crossing the stream and describe in-channel areas as lands formerly used for grazing and cultivation.

By 1945, some of the orchards had been moved away from the river, though the overall character appears largely unchanged in the historical aerial. The same is true in 2005. This area is now part of the Ventura River/Rancho El Nido Preserve.

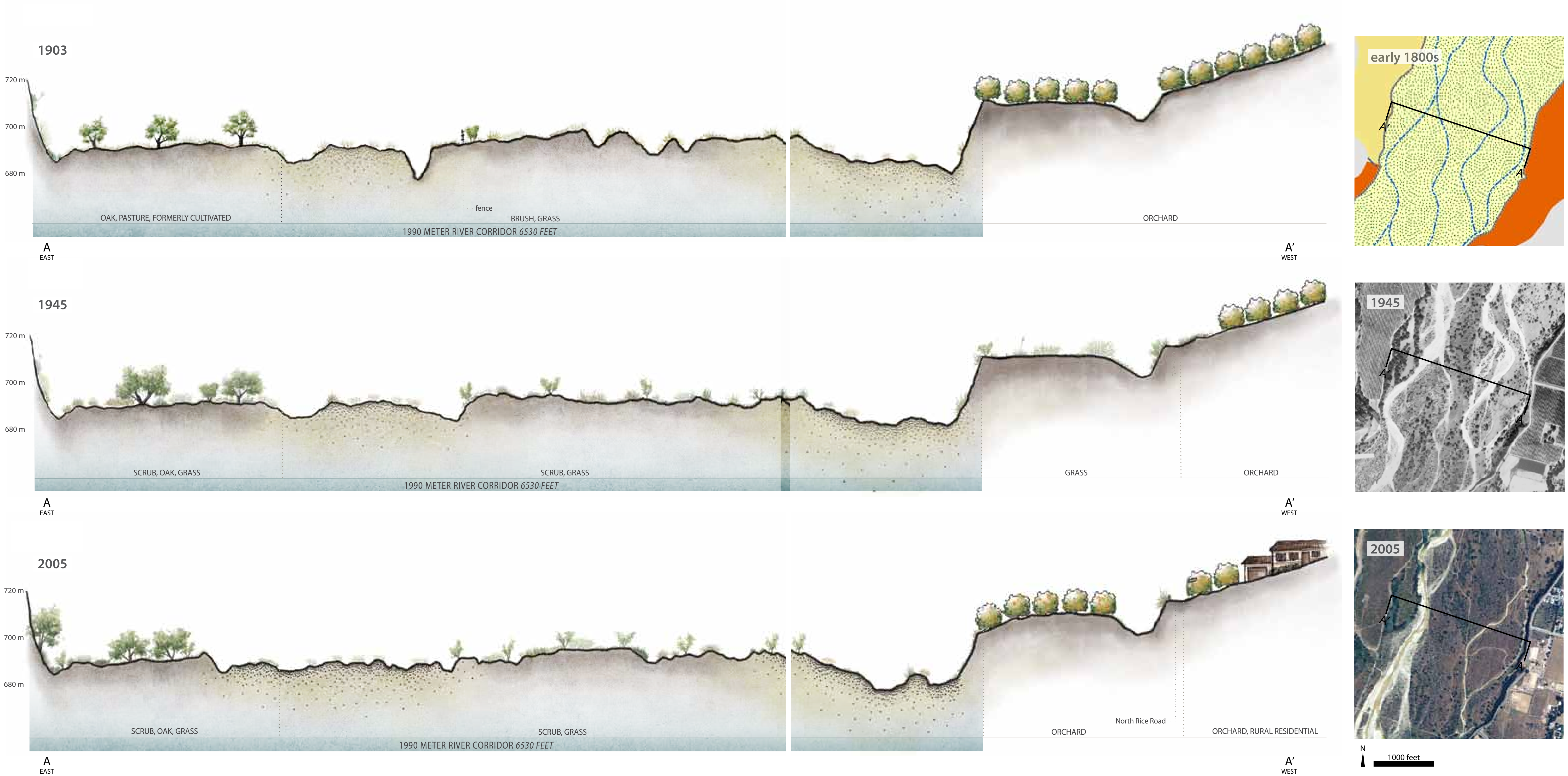


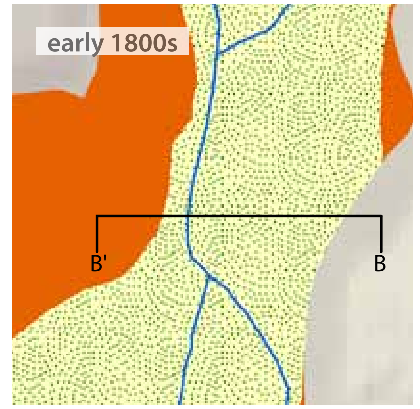
Fig. 4.23. Historical cross-sections at Meiners Oaks, 1903-2005. This time series shows the Ventura River just west of the town of Meiners Oaks, in a broad, braided section of the river about 2 miles north of the Highway 150 bridge. Broad patterns in river corridor width and ecology have remained remarkably consistent in this reach over time. Cross-sections are drawn with 5x vertical exaggeration. (Waud 1903 and Lippincott 1903, courtesy of the Museum of Ventura County; USDA 1945, courtesy of the UC Santa Barbara Map and Imagery Library; USDA 2005. Cross-sections produced by Jen Natali)

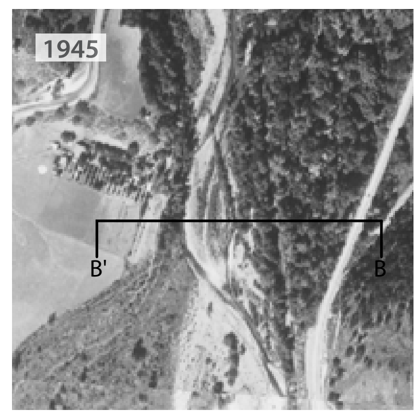
CASITAS REACH

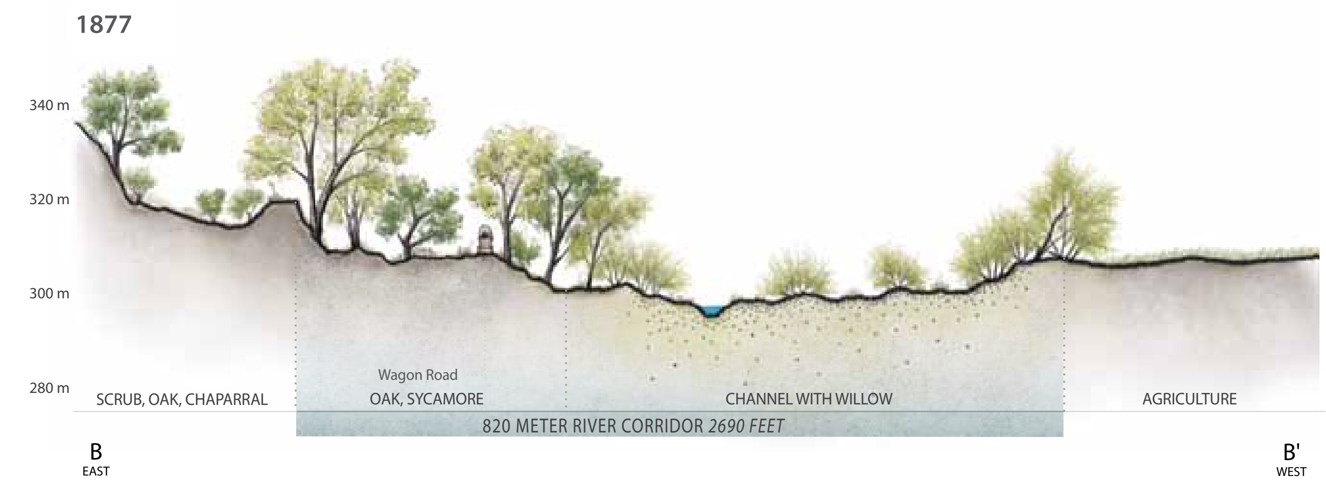
This cross section is located between the present day towns of Oak View and Casitas Springs immediately downstream of the confluence with San Antonio Creek. The toes of two hills narrow the valley here, pinching the river slightly and narrowing the river corridor.

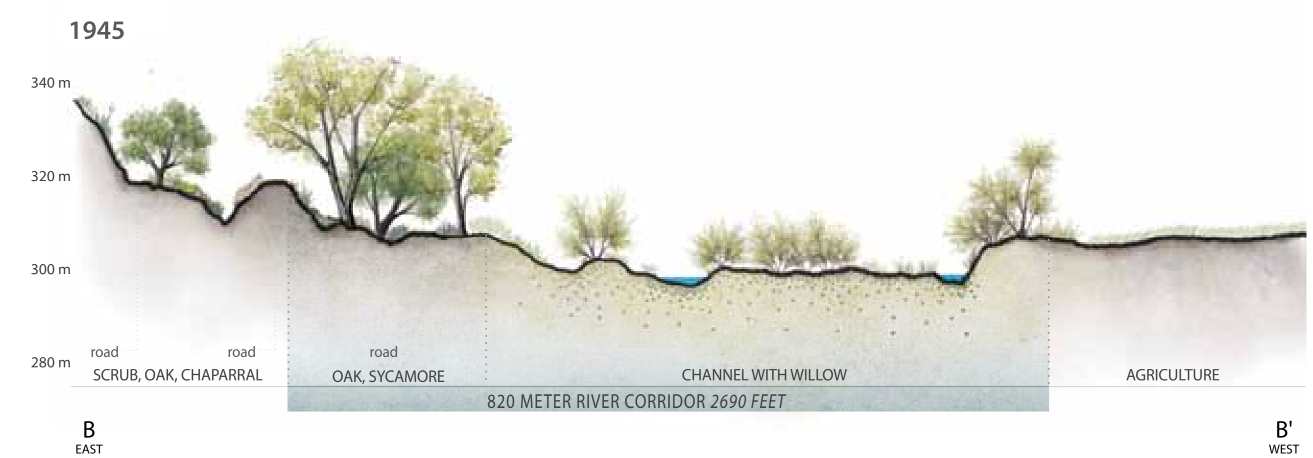
On August 3 and 4, 1877, surveyor W.H. Norway walked this transect; his survey forms the basis of the eariest cross section. Norway described the active channel as "riverwash" 460 feet wide, with a low-flow channel 16 feet wide carrying summer water toward the ocean. (This is especially notable given that 1877 was a severe drought year in the region.) On the eastern side of the river between the active channel and the hills, he noted "heavy oak & sycamore timber" on the "bottomland" surface. He also documented early modifications, including the wagon road connecting Ventura and Ojai and paralleling the river on the western side, and a fence separating agricultural fields from the river on the west bank.

Surprisingly, aerial photos from 1945 show evidently little change in riparian composition and river corridor extent from the snapshot provided by Norway in the late 1870s. The wagon road route remained, replaced by a branch line of the Southern Pacific Railroad. Broad, dense riparian forest still characterized the eastern bank. The most severe modifications occurred in the second half of the 20th century, when a levee on the west bank was constructed and the wagon road remnant transformed into several highways, including Highway 33 and the Ojai Valley Trail Road. Significant riparian forest (willows near the channel, and oaks and sycamores on the eastern floodplain) remains, though it is bisected by the Ojai Valley Trail and Highway 33.









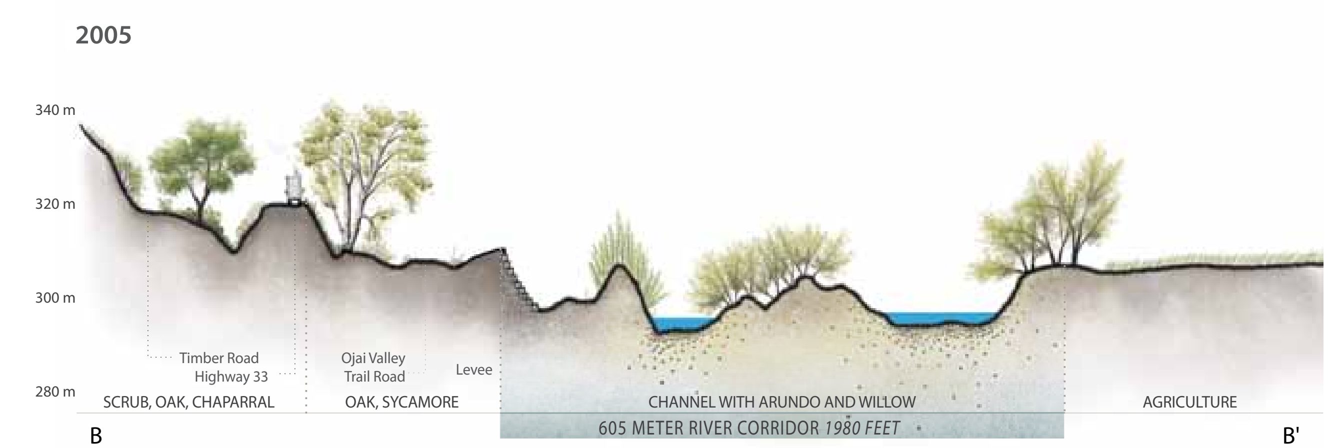


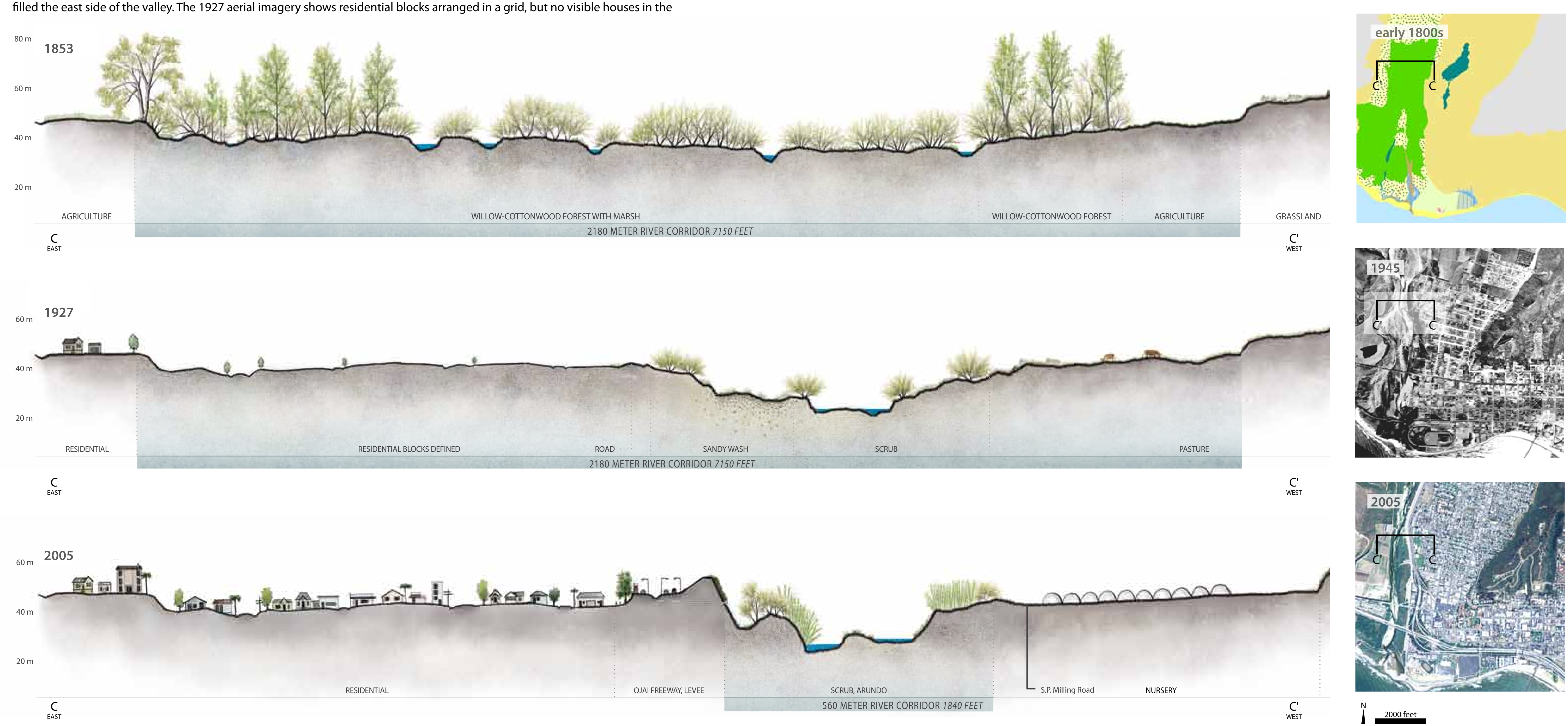
Fig. 4.24. Historical cross-sections at Casitas, 1877-2005. This series of cross-sections shows the Ventura River south of the San Antonio Creek confluence. The transect is in a reach with perennial flow, a relatively narrow river corridor (in comparison to other reaches of the river), and historically abundant live oak and sycamore. Like the Meiners Oaks reach to the north, this reach has retained many of its historical characteristics. Cross-sections are drawn with 5x vertical exaggeration. (Norway 1877; USDA 1945, courtesy of the UC Santa Barbara Map and Imagery Library; USDA 2005. Cross-sections produced by Jen Natali)

VENTURA RIVER DELTA

This cross section captures the dramatic changes over time at the mouth of the Ventura River, about ½ mile upstream of the current Highway 101 crossing. The T-sheet for this area, surveyed in summer 1855, depicts a broad (over 1.2 miles wide) river corridor dominated by interconnecting distributary channels and dense riparian forest. This is corroborated by a GLO survey conducted two years earlier in October 1853, when surveyor Robert Norris noted crossing four channels in the midst of what he termed a "willow swamp." Grassland and some early cultivation bounded the river in the "first rate land in bottom." The 1870 T-sheet resurvey confirms the continued presence of the riparian forest and marsh through the later 19th century (Greenwell and Forney 1870).

Between 1860 and 1930 the population of the city of San Buenaventura increased more than 18-fold, from around 600 residents to over 11,000. (From 1920 to 1930 alone the population of the city almost tripled; California State Department of Finance 2003.) Riparian forest area had severely decreased by 1927, and residential housing blocks encroached into the floodplain and filled the east side of the valley. The 1927 aerial imagery shows residential blocks arranged in a grid, but no visible houses in the river corridor. This may be a snapshot of a post-flood period of rebuilding, or it may be the beginning of a rapid urbanization of the lower watershed. By 2005, the city of Ventura had expanded fully into the floodplain of the river, fortified by a levee and bounded by the Ojai Freeway. *Arundo donax* has established on both sides of the narrowed river corridor; it was described as "well established for many miles along the river" as early as 1945 (Henry Pollard, in Ferren et al. 1990). Industrial agriculture and nurseries have replaced pasture on the west bank of the river.

Fig. 4.25. Historical cross-sections at the Ventura River mouth, 1853-2005. This time series shows the Ventura River at its mouth, about ½ mile upstream from the Highway 101 bridge. The area was dominated by broad willow-cottonwood forest and shallow, multi-thread distributary channels. By the early 20th century, the floodplain had been converted into a much narrower, leveed channel to make way for northward expansion from the town of Ventura. The earliest cross-section is derived from GLO notes and the mid-19th century T-sheet drawn of the river mouth by the U.S. Coast Survey. Cross-sections are drawn with 5x vertical exaggeration. (Norris 1853, Johnson 1855c, courtesy of the National Oceanographic and Atmospheric Administration; Fairchild Aerial Surveys 1927, courtesy of Whittier College; USDA 2005. Cross-sections produced by Jen Natali)



SUMMARY OF FINDINGS

The following findings represent some of the significant conclusions drawn from our research and analysis. Combined with an understanding of modern conditions, these findings can support scientists and managers working to identify restoration opportunities in the Ventura River valley. Further comparison with contemporary Ventura River corridor mapping may help identify and quantify changes over time.

1. **The historical Ventura River valley supported a diverse array of natural habitats,** including valley freshwater marsh, grassland, coastal sage scrub, oaks, and sycamores. While we were unable to map the valley floor in detail, our data indicate a broad transition from grassland in the lower valley (Avenue area) to predominantly oaks, sycamores, and scrub above Foster Park to Matilija Dam. As in the Santa Clara River valley, valley oaks were not documented anywhere in the valley. Only one wetland feature was documented on the valley floor within the study area (not including Mirror Lake).

2. **Most substantial freshwater wetland complexes occurred within the Ventura River corridor.** Aquatic habitats such as ponds, sloughs, and freshwater marshes were likely found in many perennial reaches, and a suite of saline and brackish aquatic habitats was associated with the estuary at the river mouth.

3. **The Ventura River supported a broad range of riparian species,** including trees such as sycamore, live oak, willow, cottonwood, box elder, alder, and walnut; understory species such as wild grape, wild rose, and wild blackberry; and mulefat and alluvial scrub species.

4. **Unlike on the Santa Clara River, live oaks and sycamores were common within the river corridor of the Ventura River.** While on the Santa Clara River live oaks and sycamores were almost exclusively found bordering the river's high (outer) bank, both trees were common on benches, bars, and islands in the Ventura River channel, particularly in the intermittent Oak View reach.

5. **The Ventura River mouth has shifted location numerous times over the past several hundred years,** from the hills west of the river mouth to Figueroa Street in Ventura. Many of these former river mouth areas are still susceptible to flooding. A brackish lagoon, formerly at the site of what is now the Derby Club across from Seaside Park, marked the route of one of these former river mouths.

6. **The Ventura River was generally perennial for much of its length.** The uppermost reach (below the present-day location of Matilija Dam) consistently supported year-round surface water, as did the lower half of the river (below the San Antonio Creek confluence). In contrast, the middle reach, through the western Ojai Valley and downstream of Oak View, was typically dry during the summer. The precise extent and location of summer water fluctuated in response to annual variations in rainfall and runoff.

Management Implications

- **Restoration of historical riparian habitats that have been degraded or eliminated should be considered.** Despite extensive modification, the Ventura River has retained significant habitat features, such as willow-cottonwood riparian forest remnants on the Ventura River delta and alluvial scrub in the intermittent reach near Oak View. Preservation of remnants such as these, which could serve as nodes for river restoration, is an important component of maintaining the ecological diversity of the river.

- **Riparian restoration goals should be reach-specific.** Each of the three reaches of the Ventura River we examined were characterized by different patterns of flow and riparian vegetation, providing valuable information on potential restoration targets that may be realistic for a given reach.

- **Maintaining the hydrologic heterogeneity of the Ventura River is an essential component of conserving ecological diversity.** Groundwater availability (and by extension, summer flow) is clearly a primary driver in the distribution and composition of riparian habitat.

Fig. 4.26. Ventura River at the Rancho El Nido Preserve, February 2011.

5 • OXNARD PLAIN AND CALLEGUAS CREEK

In time we went down a long, steep hill [Conejo Grade], then across a wide valley that supported a rank growth of vegetation, and came to a Mission called San Buena Ventura (good luck).

— MANLY 1894

Introduction

At first glance the Oxnard Plain appears to be an unvarying, homogeneous plain with relatively little ecological variation between expanding cities and intensive agriculture. These changes in land use mask its underlying complexity, however. In recent times the plain exhibited a complex mosaic of habitats and channels, remnants of which are still evident today.

What is now called the Oxnard Plain was known by many other names before the town of Oxnard was founded in 1898. Many early travelers did not refer to it by name, instead considering it to be the westernmost portion of the Santa Clara River valley and referring to it only as "the plain" (Crespí 1769, in Crespí and Brown 2001; Bryant 1848; Geological Survey of California 1865; Brewer [1930]1974). Those that did name the plain called it the Saticoy Plain (Hilgard 1884; the Santa Clara River was also sometimes called the Saticoy River) or the Hueneme Plain (Diller 1915).

The Oxnard Plain is a remarkably flat (under 1% slope), broad, surface, with 111 square miles sloping very gently from the hills to the coastline. With further examination, the plain reveals subtle variations in topography, soils, and hydrology that supported diverse natural habitats (fig. 5.2). We discuss these overarching factors broadly below.

First, variations in the concentration of soil salts, from both tidal flows and seasonal evaporation, created patterns of saline tidal and alkaline upland habitats that covered a large portion (43%) of the plain. The extent of alkali influence stretched far inland, following topographic lows to the west of the Camarillo Hills and near the Calleguas Creek/Revolon Slough drainages (see fig. 5.10).

Second, prominent springs related to geologic contacts, topographic depressions, and artesian conditions created zones of freshwater influence on the plain. Since relatively few watercourses traversed the Oxnard Plain, these were important sources for early settlers. On the eastern plain, lakes, wetlands, and springs in foothill valleys east of Calleguas and Conejo creeks provided a dominant freshwater influence (in addition to the creek itself). On the western portion of the plain, the presence of artesian water,

Fig. 5.1. Simomo (Spring Hill), looking west across the Oxnard Plain (opposite page). This picture, taking in 1932 as part of ethnographer J. P. Harrington's research on the Chumash, shows the edge of a small hill at what was formerly a Chumash village site. The site was well known for its flowing springs. It is now on the Broome Ranch. Note prickly pear cactus (*Opuntia* sp.) on hill in foreground. (Harrington 1932, Courtesy of the Smithsonian Institution)

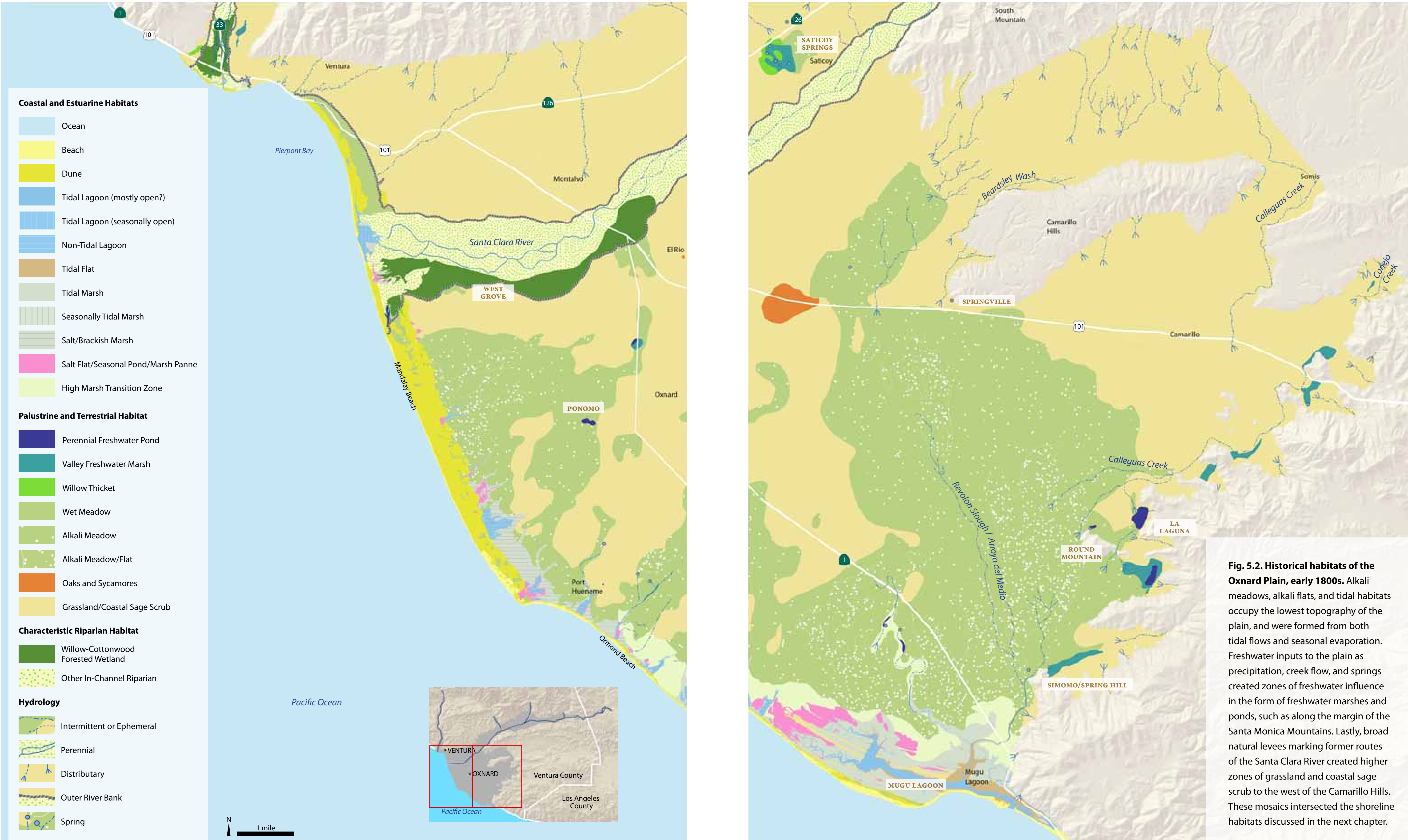


Fig. 5.2. Historical habitats of the Oxnard Plain, early 1800s. Alkali meadows, alkali flats, and tidal habitats occupy the lowest topography of the plain, and were formed from both tidal flows and seasonal evaporation. Freshwater inputs to the plain as precipitation, creek flow, and springs created zones of freshwater influence in the form of freshwater marshes and ponds, such as along the margin of the Santa Monica Mountains. Lastly, broad natural levees marking former routes of the Santa Clara River created higher zones of grassland and coastal sage scrub to the west of the Camarillo Hills. These mosaics intersected the shoreline habitats discussed in the next chapter.

along with surface water accumulations in topographic depressions, was an important source of fresh water for 19th century farmers and settlers on the plain.

Much of the Oxnard Plain was subject to artesian conditions, even well into the 20th century (fig. 5.3; Schuyler 1900, Lippincott ca. 1930; see page 38). Long-time residents recalled that “in the old days the water level was right at the surface” on the central Oxnard Plain, an aspect of the plain’s hydrology that manifested as springs, ponds and marshes, and later in the successful development of artesian wells (Bloom 1959). Even in areas outside the artesian zone, abundant water was recorded just below the surface in many places; a GLO surveyor recorded that in March 1874 in the area around the Camarillo Hills there was “no running water but there is a

Fig. 5.3. Extent of artesian conditions, 1900 (in purple) and ca.1930 (in yellow). Though both are somewhat coarse delineations, they do suggest some shrinking of the artesian zone in the first quarter of the 20th century. (Schuyler 1900 and Lippincott ca. 1930, courtesy of the Water Resources Collections and Archives)

plenty by digging” (Craven 1874a). Surveyor George Tolman (1873) made a similar observation in May 1873 regarding the same region, noting that there was “no running water, but good water to be had by digging from 30 to 60 feet.”

Third, the distribution of coarse sediment on the plain reveals aspects of its history, and helped shape its ecology. In particular, lobes of coarse sediment trace former routes of the Santa Clara River across the plain in recent geological time, marking paths of the river to the Mugu Lagoon area and (more recently) to just south of Point Hueneme. This legacy of the Santa Clara River created higher, well drained former natural levees on younger soils that supported a variety of non-alkaline dryland habitats, including grassland, coastal sage scrub, and a few sycamores. In addition, sediment deposited on the eastern plain during floods (as overbank flow and in portions of Calleguas Creek with no well defined channel) shaped the character of the eastern plain.

Few towns were established on the Oxnard Plain prior to the development of the Southern Pacific railroad around the turn of the 20th century; the early settlement patterns that predate the railroad reflect the ecological and hydrologic patterns of the plain described above. Hueneme was formally established in 1870, but an American settlement at the site dates at least to the 1850s (Johnson 1855b). The community was within the Oxnard Plain artesian zone, and was situated at the mouth of the submarine canyon used for shipping agricultural products. (Chumash occupation of the region at Point Hueneme, meaning “sleeping place,” dates even earlier; the site was used by native residents of the Channel Islands as an overnight rest stop during mainland trading expeditions; Applegate 1974.) Springville, a predecessor of Camarillo located at the western edge of the Camarillo Hills, was a farming community situated near a spring whose name clearly identifies the town’s reason for being. Oxnard began as a company town for the sugar beet processing factory, which was built in 1897 to process the beets grown on the region’s extensive alkali meadows. The city of Oxnard itself, however, was built on the non-alkaline, higher (and therefore less likely to flood) alluvium which marked a former route of the Santa Clara River.

Calleguas Creek and other watercourses

The former scarcity of defined channels on the plain, especially in the western half, is striking. Very few substantial watercourses traversed the western plain. On the eastern Oxnard Plain, creeks flowing off the Santa Monica mountains generally did not connect directly into Calleguas Creek, instead spreading out shortly after exiting their canyons onto the valley floor. Defined creeks and sloughs (including Calleguas Creek, Conejo Creek, and Revolon Slough) gave the plain a drainage density of only 1.7 miles of creek per square mile, a figure which has been greatly increased today (fig. 5.4). Instead, water traveled to the ocean through shallow, undefined surface sloughs and swales and through subsurface flow.

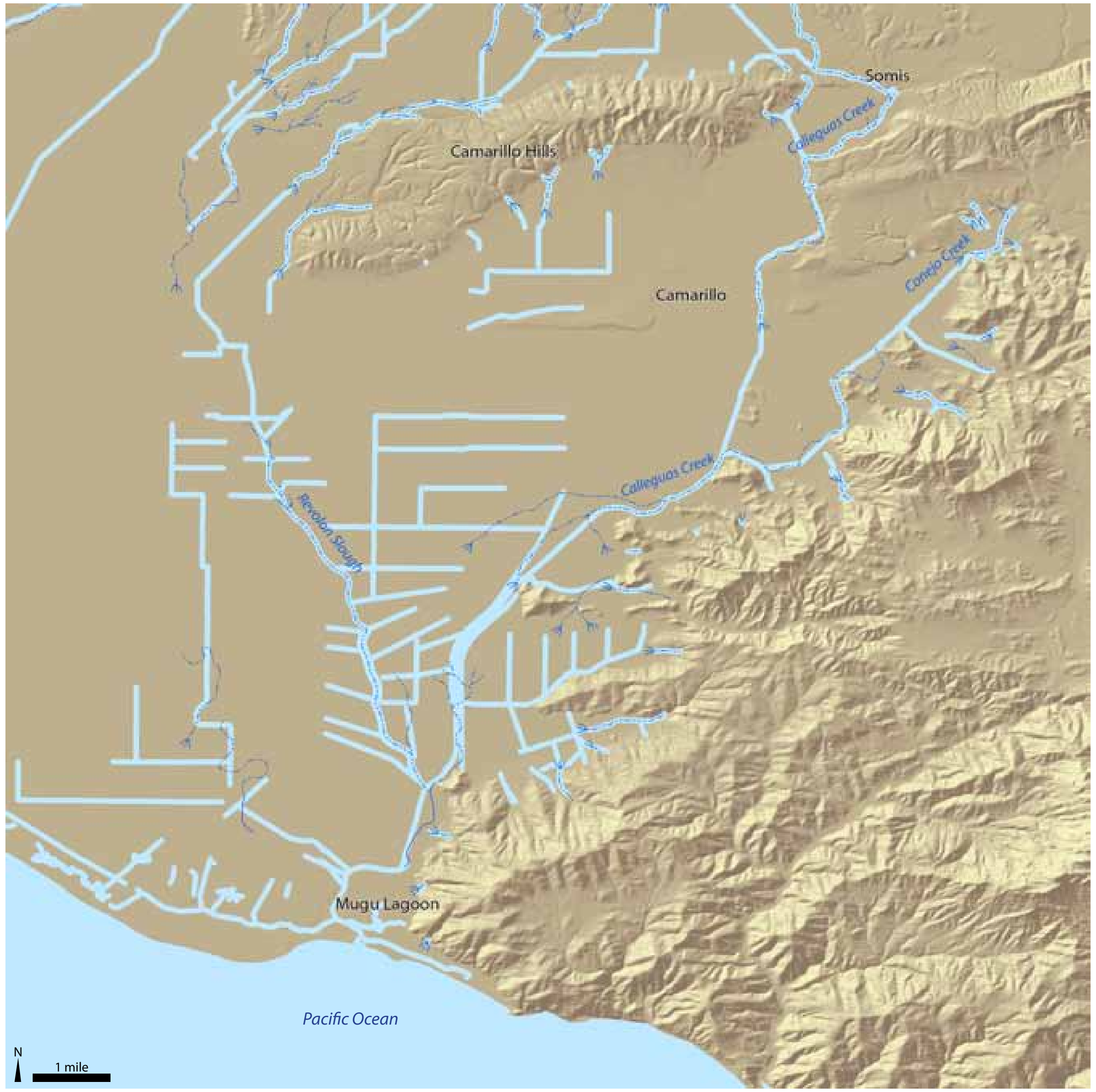


Fig. 5.4. Historical and modern drainage network of the eastern Oxnard Plain, early 1800s and 2005. The creation of new channels, such as drainage and irrigation ditches, has greatly increased the hydrologic connectivity of the eastern plain. Notably, Calleguas Creek now connects to Mugu Lagoon, and Beardsley Wash has been connected to Revolon Slough.

Calleguas Creek

Calleguas Creek drains a watershed of 343 square miles in the eastern portion of the county. Watercourses within the study area that currently drain into Calleguas Creek include Revolon Slough, Conejo Creek, and Arroyo Las Posas (the upstream continuation of Calleguas Creek). As late as the early 1900s, Calleguas Creek was known by many other names (e.g., Arroyo Simi or Guadalasca Creek), though it was most commonly referred to as Calleguas or Las Posas Creek (Norway 1860, Bard 1870a, *Ventura Signal* 1871a, Thompson and West [1883]1961, Holmes and Mesmer 1901b). Calleguas Creek enters the study area near Somis and currently has an outlet to the ocean through Mugu Lagoon.

Calleguas Creek did not maintain a defined channel from Somis to Mugu Lagoon across the Oxnard Plain prior to channelization in the late 19th and early 20th centuries. Though this has been widely recognized by researchers and managers in the watershed, little concrete evidence has emerged defining the date of early channelization efforts. The date most often suggested is 1884, though no direct evidence is cited (Steffen 1982, Onuf 1987, Swanson 1994, USACE 2000). Calleguas Creek Watershed Management Plan (Unknown 2004) states that Calleguas Creek was connected to Conejo Creek by 1889, though again no citation is given.

In addition to ambiguity surrounding the date of early modifications, no consensus has emerged regarding the location of the original terminus of the creek. The Calleguas Creek Watershed Management Plan states that no channel existed in the mid-1800s as far north as Camarillo, but provides no reference. One report (CH2MHill 2010) says it never reaches the ocean, but does not specify location of distributary.

Our findings are largely consistent with these statements. Unfortunately, we were also unable to find direct evidence of the timing of 19th century channelization projects. Attempts to pin down the precise date of channelization are complicated by contradictions in early maps: for example, some maps drawn at a coarse scale show a generalized, meandering channel through this area (Norway 1860, Hare 1875), while others show conflicting depictions of the creek despite similar survey dates (such as the soils map and geological maps surveyed in the same year; Holmes and Mesmer 1901b, USGS 1904). In addition, early ditching efforts were undoubtedly repeatedly washed out during floods, compounding the mapping confusion.

However, historical maps and textual evidence clearly support the early discontinuous nature of the creek, and its subsequent channelization (fig. 5.5). These sources indicate that Calleguas Creek maintained a defined channel to around the Highway 101 crossing, then emerged again (possibly more associated with the Conejo Creek drainage) at the current confluence of Calleguas and Conejo creeks. The creek maintained a defined channel for a short distance (approximately 2.5 miles) before terminating in a lagoon and distributary channels north of Round Mountain and CSU Channel Islands (see page 186). GLO surveyors crossing the creek recorded widths of approximately 165-230 feet at a point along the creek north of Highway 101 (east of the intersection of Highway 34 and Las Posas Road in Camarillo; Tolman 1873), and about 20-30 feet for the southern articulation of the

Fig. 5.5. Prior to channelization, Calleguas Creek maintained a defined channel only above Highway 101 (a) and for a few miles above CSU Channel Islands (labeled here at (b)). Note also the freshwater wetlands, ponds, and springs along the foothills on the eastern edge of the Oxnard Plain.

Coastal and Estuarine Habitats
- Tidal Lagoon (mostly open?)
- Tidal Flat
- Tidal Marsh
- High Marsh Transition Zone

Palustrine and Terrestrial Habitat
- Perennial Freshwater Pond
- Valley Freshwater Marsh
- Alkali Meadow
- Alkali Meadow/Flat
- Grassland/Coastal Sage Scrub

Hydrology
- Intermittent or Ephemeral
- Perennial
- Distributary
- Outer River Bank
- Spring

creek near CSU Channel Islands and northeast of the Camrosa storage ponds (Terrell 1861a).

Below Highway 101, Calleguas Creek spread into a broad, sandy wash with no defined channel until the Conejo Creek confluence. Norway (1860) described the "wash of Las Posas [Calleguas] Creek" near present-day Highway 101, though the wash was so diffuse that surveyor Henry Hancock, traveling east across the plain in June 1854 and crossing the modern alignment of Calleguas Creek near Calleguas Road (¾ mile south of Highway 101), did not mention the creek, instead noting only that there he crossed a mile-long transect of dense chaparral near where the creek runs today (Hancock 1854). An early soils map and aerial photography of this area also support the absence of a defined channel; as late as 1927 patterns of multiple routes of overflow are still visible (Nelson et al. 1917, Fairchild Aerial Surveys 1927; fig. 5.6).

South of Round Mountain, Calleugas Creek was seasonally connected to Mugu Lagoon through subsurface flow, overland flow during floods, and multiple discontinuous sloughs, swales and wetlands draining into Revolon Slough. Lugo (1855) described the connection between the lake at the terminus of Calleguas Creek and Mugu Lagoon: "In the dry season of the year, it [the lake] is very small, in the rainy season it extends down to the beach where it has an outlet" (Lugo 1855). This description is corroborated by early surveyors, who described what is now Calleguas Creek near Laguna Road only as "overflowed ground" (Terrell 1861a, Thompson 1867). The distributary channel network below the creek's terminus is also captured by an early GLO survey, which crossed one of these shallow swales six feet wide and described it using the Southern term "bayou," implying a marsh channel with slow-moving water (Washington 1853). Other overflow channels are visible on early aerial photography (Fairchild Aerial Surveys 1927, USDA 1938).

[Arroyo Las Posas] drains a large territory, most of which lies within the survey, but it has no well-defined channel and carries water only during very wet periods. It empties into the ocean through Calleguas Creek, near Mugu Point, and because of its choked channel sometimes causes damage to part of the Oxnard Plains by overflow.

— NELSON ET AL. 1920

While some early maps show Calleguas Creek having a defined channel connecting it to Mugu Lagoon (e.g., Bard 1870b, Reed ca. 1871), a literal interpretation of these maps is not supported by other textual, aerial, and cartographic evidence. Rather, these maps were likely depicting the hydrologic connection between the creek and the lagoon, which would have been connected though swales and overland flow during wet weather. Other, more detailed maps show Calleguas Creek terminating before reaching Mugu Lagoon (e.g., Terrell 1861a, Holmes and Mesmer 1901b). Two maps produced in the early 1900s (1917 and 1919) even differ on the location of Calleguas Creek south of Round Mountain, unusual for such relatively late sources and suggesting the absence of a distinct, defined channel even then (Nelson et al. 1917, Petit 1919).

The lack of a defined channel meant that during major floods, water (and sediment) would spread out over large areas of the Oxnard Plain. This was recognized by early farmers, who could often use the fertile sediment to their advantage. During much of the year, however, it appears that

Fig. 5.6. Calleguas Creek south of Highway 101, 1927-2005. In 1927 (top left), a dense network of ephemeral distributary channels (a) is visible to the east of the clearly engineered channel of Calleguas Creek (b), separated by low hills. By 1938 (top right), these channels are no longer visible; the land may have been graded. Agricultural farms occupy the area in 2005 (bottom left). (Fairchild Aerial Surveys 1927, courtesy of Whittier College; USDA 1938, courtesy of Ventura County; USDA 2005)

Calleguas Creek was dry. Descriptions of Calleguas Creek from the first half of the 20th century describe the creek as almost always dry (Holmes and Mesmer 1901c, Nelson et al. 1920, Gregor 1952). However, there is little information on the hydrologic characteristics of Calleguas Creek before major land and water use modifications (e.g., widespread drilling of artesian wells) occurred. When surveyor Terrell (1861a) crossed Calleguas Creek east of the Camarillo Hills in January 1861, he noted that it was "a dry creek"; surveyor Tolman (1873) noted the same on Calleguas Creek north of Round Mountain in April 1873. These quotes imply that portions of the creek may have even been ephemeral, with flow only after storms. The lack of water in Calleguas Creek was vehemently asserted in a letter written to the *Pacific Rural Press* from a county resident in 1877. In response to the

The silt loam on the Calleguas Ranch receives a fresh coating every year by the floods from Arroyo Santa Rosa [Conejo Creek].

— HOLMES AND MESMER 1901C

WERE THERE BARRANCAS IN VENTURA COUNTY BEFORE THERE WERE CATTLE?

On our way we came to several of those large, deep ravines, commonly called in this country 'barancas [sic],' and of which the timid have a special dread. The first two are bridged, and also the fourth one; but the third, the deepest, widest and most dangerous of all, is graded.

— VENTURA SIGNAL 1871A

Ventura County has numerous barrancas, particularly north of the Camarillo hills, in Ventura, and between Ventura and Santa Paula. Barrancas, also identified as ravines, gullies, or dry creeks, are channels characterized by steep banks and deep beds. They are often formed during severe storms, when water induces erosion and gully incision. Since barranca formation induced by flooding can be exacerbated by land uses such as deforestation and grazing, the question arises as to whether the barrancas in Ventura County predate the Mission era, particularly with respect to the introduction of grazing sheep and cattle.

Early explorers on the Portolá expedition (1769) do reference features that were likely barrancas. Costansó recorded "a road broken by streams and gullies" (*zanjones* in the original Spanish) between Santa Paula and Sespe creeks (Costansó and Browning 1992). On the same expedition, Crespí described traveling through a "dry creek bed" with its bed "a bit deep down" between Saticoy and Ventura; the Chumash they encountered led the party through the channel as a means of travel (Crespí and Brown 2001).

Historical records point to many deep barrancas present in the 1850s. While these documents do not predate land use impacts, they do predate the substantial flooding of 1861-2 as well as intensive regional agricultural development. In Ventura, Sanjon Barranca and Prince Barranca were both documented on the 1855 T-sheet (Johnson 1855c) and recorded by GLO surveys as "dry gulch" and "dry bed of creek" as early as 1853. To the south, Arundell Barranca and Harmon Barranca were also partially captured by the early T-sheet; Arundell Barranca was recorded as a "deep gulch" (Hancock 1854) and "dry gulch…about 25 feet deep" (Norris 1853) by early GLO surveys. Hancock (1853) also recorded numerous barrancas north of the Camarillo hills, including one 80 feet deep.

The formation of new barrancas is documented by a few historical sources. Mission friar Señán wrote that near Saticoy, a new barranca had formed—"mui [sic] ancho, hondo, y acantilado" (very wide, deep, and steep)—since the "año de los temblores," the earthquakes of 1812 (Señán and Vitoria 1822). He noted that the barranca had formed from a previously much smaller stream. The *Ventura Free Press* noted new barrancas formed as a result of the flooding of 1914, and implied barranca formation in earlier 19th century floods:

> New barrancas in hills. On the crest of the hill back of R.E. Brakey's home there appeared today several breaks in the soil indicating that nature had started some new barrancas; the land has slipped in several places and in years to come future cloudbursts will keep up their erosive work until there will be some topography that does not exist at this time. Our children's children will then say, doubtless, that this or that ravine started one night in January, 1914, in just about the same way as we say that something or other took place in 1884, 1875, or 1867. Verily every day makes a little history or a few changes on the map. (*Ventura Free Press* 1914)

In addition, the 1862 floods were said to have caused gully formation on San Diego County hillslopes; it is likely that similar formation of new features and incision of existing ones also occurred in Ventura County during these floods (Engstrom 1996).

While data are inconclusive, it is likely that at least some barrancas predate heavy grazing impacts, while others would have been formed during subsequent flood events and would have been influenced by these land use changes. Certainly their form was altered during the 20th century: many of the barrancas that today run off South Mountain or the Camarillo Hills and connect into Beardsley Wash and Calleguas Creek, for example, historically ended shortly after leaving their canyons.

Rural Press' assertions that Calleguas Creek and the Santa Clara River dried up due to deforestation, he wrote that "Los [sic] Posas creek rises in a big spring, and there is not a particle of evidence that it has ever averaged a greater flow per annum than it does now" (Bristol 1877).

There are a few recorded instances of wells dug in the dry bed of Calleguas Creek east of Somis and elsewhere on the Las Posas rancho in the 1870s and 1890s, suggesting ample subsurface flow (*Ventura Free Press* 1878c, Schuyler 1890). One traveler made a point to visit the wells sunk in the bed of Arroyo Las Posas in the fall of 1890:

> After a delectable lunch, we rode down to the bed of the creek to see the artesian wells. There are several of them within a few rods of each other. (Eames 1890)

Some mention is also made of use of surface water to irrigate in the early spring (*Ventura Free Press* 1877).

Very few data were found addressing riparian characteristics along Calleguas Creek. Almost no trees are recorded by GLO surveyors in the area, with the exception of a cluster of three sycamore trees in the bed of Conejo Creek at the Calleguas Creek confluence (Terrell 1861a).

In the spring of 1877, while looking at vast fields of barley perishing before his eyes, Mr. Peter Rice… selected a spot in the then dry bed of the Calleguas Creek and commenced sinking an artesian well. At a depth of about 80 feet a fine flow of water was struck."

— VENTURA FREE PRESS 1878C

Conejo Creek

Conejo Creek lost definition only about a mile after entering Pleasant Valley and the Oxnard Plain. Like Calleguas Creek, it also reformed a channel further downslope, less than ½ mile south of the Highway 101 crossing. The mouth of this lower channel connected to the historical head of lower Calleguas Creek, suggesting that lower Calleguas Creek may have had a greater historical connection to Conejo Creek than upper Calleguas.

Revolon Slough

Revolon Slough, also known as Arroyo del Medio ("creek of the middle"; Norway 1860), was one of the few natural drainages on the Oxnard Plain between Calleguas Creek and the Santa Clara River. Revolon Slough had its source just below the modern intersection of East Fifth Street and Pleasant Valley Road east of Oxnard (Norway 1860, USGS 1904), and drained into the sloughs above Mugu Lagoon (fig. 5.7).

Revolon Slough was notable as a former course of the Santa Clara River (see page 71) and as the predominant watercourse draining the central Oxnard Plain. While the slough ran through the heart of the region's alkali meadows, the natural levees to either side of the slough were not affected by alkalinity, created what Holmes and Mesmer (1901c) called "an oasis in the broad alkali flat." Farmers took advantage of the slough to drain and flush strongly alkaline lands. Over time, an extensive drainage network was created, connecting Calleguas Creek and (much later) Beardsley Wash into Revolon Slough and providing a direct outlet to the ocean through Mugu Lagoon where there was formerly none. These modifications drastically increased the drainage density of the central Oxnard Plain (see fig. 5.4).

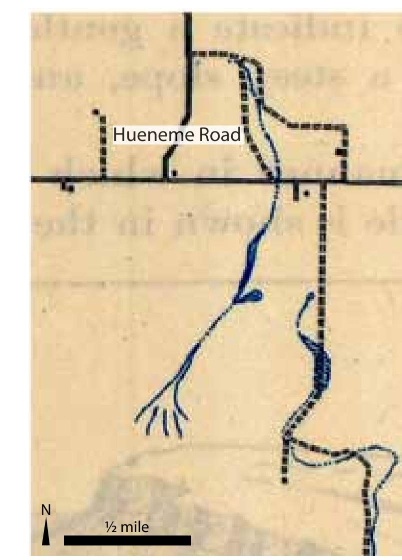


Fig. 5.7. Channels west of Revolon Slough, 1904. Disconnected sloughs west of Revolon Slough carried water from the central Oxnard Plain into Mugu Lagoon. Broader ponded areas are shown within the channel on this early USGS quad. Highway 1 now runs to the north of this complex. A willow thicket currently occupies an undeveloped segment of the meanders at lower right. (USGS 1904, courtesy of California State University Northridge Map Library)

Oxnard Plain habitats

The suite of habitats on the Oxnard Plain varied considerably from those historically found elsewhere in the study area. The majority of non-riverine wetland habitats in study area occurred on the Oxnard Plain and along the shoreline, mostly as seasonally inundated alkali meadow, extensive swaths of which covered most of the eastern (and portions of the western) plain.

Unfortunately, the habitats that dominated the Oxnard Plain are not well documented in the historical record. Many early travelers heading north from Los Angeles came down the Santa Clara River valley before heading to the city of Ventura and up the coast. Those that did cross the Oxnard Plain, such as botanist William Brewer or gold-seeker William Manly, often devoted no more than a sentence or two to the twelve mile journey across the plain, stopping only to elaborate once they reached the Santa Clara River or Ventura city. As a result, evidence for habitats on the plain is fragmentary, and often from a later date than in other regions of the county.

This section describes patterns of dryland and wetland habitat distribution on the Oxnard Plain. For descriptions of shoreline habitats, see the Ventura County Shoreline chapter (page 190).

Dryland Habitats

Though low-lying alkali meadow lands dominated much of the Oxnard Plain, higher, better-drained dryland habitats predominated on the northeastern plain (around the Camarillo Hills) and in broad fingers stretching south from the Santa Clara River, including El Rio and much of present-day Oxnard (see fig. 5.2). These coarser, higher deposits south of the river were built up by the Santa Clara River itself, and mark former courses of the river from a time when its outlet was near Mugu Lagoon or, more recently, Point Hueneme.

Early travelers crossing the Oxnard Plain were struck by the lack of trees across such an extensive area. Explorer Juan Crespí recorded in 1769 that "no trees are to be seen nearby" in the Saticoy area (Crespí and Brown 2001). Seven years later explorer Juan Bautista de Anza and his party, traveling down the Conejo Grade and across the Oxnard Plain, were forced to travel across the entire plain before camping at the Santa Clara River; they noted that it was "impossible to halt before this for lack of firewood" (Bolton et al. 1930). One hundred years later, this deficit was still a prominent aspect of the plain. One newspaper article reported that timber would be taken from the Ventura River to supply residents of "the timberless portion of the lower Santa Clara Valley" (as the Oxnard Plain was considered; *Daily Alta California* 1868). Another article from the same paper and year, describing a trip across the Oxnard Plain west toward the Santa Clara River, provided more detail on the lack of timber on the plain:

> Third day journeyed southwesterly ten miles, and struck the sea; thence fifteen more northerly to near the mouth of the Santa Clara, and up the lower bottom of that stream to camping ground in the enclosure of Mr. Pierpont. The route all the way lay over the Colonia…No spring, nor running water throughout the day's drive, nor any trees until reaching the vicinity of the Santa Clara, where a considerable body of willow, cotton-wood and some sycamore is growing. (*Daily Alta California* 1868)

These general impressions are corroborated by an 1873 GLO survey, which recorded no timber in the Camarillo area (Tolman 1873).

While the general lack of trees on the plain was clearly documented, unfortunately the actual vegetation of the Oxnard Plain was not well captured by historical sources. The sources that do address the type of vegetation on the plain describe grassy areas interspersed with scrub and, occasionally, sycamores and live oaks.

Many accounts refer in various ways to the grassy nature of the Oxnard Plain. Crespí provides the earliest description of the plain in 1769; upon rounding the end of South Mountain and viewing the plain for the first time, he described it as "a large extent…of very grass-grown flat land, widest in extent from east to west" (Crespí and Brown 2001). William Brewer, traveling across the entire plain as chief botanist of the Geological Survey of California in March 1861, also described "a fine grassy plain, with here and there a gentle green knoll" (Brewer [1930]1974). (GLO surveyor Henry Hancock (1853) also noted these knolls, recording "low sand hills covered with vegetation.") William Manly (who sometime in the winter of 1849-50 also traversed the plain from the Conejo Grade westward) described it as "a wide valley that supported a rank growth of vegetation" (Manly 1894). These general quotes are corroborated by more site-specific descriptions of "good pasturage" (Hancock 1854), "rich prairie" (Washington 1853), "alternating…belts of grass and mustard" (Hancock 1854), and "finest meadow grass and wild oat" (*Daily Alta California* 1865). It is worth noting, however, that it is unclear whether these early observations recording "grass" were referring to the alkali meadow (much of which would have also appeared "grassy") or dryland areas. In addition, non-native mustard (*Hirschfeldia incana*/*Brassica nigra*) and wild oats (*Avena* spp.) had already colonized large portions of the plain (Hancock 1854).

A few sources note areas of scrub, or timber. South of the Camarillo hills (east of the present location of Camarillo), GLO surveyors recorded a large area of scrub, describing "worthless shrubbery," "scattering chaparral," "open chaparral," "chamisal," and "wild sage" (Hancock 1854; fig. 5.8). Terrell (1861a,b) noted prickly pear cactus (*Opuntia* spp.) on both the eastern and western sides of the plain. The occurrence of trees was even more sparsely mentioned. Costansó, an engineer on the Portolá expedition of 1769, described a "spacious plain, covered with grass and with some trees, extending to the south and west as far as the sea" (Costansó and Browning 1992). GLO surveys record an area a little under a mile wide of "scattering timber" (presumably sycamores and/or live oaks) along what

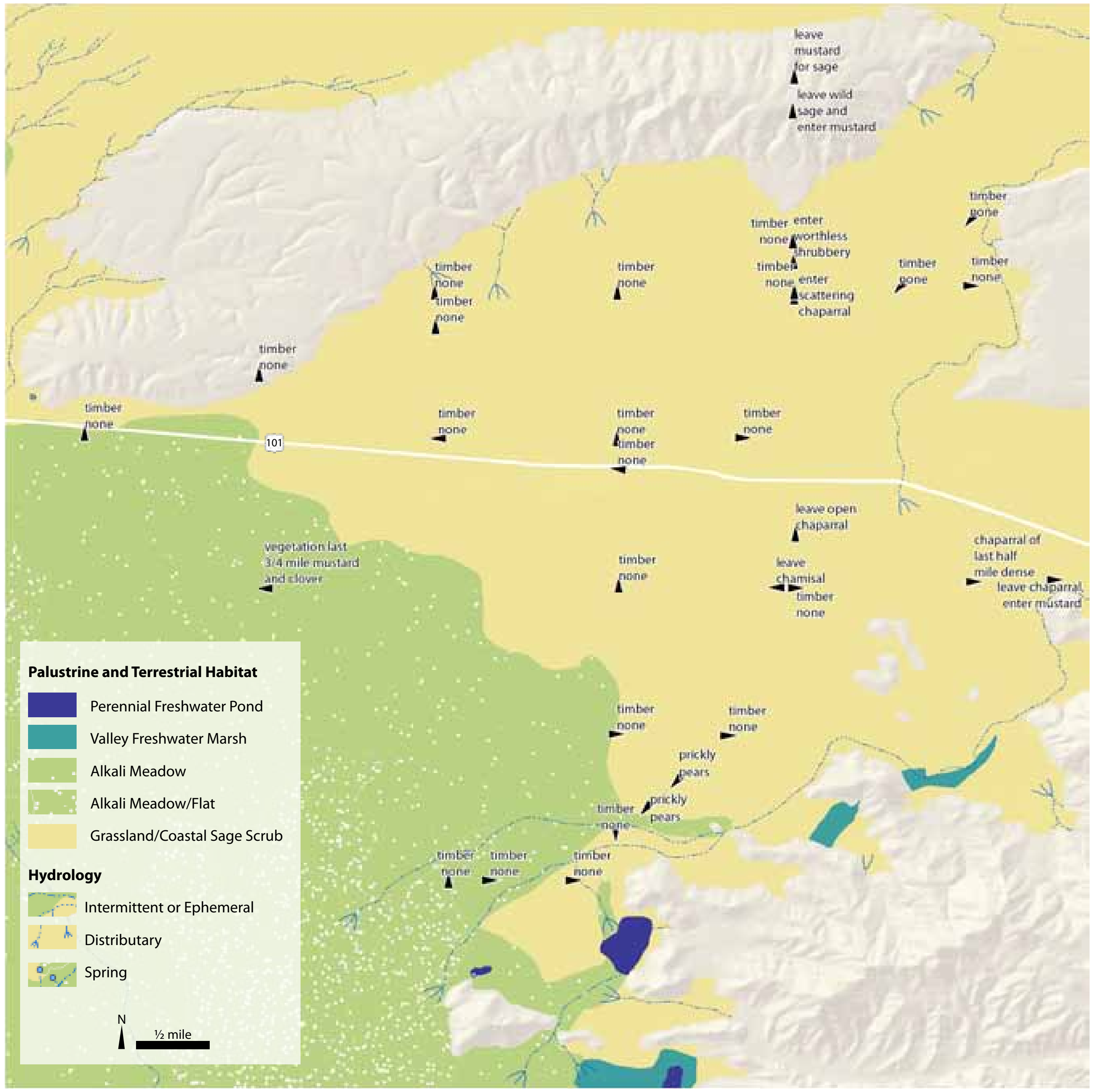


Fig. 5.8. Early evidence for historical vegetation near Camarillo, 1853-1873. General Land Office surveyors noted large areas covered in scrub, while noting no bearing trees. These quotes provide a glimpse into the variation in land cover represented by the grassland/coastal sage scrub habitat class. (The arrows represent direction of travel.) (Hancock 1854, Terrell 1861a, Tolman 1873; courtesy of the Bureau of Land Management)

is now Highway 101 just east of El Rio (Terrell 1861b, Thompson 1867). In the same area, a "grove" (species unspecified) and a few individual sycamore trees were recorded (Stow 1878 in tree layer, Power 1891). In general, however, few trees were found on the plain: the GLO survey notes only record one bearing tree on the plain, a live oak in the scattered timber mentioned above (Hancock 1854). (The only other bearing trees noted on the plain were one sycamore in the bed of Conejo Creek, and two sycamores on the edge of the valley just north of the Conejo Grade.)

On the eastern side of the Oxnard Plain near Camarillo, one sycamore in particular was recognized as an important feature: the Palo Alto (fig. 5.9). The Palo Alto, or tall tree, was the name of a lone sycamore near Camarillo.

According to one of John P. Harrington's informants, 19th century ranchers who had lost cattle would "climb this tree to see the cattle they were looking for," though it had been cut down by the early 20th century (Harrington 1913e). The tree was so well known that it was a key descriptor of the Mission's area holdings upon their sale in the 1840s: "…the Laguna Hueneme [the lagoon southeast of Hueneme], Palo Alto, the cultivated fields of Santa Paula, [and] the Mission Cañon [Ventura River valley]" (Weber 1978).

The late date, spatial resolution, and sparseness of the historical record preclude drawing conclusions about the nature of vegetation on the plain prior to the establishment of the Mission. The lack of early documentation is compounded by early impacts to the original vegetation of the plain from grazing, suppression of Chumash burning, and the arrival of non-native species such as wild oats and mustard (see page 18). As a result, the data presented here for the most part characterize the Oxnard Plain after substantial modifications; it is not clear which portions of this characterization are relevant to pre-Mission conditions.

Fig. 5.9. Lone sycamore tree on the Oxnard Plain near Camarillo, ca. 1840. This was one of the few large trees on the eastern Oxnard Plain. It was used as a lookout in the 19th century by ranchers looking for their lost cattle. By the early 20th century, it had been cut down. (U.S. District Court ca. 1840e, courtesy of The Bancroft Library, UC Berkeley)

Alkali Meadows and Alkali Flats

With the exception of the far eastern plain and slightly higher ground created by old paths of the Santa Clara River, the majority of the Oxnard Plain consisted of salt-affected, seasonally wet or flooded lowlands that could be considered alkali meadows, flats, or alkaline grasslands (fig. 5.10).

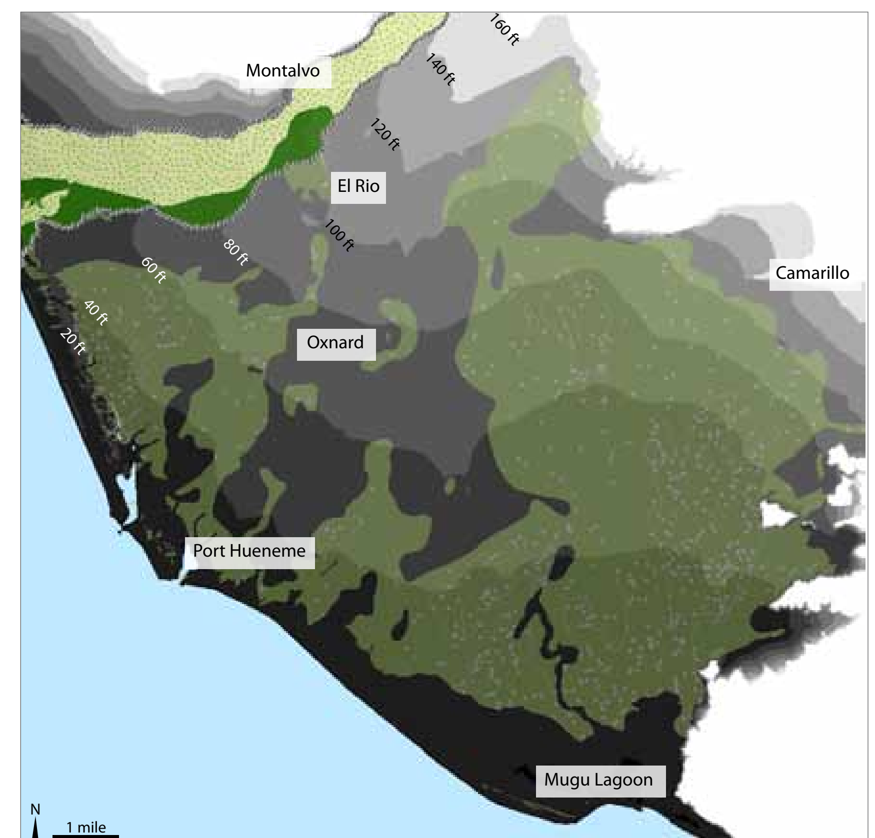


Fig. 5.10. This contour map shows the topography of the Oxnard Plain, with an overlay of mapped historical extent of alkali meadow and alkali meadow/flat. While the entire plain is extremely flat, these contours show lower elevations extending futher inland west of the Camarillo Hills, matching the furthest inland extent of alkali meadow, and reflecting the spatial extent of the Santa Clara River's alluvial fan.

Descending the ridge, we saw the surveyors of the new railroad working near the base of sandstone cliffs. Turning down a dusty road we passed a salt grass flat, on whose upper border there huddled a singular collection of buildings… This gentleman liked the looks of these bright stretches of salt grass…

— NINETTA EAMES, FALL 1890, EASTERN OXNARD PLAIN

We identified 30,240 acres of the Oxnard Plain with significantly salt-affected soils, approximately 43% of the entire area of the plain. These areas were found almost exclusively on the Oxnard Plain, with a small area also present at Saticoy.

Unlike other seasonally flooded alkaline areas in California (e.g., Soap Lake in the San Francisco Bay Area's Santa Clara Valley; Grossinger et al. 2008), the vast alkali meadows of the Oxnard Plain were not produced by clay surface soils with limited drainage. Rather, a high water table coupled with subsurface salts, limited subdrainage, and few surface drainages in the central Oxnard Plain created seasonally wet, alkaline conditions. As a result, salts were able to be flushed with successful drainage and irrigation.

Alkali conditions were comprehensively documented by the 1901 and 1917 soils surveys (Holmes and Mesmer 1901a,c; Nelson et al. 1917), which distinguished these areas because of their limited agricultural use. Indicators used by the soil surveys include salt-tolerant plants, surface salt deposits, and areas bare of vegetation—all of which are also indicative of alkali meadow character. These maps were instrumental in our reconstruction of alkali meadow and flat distribution on the plain.

The presence of certain crops (e.g., alfalfa, sugar beets, and asparagus) and poor crop growth were also clues to the presence of alkali, since few crops were able to withstand even relatively low amounts of soil alkalinity. The development of Oxnard as a national center for beet processing affirms the strong alkali influence on the local landscape since beets, while less valuable than other contemporary crops, were one of the few products that be could be successfully grown in alkaline areas (Gregor 1953). Before the sugar factory was established by Pacific Beet Sugar Company in Oxnard in 1898, the main crops grown on the plain were beans (especially lima beans, grown since 1875) and barley (since the 1860s; Gregor 1953). However, the salt-affected soils were often not well adapted to growing barley, often producing "indifferent crops of barley… quite often the barley hay contained such a great amount of salt that stock would not eat it" (Holmes and Mesmer 1901c).

While sugar beets created a profitable industry on much of the previously unfarmable plain, even sugar beets were not salt-adapted enough to successfully grow in some areas: "a great deal of this land is too alkaline even to raise beets, and it will have to be reclaimed before it can produce any useful crop" (Holmes and Mesmer 1901c). These were the most strongly alkaline areas (over 1% alkali), where "alkali weeds and salt grass alone are able to subsist, but do not afford much pasturage" (fig. 5.11; see page 180).

Early descriptions of the Oxnard Plain reinforce this interpretation of the plain as a largely treeless, alkaline lowland. In 1769, Crespí described it as a "large plain of very low, very grass-grown land" and "almost entirely level and very grass-grown soil" (Crespí and Brown 2001). Upon entering the plain near Saticoy, he noted that "no trees are to be seen nearby" except

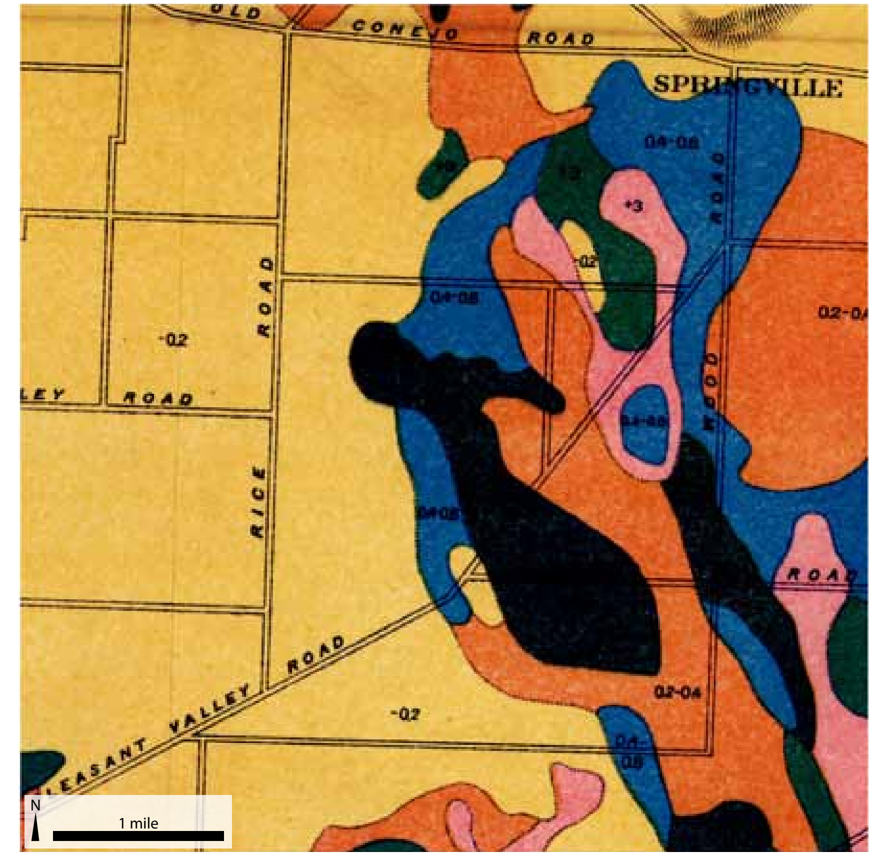


Fig. 5.11. Alkali concentrations on the Oxnard Plain, 1901. Various concentrations of alkali in the first 6 feet of the soil column were measured in the soil near the historical head of Revolon Slough (east of Oxnard and southwest of the Camarillo Hills). Concentrations of less than 0.2% were not considered to be affected by alkali, while concentrations of 0.2%-1% were mapped as alkali meadow. The most strongly alkaline areas, with concentrations over 1%, were described in the soils report as unfarmable areas where "alkali weeds and salt grass alone are able to subsist," and were mapped as alkali meadow/flat. (Holmes and Mesmer 1901a, courtesy of The Bancroft Library, UC Berkeley)

riparian vegetation along the Santa Clara River near the shore. Brewer ([1930]1974) described the plain in early spring 1861 as "a fine grassy plain, with here and there a gentle green knoll, with a few dry creeks or alkaline ponds." Notably, no bearing trees were recorded by surveyors in areas mapped as alkaline.

In a few areas, early General Land Office surveyors explicitly note salts present in such high concentrations that it was attributed to tide overflow, though the area was 3.5 miles from the upper extent of tidal influence at Point Mugu (Washington 1853). Some of these areas may represent places flooded by perched conditions along the shoreline (see page 232). In other areas, however, surveyors crossing the alkali meadow do not directly comment on the alkalinity, suggesting that many of these areas were likely well vegetated, possibly with a mix of alkaline and non-alkaline species. It is possible that portions of what we have designated alkali meadow, while chemically alkaline in subsurface soils, did not maintain an ecological expression in the form of saltgrass and other salt-tolerant species.

Alkali meadows are recognized today as a relatively rare native grassland type (Holstein 2000, CNDDB 2010). The characteristic vegetation was salt grass (*Distichlis spicata*; Holmes and Mesmer 1901c), though other salt-tolerant species such as alkalki goldfields (*Lasthenia ferrisiae*), salt marsh birds beak (*Cordylanthus maritimus* ssp. *maritimus*), spreading alkali weed (*Cressa truxillensis*), shaggyfruit pepperweed (*Lepidium lasiocarpum*), and

DISTINGUISHING ALKALI MEADOWS FROM ALKALI FLATS

In California, early soil surveyors generally attempted to distinguish and map different degrees of alkaline impact to local soils. While their intent was to determine the potential agricultural productivity of the land, their mapping also provides valuable ecological information. Surveys consistently recognize alkali effects on crop selection and productivity at >0.2% total salinity (in the top six feet of soil; e.g., Holmes and Mesmer 1901a,c; Carpenter and Cosby 1939), mapping these areas as alkali affected. On the least strongly-affected alkaline land (0.2-0.6%), beets, barley, and often alfalfa were grown. On more salt-affected land (0.6-1%), "salt grass and plants native to the alkali plains thrive and afford pasturage" (Holmes and Mesmer 1901c). We translate these areas, which typically display a significant proportion of salt-tolerant vegetation and some bare spots, as alkali meadow.

In addition, the early surveys consistently attempt to distinguish areas with more severe alkalinity levels that effectively preclude agricultural use other than sparse pasture. The associated alkalinity level for these extreme effects varies substantially among regions due to other soil conditions, for example from >0.4% in the Modesto-Turlock area (Sweet et al. 1908) to >1% on the Oxnard Plain (Holmes and Mesmer 1901a,c; Nelson et al. 1917). These higher alkalinity levels, which affect agricultural vegetation, also appear to have ecological significance. Holmes and Mesmer (1901c) describe that on the Oxnard Plain in areas with 1-3% alkali "alkali weeds and salt grass alone are able to subsist, but do not afford much pasturage," indicating sparse alkali vegetation with substantial bare ground (fig. 5.12). We translate these areas of extreme alkalinity, described as having a greater proportion of bare areas or alkali flats, as alkali meadow/flat. We use this habitat type to note the probable presence of significant seasonally wet hyperhaline flats, as well as other potential ecological differences from the surrounding alkali meadows.

Fig. 5.12. "Alkali flat in the Delta portion of the Ventura area," ca. 1901. This turn of the century photograph of the Oxnard Plain shows what the soil survey terms "alkali flat," a region with >1% alkalinity. Some alkali vegetation is shown among substantial bare, cracked ground. (Holmes and Mesmer 1901c)

hairy gumweed (*Grindelia hirsutula*) may have also been present. A GLO surveyor noted "salt weed and salt grass" (Hancock 1854) in an alkali area near Revolon Slough, referring to *Distichlis* and possibly *Cressa truxillensis*. Early botanical specimens found near Oxnard are salt-tolerant species: Davy (1901) recorded saltmarsh bird's beak (*Cordylanthus maritimus subsp. maritimus*) and Condit (1908) reported spreading alkaliweed (*Cressa truxillensis*) on alkaline soils near Oxnard.

Much of the alkaline-affected area falls within the extent of artesian conditions, as mapped by Schuyler (1900) and Lippincott (ca. 1930), suggesting a high degree of soil moisture. The widespread presence of saltgrass—a strong indicator of near-surface groundwater (Le Bihan 1944)—also reinforces the seasonally wet character of these areas. This is supported in at least one location by GLO surveyors, who described the alkali meadow northwest of Round Mountain as "overflowed ground" in January 1861 and September 1867; it is not clear whether they meant that the land was flooded at the time of survey, or that the land was seasonally flooded (Terrell 1861a, Thompson 1867).

This alkaline land is poorly drained, water being in most places not more than 10 feet below the surface and at certain seasons of the year much nearer.

— HOLMES AND MESMER 1901C

We would expect these alkali flat areas to have an extremely high proportion of salt-tolerant vegetation, but with potentially reduced diversity. For example, Mann et al. (1911) note in the Woodland region of northern California that gumplant (*Grindelia camporum*) and tarweed (*Centromadia pungens*) are limited to the more moderate alkalinity levels. At the tidal marsh margin, these areas can probably be considered equivalent to the "high marsh transition zone" (e.g., Ferren et al. 2007) with a component of euryhaline flats.

Perennial Wetlands

Wetlands occurred in three major places on the Oxnard Plain: tidal wetlands along the coast, freshwater wetlands in side valleys along the eastern side of the valley between Calleguas Creek and the hills, and in patches around Oxnard south of the Santa Clara River. In this section, we discuss the freshwater wetlands of the plain (see page 205 for treatment of coastal wetlands).

In total, we mapped 440 acres of freshwater wetlands and ponds on the Oxnard Plain. Since many features mapped as freshwater wetlands were at the alkali margins, some likely also had brackish components as part of the transition between alkali meadow and non-alkaline areas.

OXNARD AREA WETLANDS Within the alkali meadow, a mosaic of freshwater and brackish ponds, sloughs, and marshes existed in old stream and slough courses and other very low or poorly drained areas. Early travelers on the Oxnard Plain noted alkaline surface water, as did later residents: the Geological Survey of California (1865) remarked that "all the water seen on the plain was alkaline, except that of the Santa Clara River" while Thompson and West ([1883]1961) wrote that "[t]he surface water on the Colonia Rancho [which includes most of the Oxnard Plain] is generally unfit for household use." While these are undoubtedly overgeneralizations, they do reflect the general alkaline character of the plain. Brewer (1930) also observed alkaline ponds in the spring of 1861.

However, not all surface water on the Oxnard Plain was brackish. Some freshwater areas existed within the alkaline matrix, often fed by springs or created by pools of rainwater that collected in low areas. Haydock (1971) recalled that waterfowl (geese and ducks) would overwinter in freshwater areas in swales:

> The swales scattered over the valley where winter rains collected the fresh water had great attraction for them, especially for the ducks. One of these pools was in the southwest part of the Hill Ranch and covered several acres. A swale on the west side of the boulevard started about three quarters of a mile north of town [Oxnard] and ran through what is now the heart of town down to this pool. In front of the Harvey home just north of town was a smaller pool. Tules were usually to be found in these pools. Ducks frequented these pools at night, and many remained through the day if undisturbed.

The first pool mentioned above by Haydock (located on the southwest part of the Hill Ranch) was also mentioned by Bloom (1959) as a "four or five acre lake…that some years lasted all summer" and that attracted flocks of hundreds of geese. The lake is still visible in oblique aerial photography from circa 1950 as a mottled, darker area (fig. 5.13).

Also of note was Ponom or Ponomo, a pond and marsh north of Oxnard (the second, smaller pool mentioned by Haydock). The pond was noted as early as the 1840s (fig. 5.14), and was described as a "pond of fresh water" (Bard 1869) and a "tule pond" (Bloom 1959). Ponom was also a significant Chumash site, noted by Harrington's informants as a place with "a ciénega, tular and some sauces" (marsh, tules, and willows; Harrington 1913b). The name "ponom" was reported to mean "hay que cuidar" (one must be careful), because "they had fear that sometime the river of Santa Clara could change its course back to Point Mugu" (Harrington 1986a).

Undoubtedly, there were additional, less well documented wetlands historically present on the plain. In particular, one early map shows a large "sienega [sic]" south of the Santa Clara River on the plain, but without enough precision to map (U.S. District Court ca. 1840e; see fig. 5.14). Another large area that may have been a large wetland or wet meadow was shown on a later map south of the river with a somewhat characteristic wetland symbol, but more information is needed to resolve nature of this feature (Power 1891).

CALLEGUAS WETLANDS In contrast to the rest of the Oxnard Plain, the region immediately surrounding Calleguas and Conejo creeks had a more developed drainage network and contained many more freshwater wetland features. Along the eastern edge of the Oxnard Plain, a high groundwater table coupled with extremely low, flat terrain and a contact between alluvium and Conejo Volcanics extrusions gave rise to a series

Fig. 5.13. Though it appears to be dry at the time of the photo, this dark, oblong, kidney-shaped outline—now in the middle of the city of Oxnard, northeast of the intersection of South Ventura and West Wooley roads—marks the location of the former pool on Hill Ranch. It is still discernible on this ca. 1950 oblique aerial photograph. (Spence Air Photos ca. 1950, courtesy of the Benjamin and Gladys Thomas Air Photo Archives, Spence and Fairchild Collections, UCLA Department of Geography)

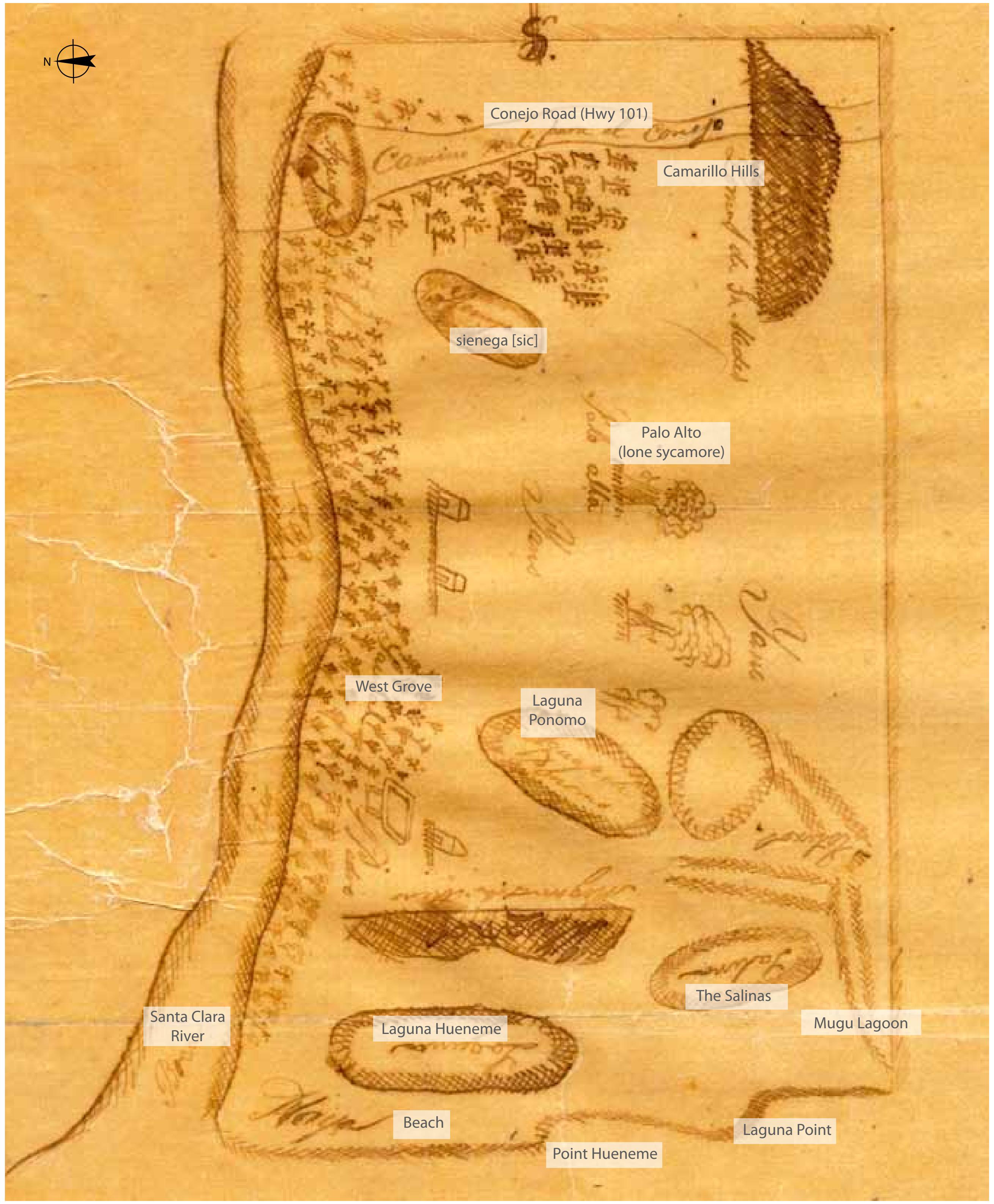


Fig. 5.14. Landmarks of the Oxnard Plain, ca. 1840. This remarkable *diseño* compresses what the cartographer perceived to be the most important features of the deltaic Oxnard Plain into one compact, rectangular drawing. While the distances are inaccurate, the relative position of features drawn on the plain is broadly correct. We were ultimately able to map some of these features, though others—such as the *ciénega* (wetland) south of Highway 101—remain mysterious. Laguna Ponomo is here shown just east of Laguna Hueneme, though later depositions record that the pond is "about five miles due north of the laguna called Hueneme" (Bard 1869). (U.S. District Court ca. 1840e, courtesy of The Bancroft Library, UC Berkeley)

of groundwater-fed seeps, springs, lakes, and marshes along substantial portions of the small foothill valleys of the Calleguas watershed (see fig. 5.5). Many of these springs occurred at the contact between alluvial loams of the valley floor and the older, largely volcanic upland bedrock, and some are likely associated with regional faulting (Tan et al. 2004) and possible impoundment behind alluvial deposits from Calleguas and Conejo creeks. We estimate that this area had about 400 acres of wetlands. Many of these areas served as major cultural landmarks in an otherwise relatively dry, alkaline area, and influenced the location of Chumash and early Spanish/Mexican and American settlements in the area.

Significant areas with springs in this region included Round Mountain (also known as Sat'wiwa or Sierrita de la Laguna; Terrell 1861a, Thompson 1867, Harrington 1913a), the small hill immediately to the north of Mugu Lagoon (not named, but near a village and spring historically called Simo'mo or Big Springs; Bowers 1879 in Benson 1997; Lugo 1855), and the southwestern point of the Camarillo Hills (near the historical location of Springville). Each of these three hills served as landmarks and places of settlement throughout the historical record. The springs at Simo'mo, for example, served as the site of the Chumash village of the same name, while the springs at Round Mountain formed a freshwater lake that gave Guadalasca Rancho its alternate name (La Laguna, Thompson 1869) and was the site of the grantee's home (by "the watering place called Guadalasca"; Lugo 1855). The spring at the nose of the Camarillo Hills was called Las Posas ("the watering holes" or "pools"), and helped name both the American settlement of Springville and the Mexican Rancho, Las Posas:

> It [Las Posas Rancho] has only one spring stream of water that of Las Posas which although very abundant is so deep that some labor is necessary to get its water out. Consequently it cannot be hoped that it will serve for irrigation and is only useful as a watering place for cattle. (Carrillo 1833)

Early inhabitants of the Calleguas Creek area used these springs and lakes as water sources for domestic water, crop irrigation, and cattle. The lake at Round Mountain was described as a primary source of water on Guadalasca Rancho by the grantee (Yorba 1837), and wet foothill valleys on Las Posas Rancho were also used as watering places for cattle (Tico 1834).

A considerable portion of this rancho [Calleguas] has living springs upon it…

— THOMPSON AND WEST [1883]1961

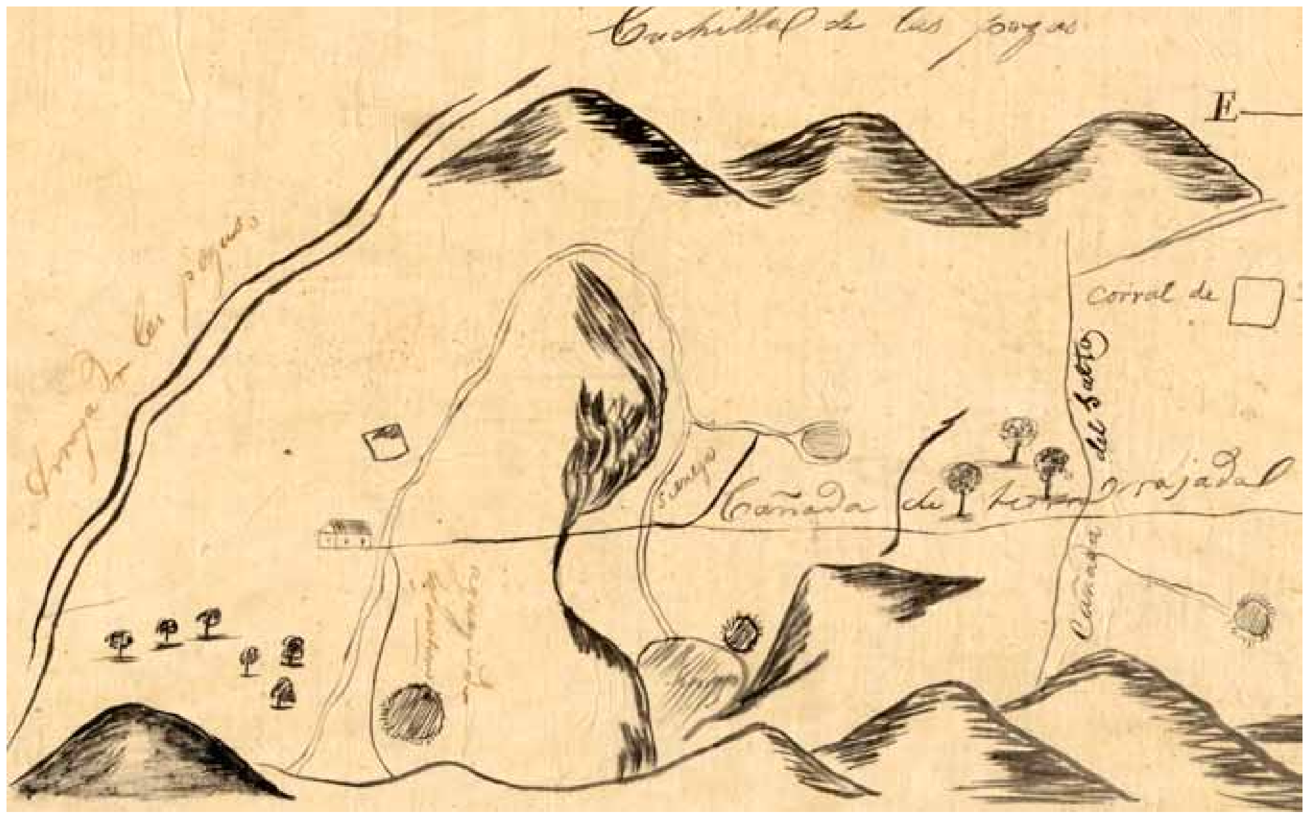
Ponds and wetlands were found in nearly every pocket valley between Mugu Lagoon and Pleasant Valley. Many occurred at the mouths of distributaries, along Conejo Creek, or coincident with springs. On Las Posas Rancho, some of these low valleys were "dependant [sic] on the seasons," presumably referring to variable utility due to seasonal flooding and the summer dry season (Tico 1834).

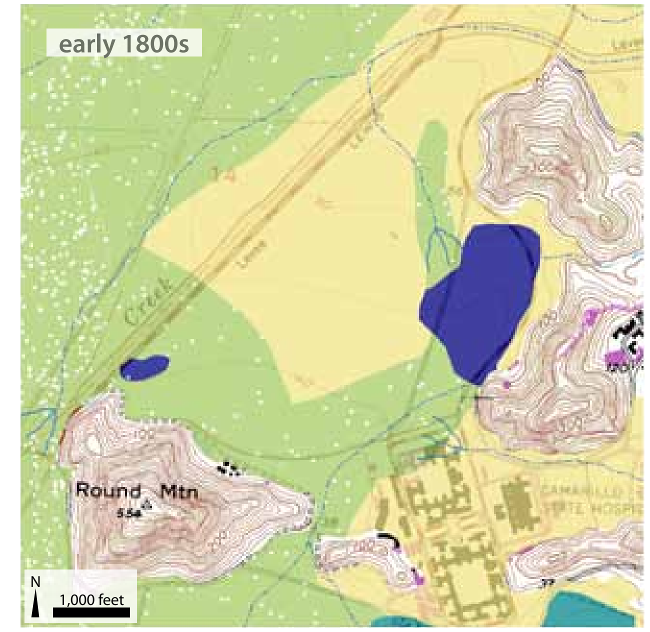
This pattern is confirmed by an early *diseño* of Calleguas Rancho (roughly the Pleasant Valley area; U.S. District Court ca. 1840a; fig. 5.15). The map shows a series of wetlands (*sienegas* [sic]) and springs up against the hills east of Calleguas Creek (Arroyo de las Posas). While the *diseño*

Fig. 5.15. While this ca. 1840s *diseño* is very schematic, it provides a generalized picture of the landscape of springs and wetlands present between Calleguas Creek ("Arroyo de las Pozas") and the Santa Monica Mountains. It depicts springs (shown as dark circles with small radiating lines) flowing into small creeks and wetlands (labeled "sienega" [sic]). One wetland shown is up against the base of the hills, while the other is just upstream of the confluence of two creeks. (U.S. District Court ca. 1840a, courtesy of The Bancroft Library, UC Berkeley)

is roughly drawn, it does depict the same pattern shown on our habitat map, suggesting that these wetlands and springs were persistent, historical features.

One notable feature was the freshwater lake at the terminus of Calleguas Creek (fig. 5.16). South of the lake, Calleguas Creek ceased to have a defined channel, instead connecting to Mugu Lagoon through a series of swales and wetlands. Guadalasca Rancho, on which the lake was located, was alternatively known as the Laguna Rancho: "The old Californians familiarly call the 'Guadalasca' the 'Laguna' (Thompson 1873, in Thompson 1869). In addition to flow from Calleguas Creek, two springs in the area—one called Guadalasca—formed the lake (Lugo 1855). The lake was described as the "only considerable watering place" on the





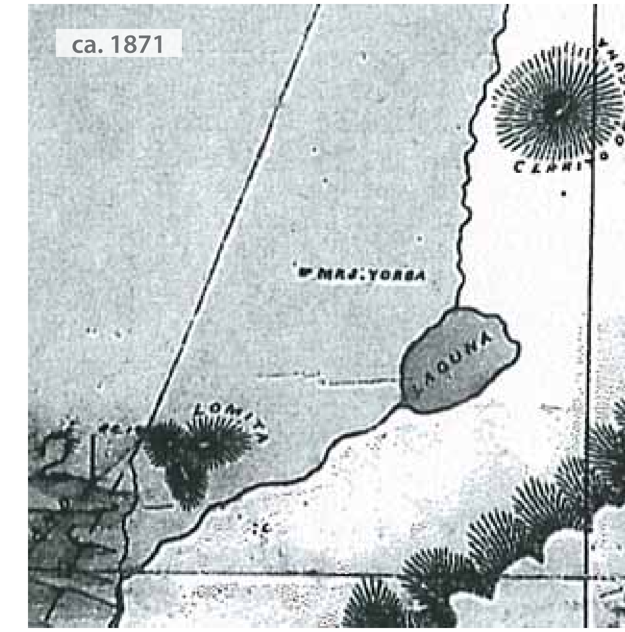
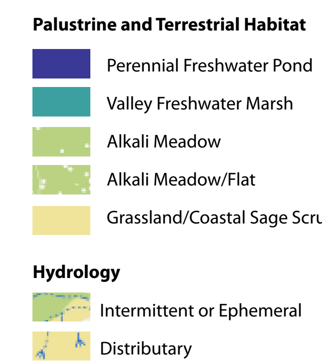


Fig. 5.16. The Laguna. Historically one of the most prominent features on the Oxnard Plain, this lake was the namesake for the Guadalasca or Laguna Rancho. It was located at the terminus of Calleguas Creek; below the laguna series of shallow sloughs and overflow connected the creek to Mugu Lagoon. Historical mapping of the lagoon is shown at left; an early map of the lake is at right. (Reed ca. 1871, courtesy of The Bancroft Library, UC Berkeley)



Guadalasca Rancho (Yorba 1837). During the wet season, overflow from the lake ran toward Mugu Lagoon both to the west and to the east of Round Mountain.

Likely as a legacy of this ecological history, some of these former wetland valleys, which were presumably relatively unattractive for development, are now parks and other public uses. Portions of the Camarillo Springs Golf Course and the area upslope of the Camrosa Water District storage ponds, for example, are located on areas mapped as former wetlands. Previous studies have recognized some wetland restoration potential in these areas (David Magney Environmental Consulting 2000), which constitute the greatest concentration of documented freshwater wetlands in the study area.

SUMMARY OF FINDINGS

The following findings represent some of the significant conclusions drawn from our research and analysis. Combined with an understanding of modern conditions, these findings can support scientists and managers working to identify restoration opportunities on the Oxnard Plain and in the lower Calleguas Creek watershed.

1. **The Oxnard Plain supported a diverse array of habitats,** from the freshwater wetlands and lakes of the lower Calleguas watershed to the alkali meadows and flats, grassland, coastal sage scrub, and chaparral of the broader plain. Just under half of the plain supported alkali meadows and alkali flats, with the remainder mostly covered by grassland and coastal sage scrub.

2. **The distribution of these habitats reflected underlying physical processes and characteristics.** Topography, soils, geology, and groundwater availability were primary factors in determining historical habitat distribution.

3. **Few trees were found on the Oxnard Plain.** Only a small number of trees were documented on the plain by 19th century observers, mostly sycamores (and one live oak) on the sand and sandy loam soils marking the former route of the Santa Clara River to Point Hueneme.

4. **Few streams traversed the Oxnard Plain, particularly in its western portion.** The plain was notable for its extremely low drainage density (only 1.7 miles of creek per square mile). The few creeks and barrancas that did cross the plain were almost exclusively discontinuous, sinking into coarse alluvium or spreading into and across seasonally wet alkaline areas. Large sloughs such as Revolon Slough (a former channel of the Santa Clara River) formed the backbone of drainage for the central plain.

5. **Calleguas Creek did not maintain a defined channel across the Oxnard Plain,** instead spreading into a broad wash around present-day Highway 101 before re-emerging downslope near Conejo Creek. The creek terminated in a lake and distributary system near the current location of CSU Channel Islands. Calleguas Creek was hydrologically connected to Mugu Lagoon through shallow sloughs and sheet flow during floods.

6. **Calleguas and Conejo creeks were intermittent on the Oxnard Plain.** Though sources describe readily available water located below the surface in both creek beds, they are consistently described as dry for much of the year.

7. **Sources document a concentration of perennial freshwater wetlands, ponds, and lakes along the eastern margin of the Oxnard Plain,** particularly east of Conejo and Calleguas creeks. The majority of these wetlands occurred near the base of small alluvial valleys of creeks tributary to Calleguas and Conejo creeks, near contacts between alluvial deposits and the Conejo Volcanics of the western Santa Monica Mountains.

Management Considerations

- **Former wetland locations in the Calleguas Creek watershed offer a number of potentially viable sites that should be considered for restoration.** Many of these sites, still located on agricultural land, may be appropriate locations for future wetland restoration projects.

- **Some of these former wetland locations have already been identified through previous research as potential floodplain restoration sites.** The large freshwater lake at the historical distributary of Calleguas Creek for which the Guadalasca/Laguna Rancho was named coincides with one of the sites identified for potential restoration in the Calleguas Creek Watershed Restoration Plan (David Magney Environmental Consulting 2000), which also includes Calleguas Creek and floodplain north of CSU Channel Islands and the Camrosa Water District facilities. In addition, Magney's conceptual wetland restoration design for Calleguas Creek at Camarillo Regional Park may have the potential to incorporate historical wetland habitat behind the Camrosa Water District storage ponds (fig. 5.17). Similar opportunities may exist at the site on Conejo Creek at Winding Brook Farm, where additional freshwater wetlands were documented. Future restoration activities at these sites could take advantage of the unique historical and hydrologic aspects of this area in designing floodplain characteristics.

- **Drainage density of the Oxnard Plain has greatly increased** with the construction of artificial drainage networks, creating more direct conduits between ocean and upland. This expansion of the drainage network has implications for contemporary distribution and residence time of water and sediment on the plain and should be considered in creek restoration projects, particularly in constructed reaches not historically present. For example, the historical form of Calleguas Creek helps explain current sedimentation issues downslope of Lewis Road.

- **Physical factors such as topography, soils, geology, and groundwater availability are still primary factors affecting contemporary habitat distribution.** An understanding of how these drivers contributed to historical habitat patterns is an essential component of the success of restoration projects.

Fig. 5.17. Camrosa Water District storage ponds, 2008. The area behind these storage ponds, formerly the site of a freshwater marsh complex, may be a potential location for wetland habitat restoration.

6 • VENTURA COUNTY SHORELINE

Where the plain meets the eastern mountain
is the Laguna Mugu, with extensive marshes and a low,
narrow sand beach, with a slight tidal opening
as if the [Santa Clara] river may at one time have
emptied here.

—DAVIDSON 1897

Introduction

Nineteenth century Ventura County exhibited a complex and heterogeneous shoreline, with a variety of habitats and morphologies associated with different estuarine and wetland systems and different formative processes (fig. 6.2). At the Ventura River mouth, willow-cottonwood forest transitioned into a small, intermittently closed lagoon, while a culturally significant beach-dammed freshwater wetland complex occupied a former river mouth to the east. A distinctive seasonal wetland area—the Pierpont lowlands—extended in a broad arc from Ventura to the Santa Clara River mouth, nearly connecting the eastern edge of the Ventura River corridor to the northwestern edge of the Santa Clara River (they were separated by less than one mile). Here sand dunes trapped Santa Clara River floodwaters and valley seepage in a recently prograded portion of the shoreline, creating a large area of seasonally inundated meadow. At the Santa Clara River mouth, willow swamps bordered a small seasonal estuary similar in form and function to the Ventura River delta (and including a freshwater wetland complex, McGrath Lake). To the south, a series of at least nine elongate lagoons—some brackish, some saline—incised the Oxnard Plain shoreline, marking former mouths of the meandering Santa Clara River. Usually blocked from the tides by substantial beaches and dunes, the water source for these lagoons was a varying mix of saline (through dune overwash and seepage) and fresh water (from precipitation, runoff, and springs). As a result, the lagoon complexes supported a gradient of heterogeneous habitats ranging from freshwater to brackish to saline, including vegetated marsh, salt flat, and open water. At the southern edge of the Oxnard Plain, Mugu Lagoon represented by far the largest coastal wetland system in the county, with extensive subtidal, tidal flat, tidal marsh, and salt flat habitat.

Recent research by Grossinger et al. (2011) puts these patterns within a Southern California regional context. The study examined these wetlands in the context of broader Southern California coastal wetlands, drawing conclusions about broad categories of estuarine systems in the region (see Grossinger et al. 2011 for more information). Ventura County historically represented at least three distinct estuarine habitat mosaics or archetypes: the compressed estuaries merging into broad riparian forest associated

Fig. 6.1. Mugu Lagoon from the east, 1923. This oblique aerial image of Mugu Lagoon shows habitats of the eastern arm of Mugu, including tidal flat, salt marsh, and the lagoon itself. The patterns shown bear a striking resemblance to those shown on the T-sheet, surveyed over 50 years earlier. (Harrington 1923a, courtesy of the Smithsonian Institution)

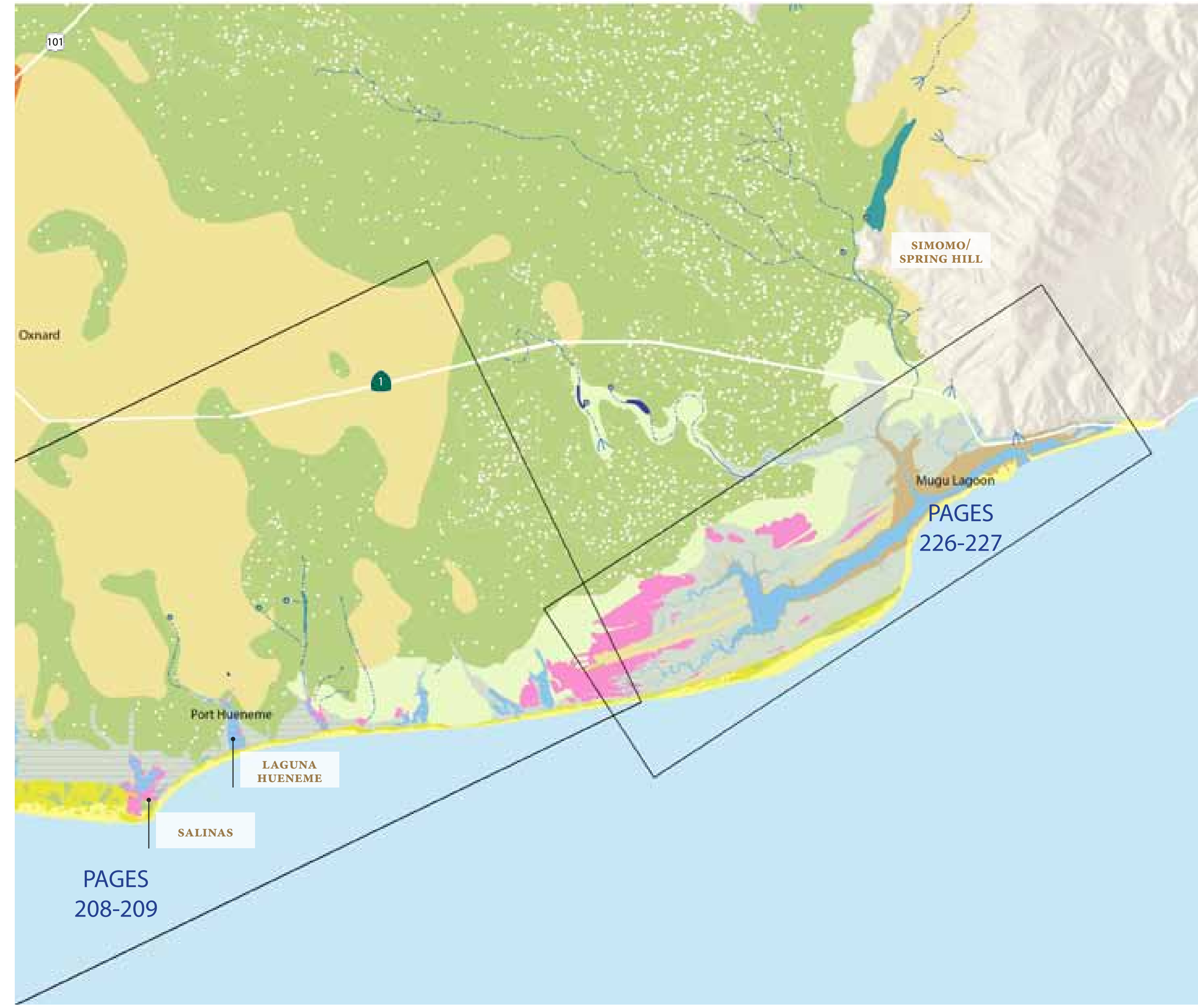


Fig. 6.2. Habitats of the Ventura County shoreline, early 1800s. At least three general types of coastal systems, or coastal archetypes, can be identified along the Ventura shoreline: freshwater-brackish estuaries associated with the Santa Clara and Ventura river mouths, dune-dammed non-tidal lagoon systems (with associated salt/brackish marsh and salt flats) marking former Santa Clara River mouths, and the large coastal wetland system at Point Mugu.

Coastal and Estuarine Habitats

- Ocean
- Beach
- Dune
- Tidal Lagoon (mostly open?)
- Tidal Lagoon (seasonally open)
- Non-Tidal Lagoon
- Tidal Flat
- Tidal Marsh
- Seasonally Tidal Marsh
- Salt/Brackish Marsh
- Salt Flat/Seasonal Pond/Marsh Panne
- High Marsh Transition Zone

Palustrine and Terrestrial Habitat

- Perennial Freshwater Pond
- Valley Freshwater Marsh
- Willow Thicket
- Wet Meadow
- Alkali Meadow
- Alkali Meadow/Flat
- Oaks and Sycamores
- Grassland/Coastal Sage Scrub

Characteristic Riparian Habitat

- Willow-Cottonwood Forested Wetland
- Other In-Channel Riparian

Hydrology

- Intermittent or Ephemeral
- Perennial
- Distributary
- Outer River Bank
- Spring

with the high-energy Ventura and Santa Clara river mouths and substantial freshwater influences; the distinctive Oxnard plain backbarrier lagoons associated with now-abandoned Santa Clara River mouths; and the large tidal wetland system at Mugu. These environments, exhibiting spatial and temporal variation in vegetation type, extent and duration of open water, salinity, and tidal connection, supported distinct mosaics of native species.

The following chapter provides a historical perspective on the patterns and characteristics of Ventura's coastal features, including the Ventura River delta, the Santa Clara River mouth, the county's backbarrier lagoons, and Mugu Lagoon.

Ventura River Delta

The Ventura River and floodplain empty into the ocean west of the city of Ventura. Historically, the estuary consisted of a large willow-cottonwood riparian forest with numerous distributary channels, a tidal lagoon and tidal flat, salt marsh, high marsh transition zone, and a number of small seasonal ponds within the marsh (fig. 6.3). Similar habitat patterns largely persisted on the T-sheet resurvey (Greenwell and Forney 1870). By the 1933 resurvey, however, most of the estuarine features were no longer depicted, including the former lagoons, marsh, and willow-cottonwood forest (Kelsh 1933a). Only limited trees (labeled "camping grounds in grove," south of the 1855 extent of forest) and salt marsh are depicted on this later survey.

The old Ventura canoe builders stored their canoes in the tule marsh at the mouth of the Ventura River. They cut and piled up tule stems so the canoe could rest out of the water, and bent the tule growing on both sides over the canoe as a sunshade. The tips of the tule stalks interlaced like the fingers of clasped hands, and a pole was laid on top to hold them in that position.

—TIMBROOK 2007

Apart from the T-sheets, there are limited data available describing the historical character of the Ventura River estuary. Ethnographer John P. Harrington's informants recalled tule marsh at the mouth of the river, where tule was collected and canoes were stored (Calendaria Valenzuela, in Hudson and Blackburn 1984; Timbrook 2007). These canoes were used on the lagoon at the Ventura River mouth (Simplicio Pico, in Hudson and Blackburn 1984). Wire rush (*Juncus balticus*) and Indian rush (*J. textilis*) were found in the sand dunes at the river mouth as well as "in the *montes*" and "at Sauzal," both designations that probably refer to the willow-cottonwood forest at the mouth (Blackburn 1963, Timbrook 2007).

Herbarium specimen records also describe the presence of this suite of marsh, flat, lagoon, and dune habitat at the Ventura River mouth, although most records are relatively late. The earliest collection, made by William Brewer in March 1861, describes the estuary and marsh as the "swamp by camp" (he collected distant phacelia [*Phacelia distans*]; Brewer [1930]1974).

Specimens collected in the dune community included marsh jaumea (*Jaumea carnosa*), beach saltbush (*Atriplex leucophylla*), California saltbush (*Atriplex californica*), branching phacelia (*Phacelia ramossissima*), Menzies' goldenbush (*Isocoma menziesii*), sawtooth goldenbush (*Hazardia squarrosa*), silver bur ragweed (*Ambrosia chamissonis*), pink sand verbena (*Abronia umbellata*), and red sand verbena (*A. maritima*) (Pollard 1945, Hagerty 1950, Pollard 1962, 1963b, 1964). A more detailed exploration of 20th century botanical specimens can be found in Ferren et al. (1990).

Fig. 6.3. Habitats of the Ventura River mouth, early 1800s. Extensive riparian willow-cottonwood forest and estuarine habitat characterized the Ventura River floodplain at its mouth.

Limited available evidence suggests that the Ventura River mouth did not close as regularly during the summer as did the Santa Clara River mouth, perhaps reflective of greater perennial flow in the lower reach in addition to lesser wave exposure. Based on the classification system of Jacobs et al. (2010), the river was a small to medium watershed in a prograding, low exposure (south facing) setting, with hydraulic estuarine formation, and would therefore be expected to be fully open or have subtidal closure more than half the time, with periodic closure up to and above high-high tide.

This analysis is supported by historical accounts. The earliest T-sheets for the two mouths, produced during the same year and the same (summer) season, show the Santa Clara River mouth separated from the ocean by a narrow barrier, while the lagoon at the Ventura River mouth maintained a narrow outlet. A GLO surveyor, surveying along the beach on July 1, 1869, noted crossing the "outlet of the mouth" of the river (Thompson 1869). The earliest evidence comes from the journal of explorer Juan Crespí in mid-August 1769 and May 1770. Crespí observed that the river "reached to the sea" in August, though at high tide there was no perceptible flow and an inlet was created (Crespí and Brown 2001). In May of the following year, however, his party was able to observe the river at low tide, and Crespí noted that "where we saw it the other time, it was not flowing but instead was ponded up and turning into an inlet; the tide was low this time, it was flowing almost as far as the very shore."

The mouth did close, though closure dynamics are uncertain and not well documented. Timing, duration, and frequency of closure would have likely varied with yearly oscillations in rainfall, as well as with anthropogenic changes in flow in the lower river over time. The only historical evidence found that directly addresses the question is a newspaper article from 1909, describing a season with abnormally high flow:

> The mouth of the Ventura river presents a sight more remarkable than for thirty years past. Indeed, not the oldest inhabitant can remember when it was just exactly as it is at present. There is a great volume of water still coming down from the mountains, and this is of a very beautiful dark green color. It has gathered in a great lagoon below the bridge, the lake presenting a frontage of almost a quarter of a mile to the ocean. Between the sea and the lagoon are piled up great masses of rock, of all sizes, tons and tons of it, and the waves run up on this at high tide, although they do not get over into the lake. The mouth of the river is at the extreme western point of the lake, a quarter of a mile further to the westward than it has ever been known to be…The stream shows small signs of closing up this summer, and very likely will not be closed. But if the lagoon remains as now, there will be plenty of duck shooting and lots of water for boating and for the boys to swim in. The lagoon in fact is deeper than it has been in years. The flood seems to have washed out the bed of the entire stream to an unparalleled depth below the old bed. (*Ventura Free Press* 1909b)

One notable feature in the Ventura River delta was a brackish lake to the west of the end of Figueroa Street. The lake marked a former outlet of the river, and covered about 2.5 acres of open water and 9 acres of marsh. This lake and former river mouth were also the site of a Chumash village, Mitsqanaqan. (See page 130 for more information on channel change at the mouth of the Ventura River.)

…there used to be a lake, but the lake is gone now. This was not an estero, nor did the water come from the river, but seeped in from sea through the sand.

—HARRINGTON 1913E

On the earliest (1855) T-sheet, the lake is shown occupying a low spot behind a narrow beach, not connected with the ocean and with substantial surrounding marsh (Johnson 1855c; fig. 6.4). It is documented similarly on the 1870 resurvey, though with a larger amount of open water adjacent to the beach. An unrelated survey from May 1868, however, shows a small lake with marsh in this vicinity with a clear connection to the ocean (Bard 1868). If this is indeed the same body of water, then the lake may have had at least an intermittent connection to the ocean.

The lake is vividly described by Chumash residents interviewed by John P. Harrington in the early 20th century. Though at the time they were interviewed the lake no longer existed, his informants recalled what it had been like decades earlier (fig. 6.5). The lake was called Tsikatskats (with variable spellings in Harrington's notes), which was translated by his informants as "sweet water running below," presumably referring to

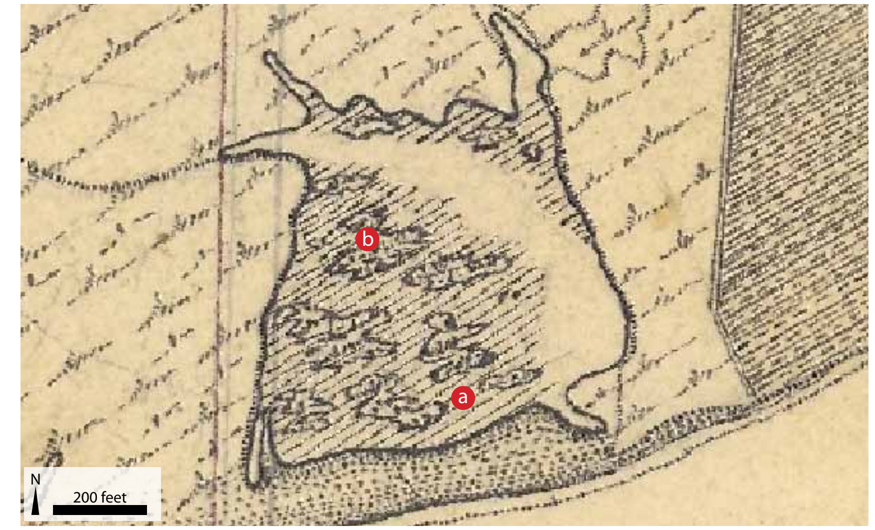


Fig. 6.4. Lake east of the Ventura River, 1855. This small brackish lake marked the easternmost extent of the historical Ventura River floodplain, and was surrounded by extensive tule marsh (shown by the closely spaced lines in the marsh on this map (a)). Though the symbol within the marsh is non-standard (b), we interpret it to be patches of grassy cover, such as saltgrass or seasonally inundated meadow. (Johnson 1855c, courtesy of the National Oceanographic and Atmospheric Administration)

Fig. 6.5. Tsikatskats, the lake at the end of Figueroa Street. This photograph, taken in the fall of 1923, shows the remnant of what was once a well known brackish lake in the Ventura River floodplain. What are likely cattails (*Typha latifolia*) are visible in the foreground, along with stands of alkali bulrush (*Scirpus* [*Bolboschoenus*] *maritimus*) and bulrush/tule (*Scirpus [Schoenoplectus] californicus*; see particularly the matted vegetation to the right of the open water). Pickleweed (*Salicornia virginica*) dominates the foreground. (Harrington 1923b, courtesy of the Smithsonian Institution; plant interpretation, Baye pers. comm.)

Fig. 6.6. Two views looking across the city of Ventura to the shoreline. A circa 1875 image (top), taken from the hill behind Mission San Buenaventura facing southwest, shows the low floodplain area east of the Ventura River. A portion of what is likely Tsikatskats lake can be seen in the distance, at a. A nearly identical view (below), taken about eight years later, shows the same area in flood. What appears to be a small seasonal pond or panne, corresponding in shape to one depicted on the T-sheet 28 years earlier, can be seen at b. (This feature is visible on fig. 6.3 as the leftmost salt flat/seasonal pond/marsh panne, shown in pink.) (Unknown ca. 1875, Pierce ca. 1883; courtesy of the California Historical Society)

groundwater from the Ventura River found beneath an otherwise brackish lake (Harrington 1986a,b). It was described as a "pool of brackish water," surrounded by abundant tule (Harrington 1986b):

> The former lake situated where the pool of water is now situated, west of the lower end of Figueroa St. was called in V. tciqatcqatc, meaning "sweet water running below". There used to be much tule there where the tule is now. The lake was where the water is now. (Harrington 1986b)

The lake, only present as a small pond/slough complex in 1913 as described by Harrington's informants, was barely visible on the 1927 aerial imagery, and left unmapped on the 1933 T-sheet resurvey. The area, historically part of the Ventura River delta, continued to flood well into the 20th century (fig. 6.6). It has remained in relatively unintensive use even today (it is now the parking lot across from Seaside Park at the Derby Club).

Santa Clara River Mouth

The mouth of the Santa Clara River encompassed a diverse array of freshwater, brackish, and saline habitats. A seasonally open tidal lagoon, bordered by tidal marsh, formed the outlet of the river. To the north and south, alkaline/saline habitats (e.g., alkali meadows and salt flats) as well as abundant freshwater habitats (wet meadows, willow-cottonwood forests, and a freshwater lake and surrounding marsh) were also present (fig. 6.7 and 6.8). Under Jacobs et al.'s (2010) definitions, the Santa Clara River mouth regularly closed above high-high tide or perched, with seasonal breaching and opening to the subtidal level. This closure pattern reflects the river mouth's exposure to wave action in addition to freshwater inputs from the watershed.

> *I would state here that there is one peculiarity in the creeks and many of the rivers and small esteros on the southern coast of California, and that is that in the dry seasons the creeks and rivers sink before they get to the ocean, and their mouths are closed or filled up with drifting sand…*
>
> — Unknown ca. 1869

The seasonality of the estuary is well documented by historical accounts. The earliest detailed depiction of the lagoon at the river mouth, surveyed during the 1855 summer field season, shows the lagoon separated from the sea by a narrow beach (Johnson 1855c). In a report associated with this survey, Johnson explains that though at the time of writing (October 1) the lagoon was not connected with the ocean, "after the rains of winter begin, it…has water enough to break through the narrow sand-beach at present separating it from the sea" (Johnson 1855a). A subsequent U.S. Coast Survey report supports this, stating that "in the rainy season a volume of water is brought down having sufficient force to break through the narrow sand beach and flow into the ocean" (*Daily Alta California* 1857; a direct quote from Davidson 1864). These descriptions are corroborated by other (albeit less precise) 19th century sources, which also describe a lagoon with "no visible communication with the sea, save when in winter the floods tear away the intervening wall of sand" (Thompson and West [1883]1961; see also Storke 1891) and a river "blocked up by sandhills in summer" (Cooper 1887).

Maps also support this variability: some cartographers showing the lagoon open to the ocean, while others show no connection. One early sketch shows a narrow "salt laguna" at the mouth of the river, with no connection to the ocean (Unknown ca. 1870). Another much later map also shows a large, disconnected lagoon (Farrell 1935). However, other maps show the lagoon with a clear tidal connection (e.g., Stow 1877, Schuyler 1900, Holmes and Mesmer 1901b, Kelsh 1933b; fig. 6.9). The earliest topographic quad and a historical soil survey contain an intermediate depiction, showing thin blue lines connecting the lagoon to the ocean (USGS 1904,

Fig. 6.7. Habitats of the Santa Clara River mouth, early 1800s. A seasonally open tidal lagoon, tidal marsh, alkali meadows, and salt flats, as well as abundant freshwater habitats (wet meadows, willow-cottonwood forests, and a freshwater lake/surrounding marsh) characterized the mouth.

Fig. 6.8. Habitats of the Santa Clara River mouth, here overlaid on a modern aerial image, illustrate the former extent of estuarine and riparian habitats. (USDA 2009)

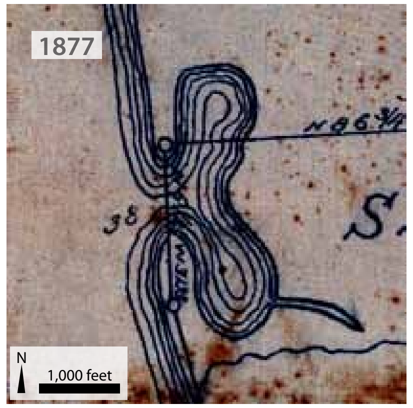


Fig. 6.9. Seasonally tidal lagoon at the mouth of the Santa Clara River, 1877. An early depiction of the lagoon open to the ocean. (Stow 1877, courtesy of the Museum of Ventura County)

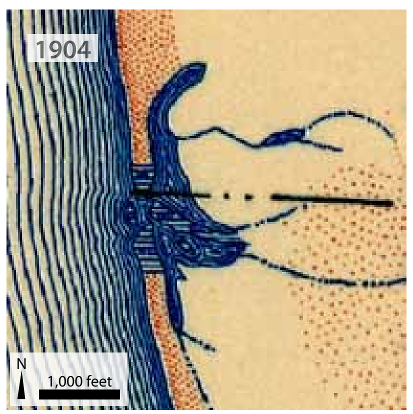


Fig. 6.10. Seasonally tidal lagoon at the mouth of the Santa Clara River, 1904. Rather than showing the lagoon as open or closed, this historical topographic quad uses thin blue lines perpendicular to the coastline to represent the connection between the lagoon and the ocean. (USGS 1904, courtesy of CSU Northridge Geography Map Library)

Nelson et al. 1917; fig. 6.10). Unfortunately, none of these maps specify the season of survey.

The T-sheet resurvey for the river mouth, conducted in January and February 1933, supplies a detailed depiction of the lagoon in winter, and provides a useful counterpoint to the summer survey of 1855. In the resurvey, the lagoon is open through a narrow breach in the sand (Kelsh 1933b). The surveying party describe the closure dynamics in the accompanying descriptive report:

> In dry weather this river mouth is practically or wholly closed. At the time of the survey (Jan-Feb 33) a steady shallow stream about 25 M. [80 feet]wide was flowing as shown, but when place was visited in October for additional notes on recent developments the mouth was closed. (Kelsh and Green 1934c)

This description is consistent with roughly contemporary descriptions of the lagoon from engineer C. E. Grunsky, who writes that "during the summer and fall, and, occasionally, throughout the entire year, the mouth of the river is blocked by a barrier of beach sand piled up by the ocean waves" (C.E. Grunsky Company 1925). He also explains some of the steps local landowners were taking to diminish the size of the lagoon:

> The mouth of the river is closed to the ocean for a considerable period of time each year by a barrier of sand which is thrown up by the ocean waves. The crest of this barrier is usually at such a height that when the river begins to flow in early winter its water accumulates behind the same to a height which the landowners in the vicinity find undesirable. An artificial cut is then made through the barrier and the ponded water escapes. If there is abundant rainfall and a fair amount of runoff the cut is kept open by the flowing water. If there is but little water to be discharged into the ocean the cut may be repeatedly closed by the ocean storms in a single season.

The limited available evidence describing tules, cattails, willows, and pondweed suggests substantial freshwater influence on the Santa Clara River estuary. The presence of perennial flow in the lowest reach of the river (see chapter 3) and persistent summer closure have the potential to create strong freshwater-brackish zones in the lagoon and surrounding wetlands (ESA PWA et al. 2011). The willow-cottonwood forest of West Grove also suggests freshwater conditions. A birder documented a "tule-bordered lagoon" near the mouth, as well as numerous sloughs with "a dense growth of pondweed [*Stuckenia pectinata/Potamogeton pectinatus*]" (Hoffmann 1921, 1926). Cooper, describing a visit to the river mouth in early spring of a dry year (1872), still noted fresh conditions, as well as the presumed inter-annual variability of habitats at the mouth:

> On May 10, 1872, I visited the mouth of the river purposely to see what birds bred there, but I found only a Mallard sitting among the cat-tails in the wettest part of the marsh, most of which seemed too dry for safety… Cattle grazed all over the marshes…The advantages for birds to breed there must vary much in different years. (Cooper 1887)

Fig. 6.11. This 1947 view of the coastline around the Santa Clara River mouth shows McGrath Lake (a) to the south of the closed river mouth (b) and the Pierpont lowlands to the north, together composing the low, broad floodplain of the river at its mouth. The city of Ventura can be seen in the background. (Spence Air Photos 1947, courtesy of the Benjamin and Gladys Thomas Air Photo Archives, UCLA Department of Geography)

In addition to West Grove, substantial freshwater habitat was present in the form of freshwater McGrath Lake and the extensive, seasonally flooded wet meadow covering the Pierpont lowlands (what today is the low-lying area around the Ventura harbor; fig. 6.11). These floodplain areas would have been inundated during extreme floods by the Santa Clara River.

McGrath Lake is one of the few remaining coastal water bodies on the Oxnard Plain shoreline, though its origins are different than the mostly closed, brackish/saline tidal lagoons historically to the south (and derived from ancient river flows). Unlike these lagoons, McGrath was a freshwater lake, with hydrologic inputs derived primarily from active surface flows from the Santa Clara River and groundwater. The lake is shown on the region's T-sheet, labeled "fresh water" (Johnson 1855b; fig. 6.12). The lake as shown here was 8 acres, with 5 acres of fringing freshwater marsh. The lake occurred in a low spot between parallel ridges of sand dunes, and was also surrounded by willow thickets and seasonally inundated grassland. Cooper

Quite a number of persons were down in McGrath's bottoms last Sunday 'a blackberrying,' but the crop seemed to be very light this year…

—Ventura Free Press 1891a

Fig. 6.12. McGrath Lake, 1855. The lake occurs at the boundary of two T-sheets, and is mapped by both. On this sheet, covering the area from McGrath Lake to Hueneme, the lake is labeled "fresh water," a rarity on the Oxnard Plain. (Johnson 1855b, courtesy of the National Oceanic and Atmospheric Administration)

Third day journeyed southwesterly ten miles, and struck the sea; thence fifteen more northerly to near the mouth of the Santa Clara, and up the lower bottom of that stream to camping ground in the enclosure of Mr. Pierpont.

—DAILY ALTA CALIFORNIA 1868

(1967) described stands of tule (*Scirpus [Schoenoplectus]* spp.) associated with the lake.

For whatever reason, the historical record is mostly silent on McGrath Lake, though it was likely the site of many summer excursions in the late 19th and early 20th centuries. One record, from a 1910 newspaper article identifying potential park locations on the Oxnard Plain, describes the lake as part of the larger habitat community at the site, noting that "another spot that is a very fine one for the people of Oxnard and community would be at the McGrath Grove, a willow grove beside a fine lake, the property of the Dominick McGrath estate and the scene of numerous picnics" (*Oxnard Courier* 1910).

Though the appellation has persisted, the precise location of the lake has shifted substantially over the past 150 years. What was historically considered to be McGrath Lake is currently predominantly willow-cottonwood forest and developed land; only the tail of the historical lake overlaps with the current lake-marsh complex (fig. 6.13). It is unclear when this shift occurred, though it had clearly happened by the time the first aerial imagery was flown (1927) and the T-sheet resurveyed (1933). Both sources show an extent of open water almost identical to what was present in 2005, with a large area of marsh north of the lake and covering the lake's former position (Fairchild Aerial Surveys 1927, Kelsh 1933b). Overall, the extent of the lake has increased from eight acres in 1857 to fifteen acres in 2005.

To the north of the mainstem Santa Clara River, the Pierpont lowlands were a broad, low coastal flat extending more than 2.5 miles northward, nearly to the Ventura River, and comprising the westernmost extent of the Santa Clara River delta (fig. 6.14). Located between sand dunes and a bluff marking a former coastline, the flat trapped water from the Santa Clara River during floods, creating a large area of seasonally inundated wet meadow. This feature of the Pierpont area is captured by the early T-sheet survey, where "overflowed during winter" is written across the entire plain. The feature is a result of progradation, as Ventura River sediments were deposited north of the convex Santa Clara River mouth (Putnam 1942).

By the turn of the 20th century, the seasonal wetland between the dunes and the bluff was under cultivation with beets and barley, though the area must have still been frequently flooded (Waud ca. 1899). By the late 1920s, the northern portion of the lowlands had been subdivided and a few houses built on the wetland and dunes, though evidently not without trouble—the T-sheet records that "small streets beyond those shown [are] buried in sand" (Fairchild Aerial Surveys 1927, Kelsh 1933b; see fig. 6.14). This area is what would become the modern subdivision at Pierpont Bay, north of the Ventura Marina. Flooding is still an issue in portions of the Pierpont area, and wetlands are still present at Alessandro Lagoon at the northeastern end of the lowlands (see fig. 6.29).

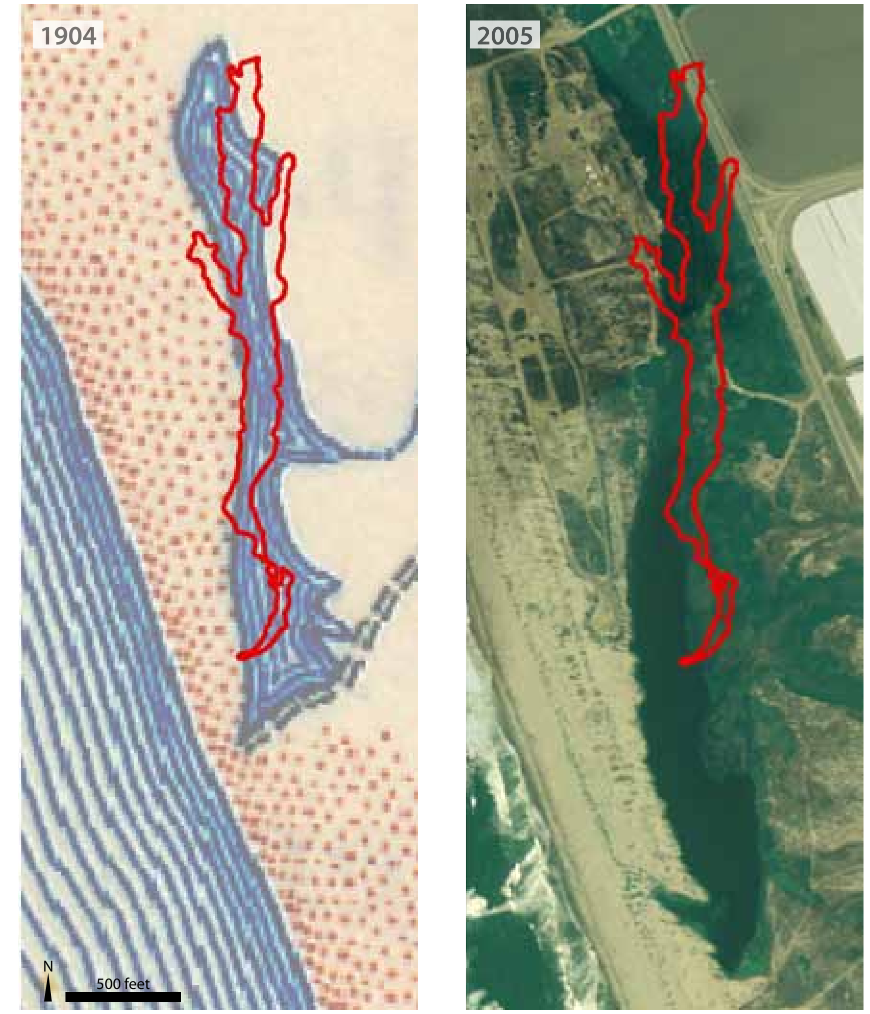


Fig. 6.13. Comparison of historical and modern location and extent of McGrath Lake. Between 1855 and 2005, McGrath Lake has shifted about 1,500 feet to the south. However, the extent of open water appears broadly comparable. The 1904 historical topographic quadrangle (at left) shows the lake covering a broad extent roughly comparable to the 1855 mapping (shown in red outline). (USGS 1904, courtesy of CSU Northridge Map Library; USDA 2005)

Oxnard Plain Shoreline

From the mouth of the Santa Clara River to Mugu Lagoon, a broad barrier beach-dune system characterized the Ventura shoreline. Like the Oxnard Plain itself, this system—and the associated series of backbarrier lagoons and wetlands extending for nine miles downcoast—were formed by the Santa Clara River, each lagoon marking a former mouth of the river and dunes indicating the Ventura and Santa Clara rivers' ample sediment supply. These non-tidal lagoon complexes covered a total of 1,000 acres with open water and associated marsh habitats (compared to Mugu Lagoon's 2,550 acres), collectively making them the second largest coastal wetland area in Ventura County (fig. 6.15). (These acreages do not include the adjacent high marsh transition zone, which accounts for an additional 1,640 acres of wetland habitat.) A combination of coastal development (including dredging and drainage), with the reduction of sediment supply from the

Fig. 6.14. Between 1855 and 2005, the seasonally inundated lowlands at Pierpont have been heavily developed. The beginnings of a street grid can faintly be seen on the historical aerial in the dunes (middle); this same street pattern has persisted to the present day (right). Today, this area includes the Ventura Harbor. Note that a subdivision shown on the northern part of the Pierpont lowlands is now part of San Buenaventura State Beach. (Johnson 1855c, courtesy of the National Oceanographic and Atmospheric Administration; Fairchild Aerial Surveys 1927, courtesy of Whittier College; USDA 2005)

Ventura and Santa Clara River watersheds, has drastically altered this portion of the shoreline (Orme 2005).

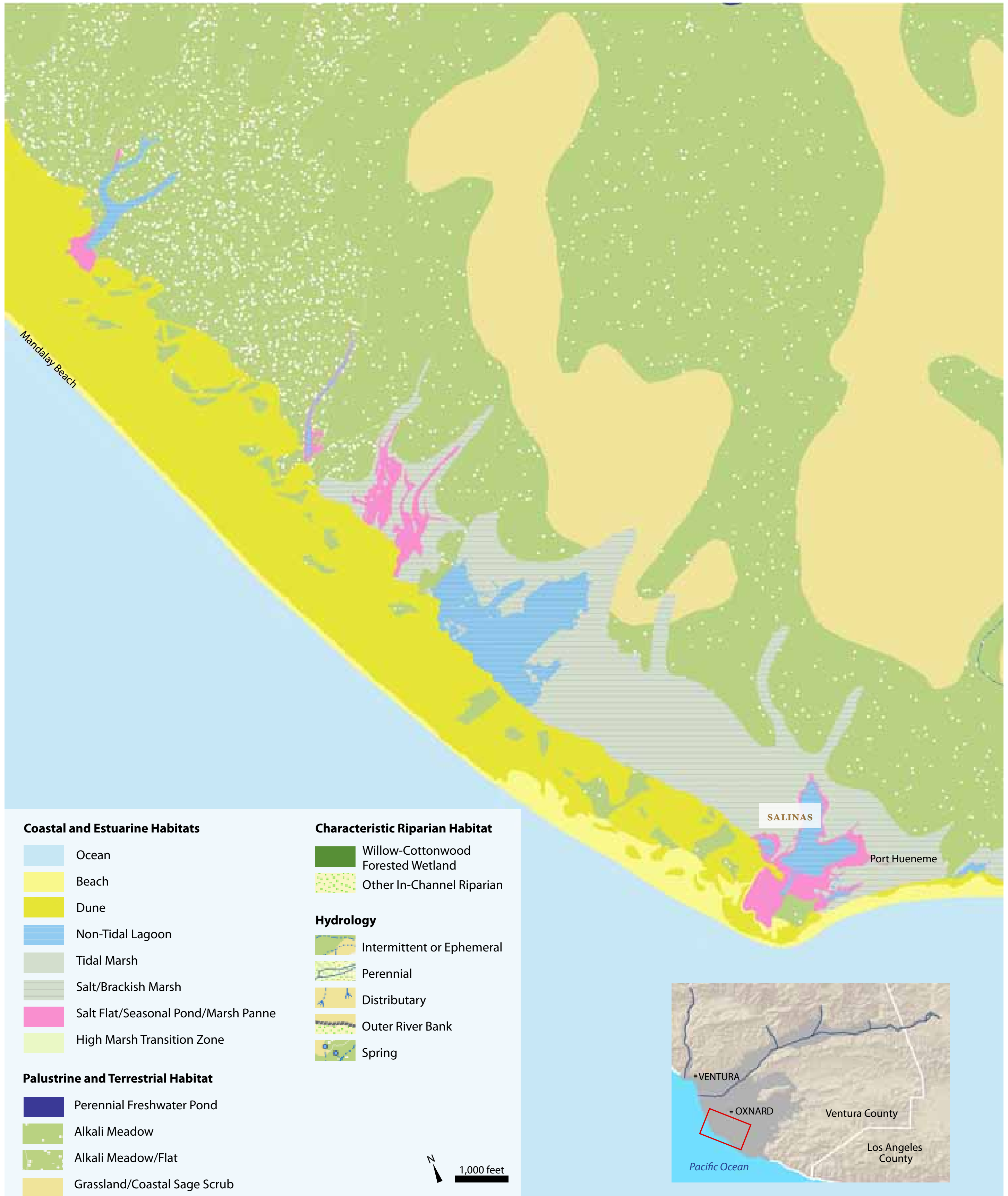
Broadly, the lagoon complexes shared multiple characteristics. Most had high marsh to open water ratios, and were dominated by extensive areas of vegetated emergent wetlands rather than open water. They also shared similar tidal dynamics, since each lagoon maintained little to no tidal access and most were blocked by substantial sand dunes. However, in other respects the systems were quite heterogeneous, with a broad array of variable ecological and hydrological expressions. In particular, the salinity concentrations and degree of seasonal inundation both varied widely across systems, in turn implying variations in lagoon depth and the quantity and source of hydrologic inputs. In addition to this inter-lagoon complexity, each lagoon complex also experienced yearly fluctuations in salinity and degree of inundation. As a result of these broad variations by year, season, and lagoon, early sources can be challenging to interpret.

Despite fragmentary historical documentation, many of these similarities and distinctions are captured by early accounts. While fine distinctions (e.g., perennially inundated lagoon versus seasonal pond) may be challenging to make with the available data, the overall characterization of the Oxnard Plain shoreline as a region with a matrix of perennial lagoons, seasonal ponds and salt flats, and salt/brackish marsh is very clear. These four factors—ecology, tidal access, seasonality, and salinity—are explored in detail below.

Deponent avers that there are numerous salt ponds along the whole length of coast from the mouth of the river Santa Clara to the south west corner of the rancho…

—Bard 1869

While they are typically thought of as lagoons, most (65%) of the aggregate area was vegetated marsh, as shown by the USCS T-sheet (Johnson 1855b, 1857). Seasonally flooded salt flats composed another significant proportion of the total area. (Our mapping shows 12% of the total area as salt flat, though this extent might have increased in dry years.) As is the case for other coastal wetland systems in Ventura County, however, little detailed documentation exists describing the historical plant community composition of these lagoon complexes. The idiosyncratic data we discovered mostly describes the Hueneme area, and emphasizes the marshy nature of these systems. Documented plants from narrative accounts include Indian rush (*Juncus textilis*) and a "salt grass point" in the Hueneme area (Eames 1889, Blackburn 1963). Early botanical specimens were collected at Hueneme from both brackish and salt marsh habitats, including obligate wetland species such as Virginia glasswort (*Salicornia virginica*), saltmarsh baccharis (*Baccharis douglasii*), salt sandspurry (*Spergularia marina*), the currently rare species saltmarsh bird's-beak (*Cordylanthus maritimus* ssp. *maritimus*), and the federally endangered Ventura marsh milkvetch (*Astragalus pycnostachyus* var. *lanosissimus*) (Kline 1924, Peirson 1925, Craig 1927, Purer 1935). A few accounts also describe the abundant waterfowl found around these lagoons, especially in the winter, such as "flocks of wild duck" (Eames 1889) and "many thousands" of geese and ducks (Haydock 1971). One account, from a journal entry describing an outing in March 1902, records more detail:



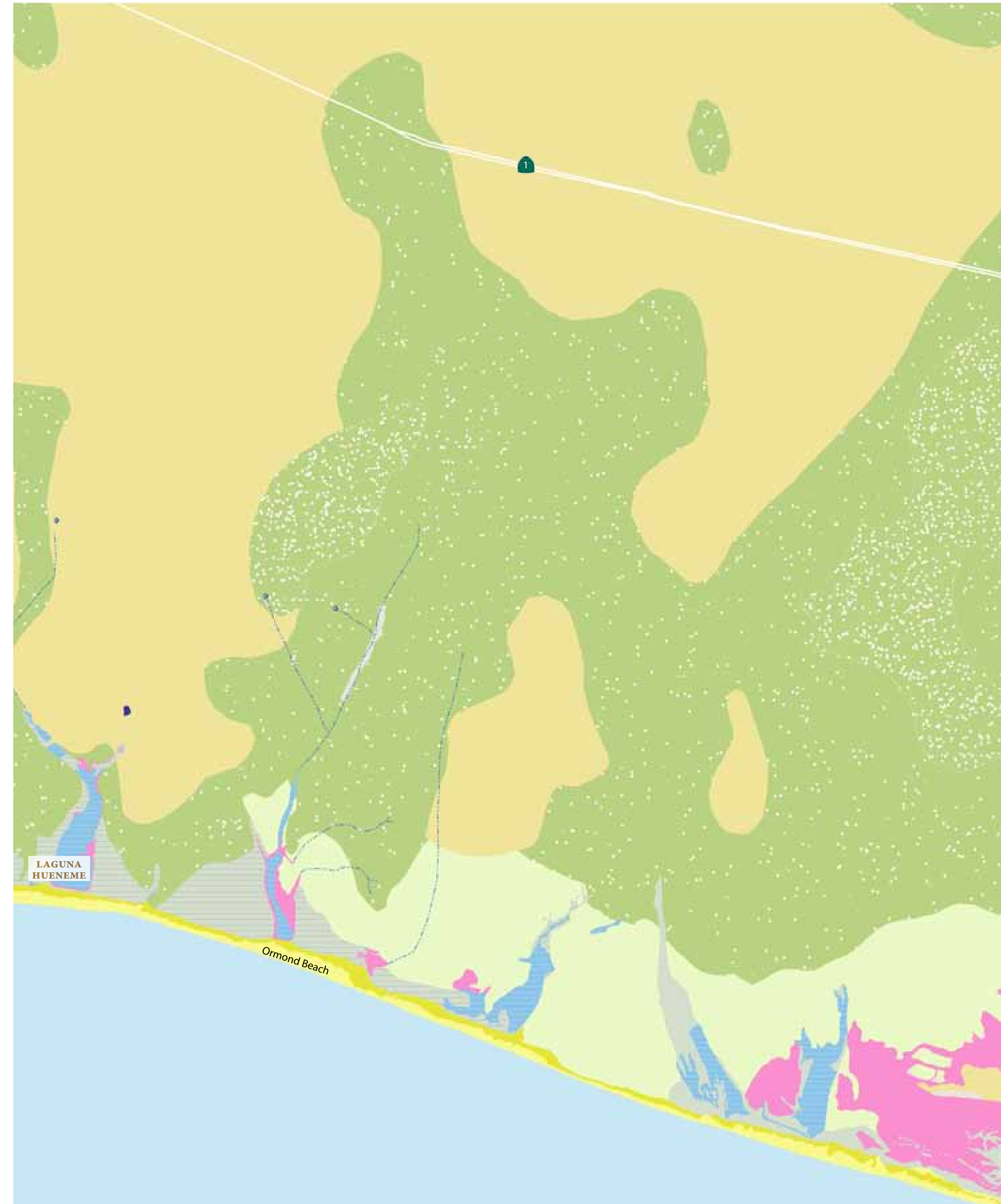


Fig. 6.15. A series of backbarrier lagoons, salt flats, and marshes stretched from south of the Santa Clara River mouth all the way to Mugu Lagoon (the western edge of which is at the right edge of this spread). Separated from the ocean by often extensive dunes, these systems were characterized by variable salinity, seasonality, and habitat proportions. (See fig. 6.24 for the modern aerial of this area.)

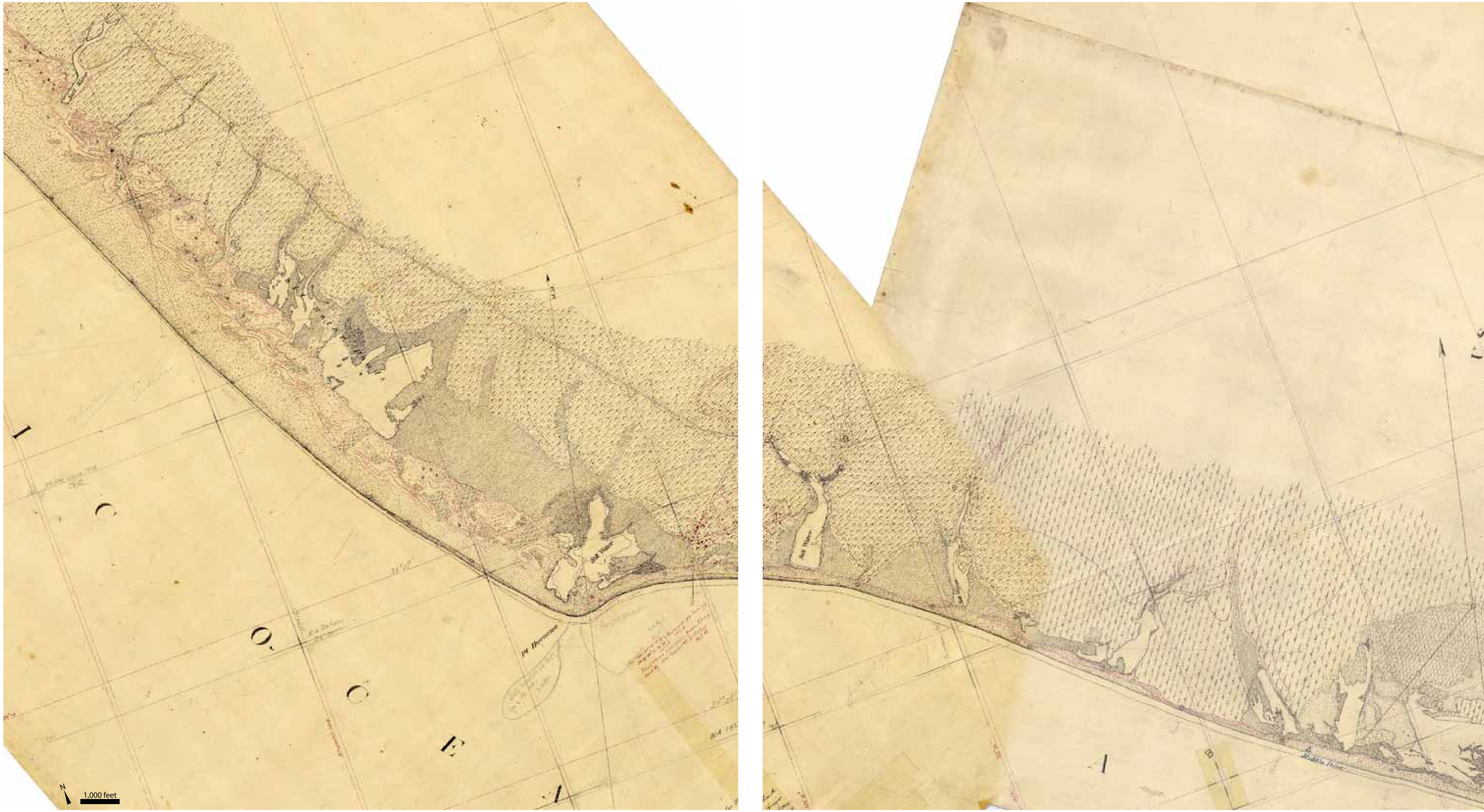


Fig. 6.16. The earliest detailed surveys of the Ventura shoreline, completed in 1855 and 1857, show the coastal wetlands with impressive precision. (Johnson 1855b and Johnson 1857, courtesy of the National Oceanographic and Atmospheric Administration)

> …we drive along in full view of several islands and observe the sand bar that waves have thrown up, that prevents the water from coming in where it formerly held sway thereby leaving a marsh and beach and many enclosed lakes and streams in and upon which are all kinds of denizens of the deep, fowls and some animals. We note three flamingoes, many water-snipe, pelicans in great numbers and ducks in flocks and pairs; and many familiar birds in these ponds are shovel-bills (resemble shovels and dig in sand)…There was an oyster bed at the point but it has been destroyed by waves and sand. (Wallace Weston Brown, in Brown 1981)

By far the most detailed depiction of the suite of coastal lagoons is provided by a set of USCS T-sheets produced in the summers of 1855 and 1857, the maps upon which the bulk of our own historical habitat mapping is based (Johnson 1855b,c and Johnson 1857; fig. 6.16; see Grossinger 2011 for more discussion of these sources). These early surveys depict the lagoons as a series of open water/salt flat/marsh complexes separated from the ocean by sand dunes, which range from 300 to 3,300 feet wide and with high points consistently above 60 feet in elevation northwest of Hueneme. None of the lagoons are shown with a tidal outlet, and the lagoons' square-end shapes and the presence of the wide, vegetated barrier dunes suggests that these systems opened relatively infrequently. These systems, though

not identical, could generally be considered perched and/or dune-dammed (Jacobs et al. 2010).

This depiction of the lagoons—as a series of small systems with an infrequent tidal connection—is supported by supplementary sources, which confirm the persistence of these features throughout the 19th century. An early resident testified in 1869 that the two lagoons at Hueneme had been present as long as he had known the area, "as early as 1837 or before that time" (Gonzales 1869). Subsequent independent depictions of the lagoons are consistent with the T-sheet, matching the general location and extent of each feature, though these maps generally did not map salt marsh and fail to distinguish between salt flat and open water (Bard 1870a,b; Reed ca. 1871; Stow 1877; Schuyler 1900; Holmes and Mesmer 1901b; USGS 1904). None of these maps show any of the lagoons with a tidal connection. Narrative descriptions also support the largely non-tidal aspect of the lagoons. It was stated that the two lagoons at Point Hueneme "are some distance from and do not communicate with the sea" (Smith 1871), while the lagoons north of Point Hueneme "have no daily communication with the ocean, but on occasions of storms the waves sometimes wash over from the sea into said

LAGOONS AND DUNES

A broad barrier beach-dune system stretched from the Santa Clara River mouth to Mugu Lagoon, separating the numerous lagoon-salt marsh complexes from the ocean (fig. 6.17). The early T-sheets capture the complex Aeolian topography with characteristic detail, with solid and dashed (intermediate) red contour lines indicating 20 foot contour intervals. The mapping indicates that the dunes were broader and taller north of Hueneme, with the highest points consistently above 60 feet. Sand dune width ranges from 300 - 3,300 feet. This dune topography was described by another observer as a "continuous, high sandy beach or sea wall," where "hills and sand ridges—some of them being 60 to 75 feet high, lying parallel with the beach line—widen out and occupy a space of from half to three fourths of a mile" (Reed 1871).

Vegetation varied with position on the dune structure, with different species characterizing the foredune, middle, and inner/backdune zones. These patterns are described by Cooper (1967), who described vegetation on the dunes near Hueneme: saltbush (*Atriplex leucophylla*) and verbena (*Abronia* spp.) on the foredune, herbaceous cover and salt grass (mapped as alkali meadow) and "extensive thickets of the usual species of willow" on the middle zone, and shrubs on the innermost dunes. Many of these patterns are also reflected on the T-sheet, in particular the middle dune zone patterns of large patches of grass in dune depressions and occasional willow trees and groves. Dune species recorded near Mandalay Beach in 1930s specimen records include yellow bush lupine (*Lupinus arboreus*), beach evening-primrose (*Camissonia cheiranthifolia* ssp. *suffruticosa*), and pink and red sand verbena (*Abronia umbellata* and *A. maritima*), among many other species (Fosberg 1931a,b; Wolf 1931; fig. 6.18). Dunes in the Pierpont Bay region were recorded to have seacliff buckwheat (*Eriogonum parvifolium var. parvifolium*; Craig 1927).

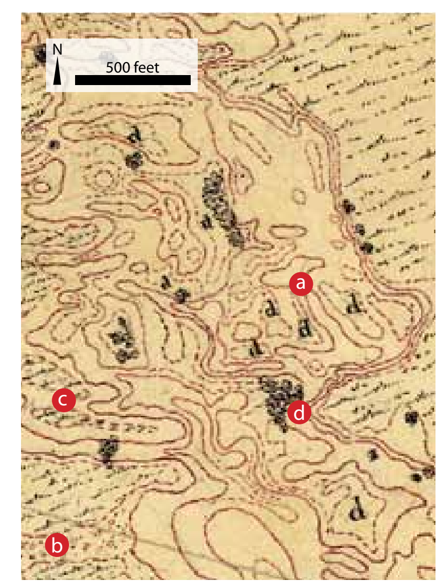


Fig. 6.17. Dune topography and vegetation near McGrath Lake, 1855 (left). Surveyors indicated a depression in the dunes with the letter "d" (a), while the small red circles are thought to indicate dune tussocks (b) (Grossinger et al. 2011). The grassy symbol in some of the dune depressions (far left of image) is alkaline grassland (c). A few willows are shown on higher portions of the dunes (d). This detail is from the dunes north of West Fifth Street. (Johnson 1855/t-576, courtesy of the National Oceanic and Atmospheric Administration)

Fig. 6.18. "Hueneme Point from east," 1913 (right). Linguist and ethnographer John P. Harrington took Chumash elder Fernando Librado on a series of field trips around Ventura County, documenting significant places and place names. Librado, who would have been in his 70s at the time of this photo, is shown standing in the dunes at Point Hueneme. Some dune vegetation can be seen, including red sand verbena (*Abronia maritima*) and likely shrubby beach primrose (*Camissonia cheiranthifolia* ssp. *suffruticosa*; Baye, pers. comm.). This is consistent with Cooper (1967), who noted that verbena was characteristic of the "hillocks" of the foredunes near Hueneme. (Harrington 1913c, courtesy of the Smithsonian Institution)

salt ponds" (Rodriguez 1871b). Of the two lagoons at Point Hueneme, one resident wrote:

> Neither of these waters are connected with the sea, but both of them are disconnected from the beach by sand hills. It is possible that during the high Spring tides the water may swash over the sand hills in front of the Salinas, as there is very little vegetation growing on the sand hills in front of the said 'Salinas'—but deponent has never witnessed such over swash, though he has been along the coast here at this point very frequently and at all seasons of the year… (Bard 1871)

…there are no esteros, lagunas, or salt ponds other than the Estero Grande [Mugu Lagoon] that have outlets to the sea…

—STOW 1871

Lagoons north of Point Hueneme were blocked from the tides by substantial sand dunes which would have almost never been breached by the ocean, while lagoons south of Point Hueneme, bordered by much smaller dunes, may have experienced more frequent dune overwash.

Though the series of lagoonal systems was composed of at least four distinct complexes, early observers often referred to them as one large, continuous backdune feature (with a few notable exceptions—see below). Early references to "a strip of swampy land full of sloughs, and lagunas…from a half to three quarter of a mile in width" or "sloughs and marsh lands back of the sand hills" extending from the Santa Clara River to Mugu Lagoon illustrate this point (Thompson 1867, Haydock 1971). This is consistent with the habitat patterns represented on the T-sheet, on which lagoons are connected by extensive tidal marsh and seasonally inundated alkali meadow. This entire wetland area would have been flooded for much of the winter, creating one large marsh extending, in some years, all the way to Mugu Lagoon. In the summer, large portions of the shallow lagoons dried up, creating extensive salt flats.

These fluctuations in the quantity of open water throughout the year present a challenge in mapping these systems, particularly the lagoon (open water) and salt flat components. Lagoons and salt flats are similar geomorphic features at different points of the hydrologic spectrum: substantial components of many coastal lagoons dried out during the summer, while many salt flats were flooded during the winter, making the distinction between an open water lagoon and a salt flat somewhat arbitrary. This is reflected in historical sources as well; a few features mapped as ponds or lagoons in one source are mapped as a salt flat in another. Luckily, many of these nuances were captured by early maps and accounts which specified the degree of inundation of various lagoons at different times of year. Olivas (1861) stated that between two of the lagoons north of Hueneme, "all the space between the two lakes at certain seasons of the year is covered with water—at other times it is dry between these." At the south end of the lagoon series, another resident noted that the lagoons only connected with Mugu Lagoon "in years where there is much rain, when they may discharge their surplus waters in the said estero" (Rodriguez 1871a).

I know the two ponds [lagoons at Hueneme]—they are well known, at times there is dry land between them—they are close together.

—ANTONIO MARIA OLIVERA 1857

During the summer the region would have looked very different, with many of the seasonal ponds and even shallower lagoons drying up partially

or completely. Ornithologist James G. Cooper spent two "uncommonly dry" summers in the region in 1872-1873, and noted that at that time he "could ride a horse through almost any part" of the coastal marshes, "the exceptions being some salt lagoons encrusted with the white crystals, and unfit for nests, besides being almost deserted by all the birds, those seen being only a few small Waders and Sparrows" (Cooper 1887). Another party inspecting the lagoons during the dry season as part of a land dispute in 1871 only found water in three of the lagoons: the two at Hueneme Point and another small lagoon to the east (Reed 1871). Reed further stated that "I judge the water in these lagunas to be about on a level with high tide; the ordinary tides rising only about four feet, and spring tides about five feet, on this coast…In the summer, they contain very little water—the evaporation being almost equal to the seepage through the sand hills from the sea." (It should be noted that seepage from the ocean may have been unlikely prior to groundwater extraction on the Oxnard Plain; Swift pers. comm.)

These general observations are corroborated by annotations on an early map, which identifies some lagoons as "salt ponds" and another as "dry pond" (Bard 1870a; fig. 6.19). Remarkably, the T-sheet also has annotations describing summer conditions, written in exceptionally faint pencil within some of the lagoons and seasonal ponds. A few (for example, two seasonal ponds south of modern-day Channel Island Boulevard) are labeled "dry," another portion of one as "salt land" (perhaps marking an exposed portion of the lagoon), while others are labeled "salt water."

Despite outward similarity—each lagoon is consistently described as "salty" by 19th century observers—such variations in hydrology and topography across different lagoon complexes created variations in salinity between and within systems. Water sources for these lagoons were a mix of saline input (from sea spray and possibly from infrequent dune overwash and seepage) and fresh water input (from precipitation, runoff, and springs). Evidence indicates that some of these lagoons were fed by freshwater springs, and therefore would have maintained fresh-brackish-saline gradients and salinity stratification with depth (Parsons 2004, ESA PWA et al. 2011). Conversely, other lagoons had extremely small watersheds and no defined

Fig. 6.19. Coastal lagoons near Point Hueneme, 1870. Four lagoons between Point Hueneme (at left) and Mugu Lagoon (western edge visible as "mud flat" at right). Though we mapped each feature as a non-tidal lagoon, note the labels on the lagoons—meaningfully, each of the four lagoons is labeled slightly differently. The Salinas was so known because of its use as a collection site for salt in the 19th century, suggesting substantial hypersaline and salt flat components. Similarly, the "dry pond," though it would not have dried out completely every year, may have been shallower than adjacent lagoons. The "Laguna Hueneme" was well known for its freshwater inputs. The "salt pond" was found at the mouth of what is known today as the Oxnard Industrial Drain at Ormond Beach. Despite outward similarity, this map suggests substantial variation in hydrology and habitats across systems. (Bard 1870b, courtesy of The Bancroft Library, UC Berkeley)

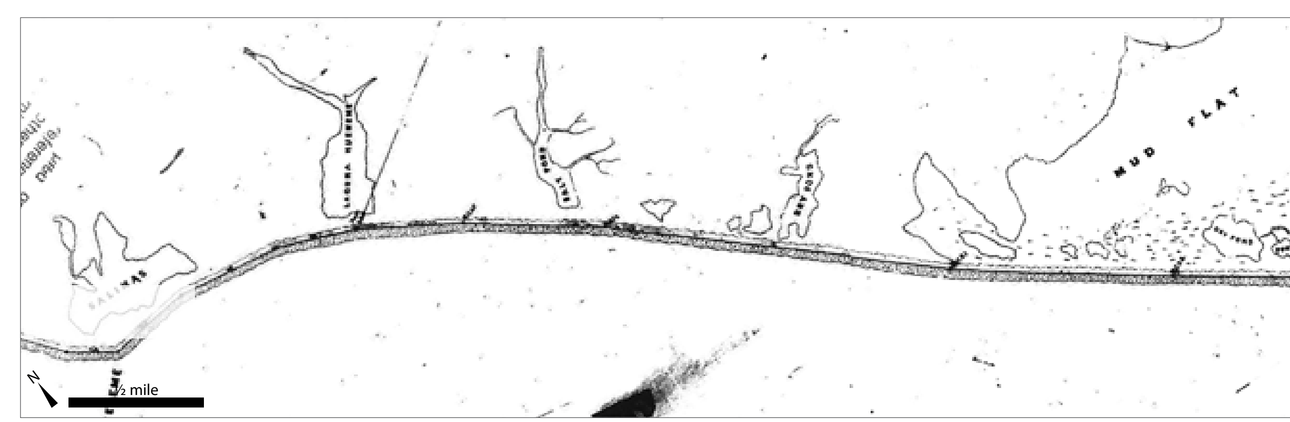
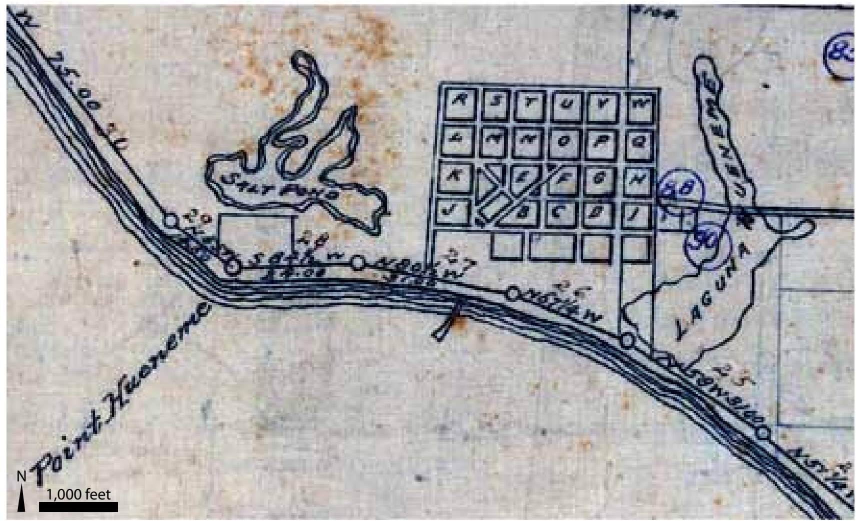


Fig. 6.20. Lagoons near Hueneme, 1877. Two well recognized lagoons were found on either side of the town of Hueneme (shown in its nascent form here). The "salt pond," to the west of town, was known as the Salinas. To the east was spring-fed Laguna Hueneme. (Stow 1877, courtesy of the Museum of Ventura County)



surface channel for freshwater input, and as a result maintained saline or hypersaline conditions. Different systems would have included different components, ranging from perennial freshwater zones in the upper portions of spring-fed lagoon/slough complexes to hypersaline salt lagoons, salt flats, and seasonal pannes.

An extreme example of this variability is found in the two ponds formerly near Hueneme (fig. 6.20). Both lagoons were well known in the 19th century, with names preserved in the historical record. To the west of Hueneme, at the current site of the port of Hueneme, was a salt water lagoon called Sitiptip by the Chumash (Harrington 1913e) and La Buena Salina or the Salinas by Spanish-speaking residents (Harrington 1986a). The Salina was so called because of its use as a gathering place for salt, implying that substantial portions of the lagoon were shallow enough to dry out during the summer for salt harvesting (fig. 6.21). This lagoon was described as the place were early residents would gather salt, and which was "well known to and is designated by the older inhabitants as the place where a certain Dr. Poli, several years ago was accustomed to collect salt and to ship the same to San Francisco" (Bard 1869, Bard 1871). This is reflected in our mapping from the T-sheet, where the ratio of salt flat to open water is 1.4.

The laguna, or lake, at Hueneme, is shown on the diseño near Point Hueneme, and also on the U.S. Coast Survey map, and the small 'salinas,' or salt ponds, further inland. Between the laguna and salt ponds, at Hueneme, and the sea, is a wide barrier of high land, 'staying the sea,'…

—FERNALD & RICHARDS AND GREEN 1871

To the east of Hueneme, another lagoon covered approximately 35 acres. Unlike the Salina to the west, this lagoon had a very low ratio of salt flat to open water, only 0.14. It was popularly known as Laguna Hueneme (and to the Chumash as Sislomow; Harrington 1913e). The use of the term *laguna* (lake) here is notable, and unique to this lagoon. It may refer to a greater water depth, the relative lack of salt flats, or to a difference in salinity from the salt ponds surrounding it. It was quite renowned, and was included in the language of the 1846 sale of the San Buenaventura Mission as a primary landmark: "the *Laguna Hueneme*, *Palo Alto* [a large sycamore tree on the Oxnard Plain], the cultivated fields of Santa Paula, [and] the Mission Cañon [Ventura River valley]" (Weber 1978).

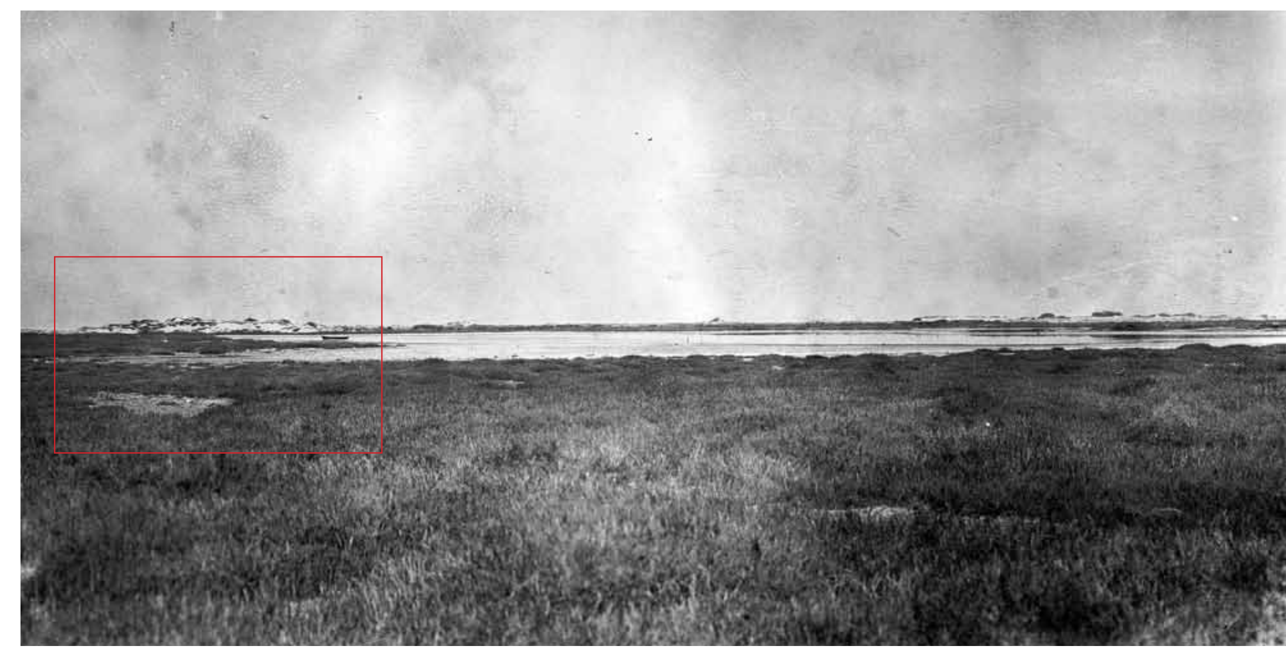


Fig. 6.21. The Salinas, 1913. These two images provide two different views of the Salinas lagoon, formerly located where the port is now. The view is generally southwest; high dunes (top and middle) and the Point Hueneme lighthouse (top; built in 1874) can be seen in the background. In the foreground, extensive salt marsh (mainly pickleweed, probably with some salt grass component and visible pannes) stretches toward the lake. A small boat (detail; at left) can be seen on the lagoon in both pictures, indicating some depth. (Harrington 1913b,d; courtesy of the Smithsonian Institution)

WHAT IS AN ESTUARY?

The abundance of information preserved in the historical record about these coastal lagoons, in particular about the Salinas and Laguna Hueneme, is in large part thanks to an early land dispute. The resulting court case centered on the wedge of land on the Oxnard Plain between two interpretations of the eastern boundary position for the Río de Santa Clara o la Colonia Rancho. The case largely hinged on the use of the word *estero* in the original property description (translated variously as a salt marsh, tidal creek, or estuary), where the boundary was described as hitting the coastline "between two *esteros*." But what, exactly, was an estero? And to what feature in Ventura County did the term refer? The grant's owners contended that the term referred to the two sloughs or arms feeding into Mugu Lagoon, and that *estero* should be translated as "estuary," and argued that the term must refer to a water body with a tidal connection. The settlers, however, interpreted the term to refer to Laguna Hueneme and the Salinas, arguing that Mugu Lagoon was an *estuario* (estuary), while *estero* was a broader term that referred to the salt lake and marsh complexes along the coast and was unrelated to the tides. (The settlers' interpretation would have opened up a wedge of land between Point Hueneme and Mugu Lagoon for settlement.) Ultimately, the dispute was resolved in favor of the land owners, and the boundary line was run to Mugu Lagoon.

Fig. 6.22. "Duck shoot near Hueneme," ca. 1889. This image shows a portion of Laguna Hueneme in the late 19th century. The lagoon is surrounded by tule (likely *Scirpus [Schoenoplectus] californicus*). What is likely sago pondweed (*Potamogeton pectinatus/ Stuckenia pectinata*) can be seen in the foreground (Collins pers. comm.). This photograph, also included as a lithograph in an 1889 article in *Overland Monthly and Out West* magazine on traveling in Ventura County, matches the description included in that article well: "spears of purple reeds [likely tule], with flocks of wild duck plowing luminous furrows across its steel-gray floor" (Eames 1889). (Brewster ca. 1889, courtesy of the Museum of Ventura County)

The most notable aspect of Laguna Hueneme, however, was its freshwater input from springs on the Oxnard Plain. Though this characteristic was not unique to the laguna (it has also been documented for the lagoon immediately to the east; Parsons 2004), it is extremely well documented in this case. Early residents testified that the laguna was "fed by springs of fresh water" (Bard 1871). This characteristic of Laguna Hueneme is a product of its status as a former mouth of the Santa Clara River, relatively recently occupied and still the recipient of substantial freshwater flows (see page 71). Though Laguna Hueneme itself is long gone, this is still the case today: the Hueneme Drain/Bubbling Springs Drain, a man-made channel which occupies the location of the former slough which fed into the lagoon, has perennial flow today as a result of springs (HDR Engineering 2009).

We stopped our horses on a rustic bridge that we might better view the Laguna, winding sinuously among its spears of purple reeds, with flocks of wild duck plowing luminous furrows across its steel-gray floor.

—Eames 1889

Despite this, the laguna was still considered to be a "salty" lagoon, labeled "salt water" on the T-sheet and described as salty in court testimony: "though the Hueneme is fed by fresh water springs" (Johnson 1855b, Reed 1871). It is likely that portions of the laguna (for example, closest to the shore) were saline, while other portions further upslope were brackish. An early image of a portion of the laguna shows abundant tule fringing the water (fig. 6.22).

Fragments of the Laguna Hueneme complex have persisted to the present day in the form of Moranda Park/Bard's Bubbling Spring. Though the lagoon looks largely intact in the 1938 aerial imagery, it was drained shortly thereafter, apparently filled with sediment from the dredging of the harbor at the site of the Salina lagoon (Moranda 1999, Maulhardt 2005). Currently, though the lagoon has been completely drained and filled, the slough that fed it still runs to the ocean in the same location. This is also true of the formerly spring-fed lagoon to its east, at Ormond Beach.

Most traces of the other lagoon complexes have been completely obliterated over the past 100 years (figs. 6.23 and 6.24). Much of this change had already happened by the early 1930s, by which time a five mile long drainage ditch, stretching from south of the Santa Clara River all the way to its outlet at Hueneme and bisecting the former locations of many of the coastal lagoons, had been constructed to drain the area.

Many lagoons became salt flats or marshes, tidal marshes became alkali meadows, and alkali meadows were in large part flushed and cultivated. Historical aerial imagery from 1927 and 1938 hint at this transformation, showing a long canal bisecting dry flats and clearly salt-affected land where 1850s surveyors mapped lagoons. The USCS T-sheet resurvey from winter 1933 captures the lagoons' disappearance even more explicitly (Kelsh 1933b and Kelsh 1934; fig. 6.25). Precise annotations describe former lagoon locations as "former salt pond (now drained)" in the Mandalay Beach area, "ponds formerly shown now drained" near Channel Islands harbor, and "pond, apparently drying up" at the south end of Ormond Beach. Other lagoons are shown with a combination marsh/lagoon symbol. The obvious exception is the spring-fed Laguna Hueneme, shown with substantial water

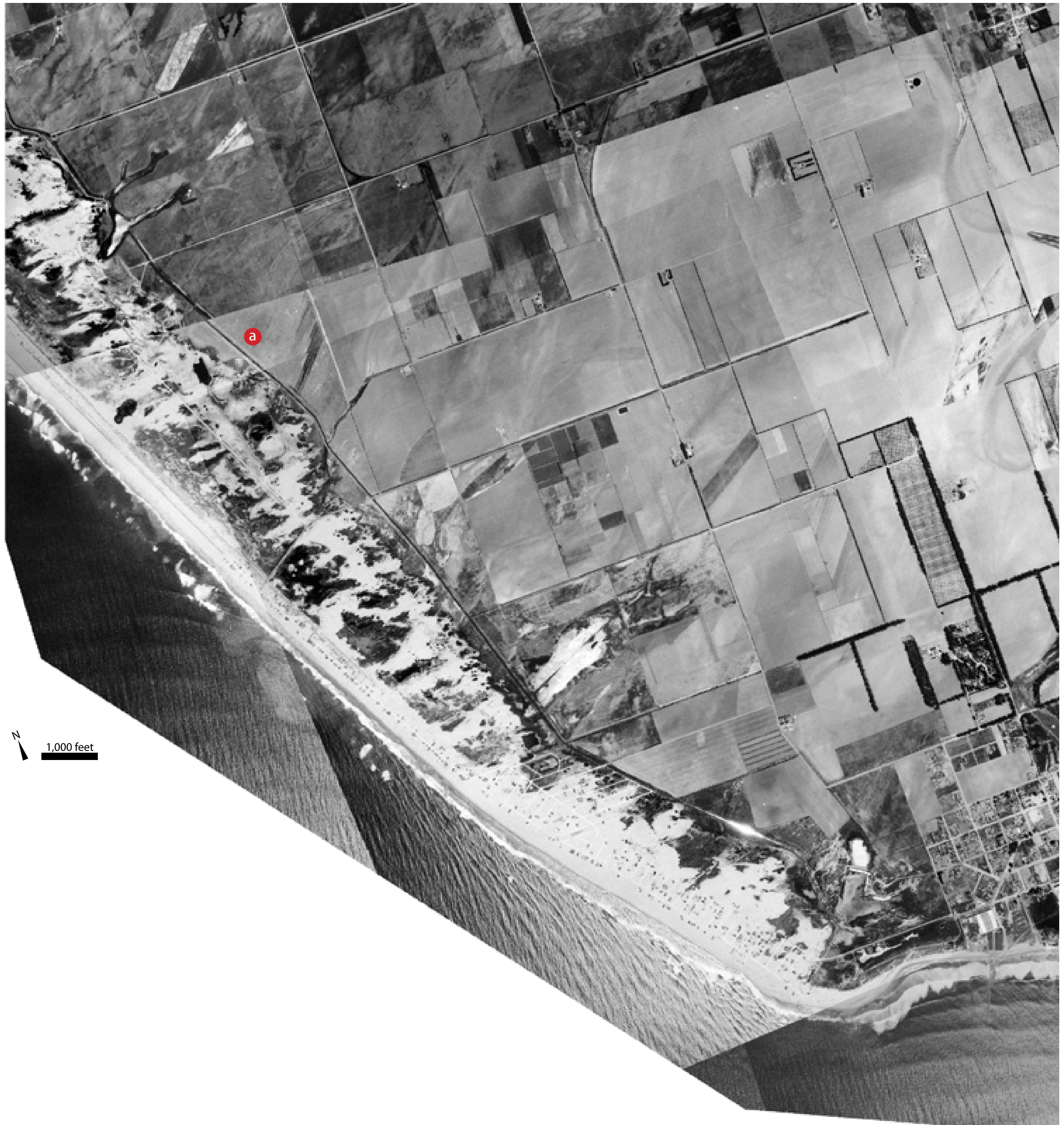


Fig. 6.23. Oxnard Plain shoreline,1927/1938. Traces of most of the 19th century lagoon complexes are still visible at the time these photos were taken in the 1920s and 1930s, though it is clear that many are in the process of being drained by the long canal seen at left (a). A few lagoons, such as Laguna Hueneme (b) and the adjacent lagoon to the east, still appear to be filled with water. Traces of the former Santa Clara River channel are clearly visible at (c), feeding into Laguna Hueneme. (Fairchild Aerial Surveys 1927, courtesy of Whittier College, USDA 1938, courtesy of Ventura County)

Fig. 6.24. Oxnard Plain shoreline, 2005. By 2005, most traces of the former lagoon complexes have been erased. A few markers remain, such as sloughs near Ormond Beach that used to empty into lagoons (portions of which have been repurposed as the Oxnard Industrial Drain and the Hueneme Drain). A lagoon similar to former features has formed to the east of Laguna Hueneme at Ormond Beach. (USDA 2005)

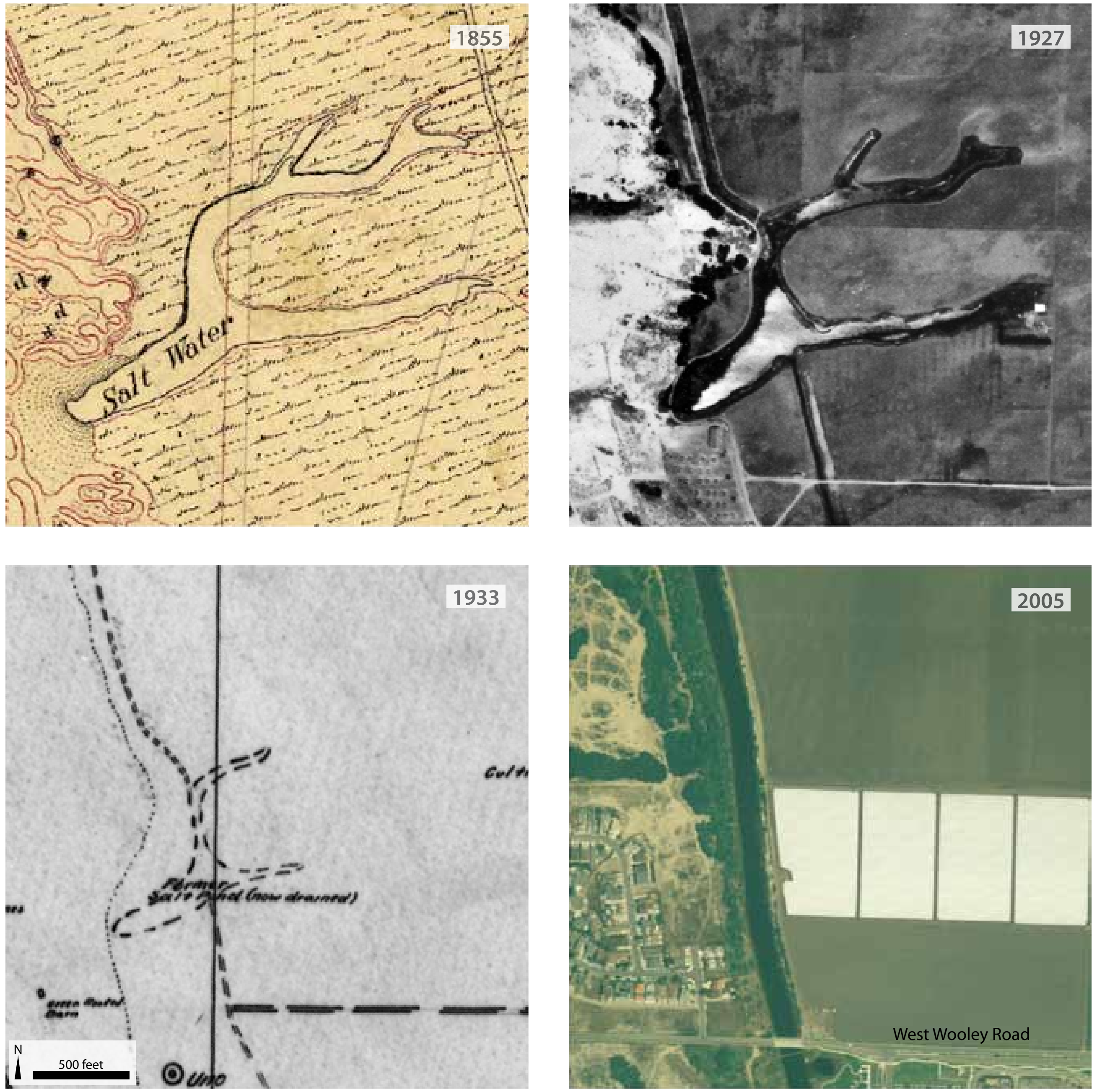


Fig. 6.25. In 1855, a small (14 acre) coastal lagoon was recorded by the U.S. Coast Survey, at what is now the end of West Wooley Road at Mandalay Bay (top left). Nearly 80 years later, in the descriptive report accompanying the T-sheet resurvey, the cartographers note that a drainage ditch (visible here on the aerials; top right) "has drained the salt pond shown on the former work… although the general shape as a dry hole is still apparent" (bottom left; Kelsh and Green 1934c). By 2005 all traces of the lagoon have been erased: only the drainage ditch remains (bottom right). (Johnson 1855b, courtesy of the National Oceanic and Atmospheric Administration; Fairchild Aerial Surveys 1927, courtesy of Whittier College; Kelsh 1933b; courtesy of IMC; USDA 2005)

in the aerial imagery and apparently intact on the resurvey. The two lagoons on either side of it, the Salinas and another spring fed lagoon to the east (at Ormond Beach), are shown with what appears to be both open water and marsh components.

Changes are also documented in the surrounding former salt marsh and high marsh transition zone, labeled as "dried up marsh," "meadow" or "marshy meadow," and "dry salt meadow." In a few portions of the former salt marsh (and in much of the former alkali meadow) the resurvey identifies "cultivated field." In the descriptive report accompanying the T-sheet resurvey, the surveyors describe this transition:

> East of this town [Hueneme] the country has remained in an undeveloped state except for the fact that farming has increased and developed this area for truck farming. As a result small swamps and sloughs have been filled in, and the farm land pushed out towards the coast, in turn tending to dry up the small ponds lying behind the sand dunes along the coast… From Hueneme west the beach area has been developed into a series (continuous) of summer resorts…Behind this ridge [of sand dunes] a long drainage ditch parallels the coast, draining into the sea just west of the Hueneme Lighthouse. This has completely eliminated the ponds previously shown, and the whole area has been developed into farming country. (Kelsh and Green 1934b)

Mugu Lagoon

Mugu Lagoon, known historically as the Estero Grande or Mugu Laguna, was one of the largest coastal wetland systems in Southern California, covering about 2,550 acres in the mid-1850s. (An additional 1,110 acres of high marsh transition zone formed an ecotone between Mugu Lagoon and the alkali meadows of the Oxnard Plain.) The lagoon occurs in a structural basin formed by the folding and faulting of marine sediments. The lagoon itself is trapped in an embayment behind prograding beach spits (Warme 1971, Jacobs et al. 2010).

The lagoon/marsh complex was the site of a broad range of coastal wetland habitats, many of which are still present today due to Mugu Lagoon's relative protection within the Point Mugu Naval Station. The complex contains the largest coastal wetland remnant in southern California today (Orme 2005).

A number of researchers have studied the history of cultural and physical change at Mugu Lagoon at length (e.g., Warme 1971, Steffen 1982, Onuf 1987, Swanson 1994, USACE 2003). An exhaustive search of the available historical record yielded little additional detail on early ecological patterns and processes at Mugu Lagoon, understandable given the region's extensive salt marshes and subsequent lack of intensive early development. As a result, we focus here on discussion and interpretation of the 1857 T-sheet (the most detailed early picture of the area), bringing to bear supplementary sources to describe the patterns of historical habitat distribution in the area.

October 26. At noon we made a little tea and were eating it when suddenly the wind blew a spark into a bunch of green tule, which was in a blaze in a minute, the flames spreading with great rapidity… Fortunately an estero prevented its spreading far and by night we had it subdued.

—Bowers 1879, in Benson 1997; at Point Mugu

Fig. 6.26. Habitats of Mugu Lagoon, early 1800s. The historical habitat mosaic surrounding Mugu Lagoon included substantial amounts of subtidal habitat, tidal flat, tidal marsh, tidal channels, marsh pannes, salt flat, vegetated former dune strands, and high marsh-alkali meadow transitional zones.

Coastal and Estuarine Habitats

- Ocean
- Beach
- Dune
- Tidal Lagoon (mostly open?)
- Tidal Flat
- Tidal Marsh
- Salt Flat/Seasonal Pond/Marsh Panne
- High Marsh Transition Zone

Palustrine and Terrestrial Habitat

- Alkali Meadow
- Alkali Meadow/Flat
- Grassland/Coastal Sage Scrub

Hydrology

- Intermittent or Ephemeral
- Perennial
- Distributary

This map is now available in greater resolution than previously (Grossinger et al. 2011).

The historical habitat mosaic at Mugu Lagoon included substantial amounts of subtidal habitat, tidal flat, tidal marsh, tidal channels, salt pannes/seasonal ponds, salt flat/playa, vegetated former dune strands, and high marsh-alkali meadow transitional zones (fig. 6.26). Most of these features are shown in detail in the 1857 US Coast Survey T-sheet (Johnson 1857; fig. 6.27). The predominant habitat type at this time was tidal marsh (58%), with the remainder of the area distributed among subtidal water (14%), tidal flat (12%), salt flat/marsh panne (10%), and open water ponds (5%).

Mugu Lagoon included a relatively large subtidal area compared to most other Southern California estuaries (Grossinger et al. 2011). Historical maps also show evidence of extensive tidal channel networks as well as former beach ridges reflecting former shoreline positions (Thompson 1994). Historical botanical records support the prevalence of tidal marsh in the first half of the 20th century, with specimen localities described as "salt marsh on shore of lagoon," "dry salt marsh," "border of salt marsh," and "mudflats around tidal lagoon" (Fosberg 1931c,d; Hoffmann 1932a; Nobs and Smith 1948). Salt marsh vegetation captured in early (pre-1950)

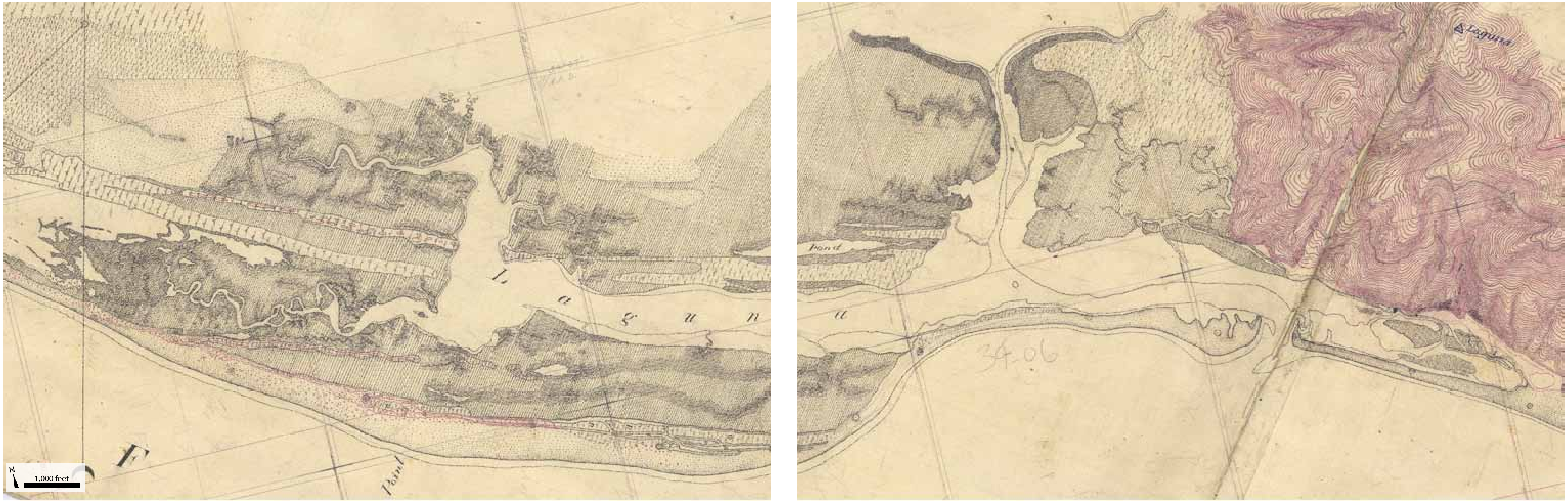


Fig. 6.27. Mugu Lagoon, 1857. (Johnson 1857, courtesy of the National Oceanic and Atmospheric Administration)

records includes Virginia glasswort (*Salicornia virginica*), Parish's glasswort (*Salicornia subterminale*), marsh jaumea (*Jaumea carnosa*), and marsh rosemary (*Limonium californicum*) (Howell 1927; Fosberg 1931c,d; Purer 1935). The T-sheet resurvey of 1932 described the salt marsh south of the western arm of the lagoon as "low coarse eel grass" (Kelsh 1933b).

Supplementary sources help confirm habitat interpretations on the T-sheet. In particular, Thomas Bard's 1870 map of Mugu Lagoon is another highly detailed mid 19th-century depiction of coastal wetlands, and provides independent confirmation (after the 1861-2 flood) of many of the features shown on the T-sheet 15 years earlier. For example, Bard (1870a) confirms stippled areas shown on the T-sheet at the marsh margin as unvegetated salt flats, and refers to the salt grass area and neighboring salt flats as "mudflats," generally confirming their alkali playa characteristics. An early soils map helps confirm the extent of salt marsh depicted on the T-sheet (Nelson et al. 1917).

We soon came to miles of marked surface, overflown by salt water in the winter and spring season, when the tides and winds are highest. At such times they are the shallow extension of the western branches of the Estero Grande—the now bare surface being then covered with water…

—Reed 1871, describing the salt flats of western Mugu Lagoon

These sources also provide details not represented on the T-sheet, particularly at the upland edge of Mugu Lagoon (since the early T-sheet does not consistently map the full inland extent of tidal marsh). The full extent is indicated by these additional sources (6.28; see also fig. 6.2). The zone of strong alkali influence shown on the 1917 soils map provides a continuous boundary for the inland extent of tidally-influenced habitats across the entire lagoon complex, while the Bard map provides clues to the nature of the habitat at the upland edge of the marsh. The map shows a number of areas of "Juncal" or "Juncal Grande" on the upland edge of the marsh, a now-rare ecotone between tidal marsh and the adjacent lowlands of the Oxnard Plain that we mapped as high marsh transition zone. These depictions presumably represent large stands of Juncus, likely spiny rush (*Juncus acutus*), which was collected extensively in the area by native peoples for basketry (Timbrook 2007). *Juncus acutus* var. *leopoldii* was collected at the site in the 1950s and 1960s (Raven and Thompson 1959) and is reported today (USACE 2003). The presence of these large stands of rush indicates substantial brackish tidal marsh zones, both at the eastern margin towards the Calleguas Creek drainage and elsewhere in the marsh. These habitats appear to have been greatly reduced today. This modification to Mugu Lagoon may have significant habitat implications. For example, the rare light-footed clapper rail (*Rallus longirostris levipes*) is found to nest at Mugu Lagoon primarily in the spiny rush stands (USACE 2003).

The T-sheet indicates the presence of this high marsh ecotone in a few places, using a subtle variation in symbology at the northwest edge of Mugu Lagoon to show the broad transitional area between the tidal marsh and adjacent alkali meadow (Johnson 1857). The surveyor fortunately provided a clue for the interpretation of this symbol, annotating the margin with the words "line of salt grass" in faint handwritten pencil. We interpret this annotation as the distinction between the high marsh ecotone (which would have presumably had a high concentration of saltgrass (*Distichlis spicata*)), and the adjacent alkali meadow, which may have been a matrix of salt-tolerant and other grassland species.

Despite the detail these sources provide, the full former inland extent of the Mugu complex is unknown, and there is some indication that it once extended substantially further inland. Dr. William Livingston, who grew up in the Hueneme area in the 1870s and 1880s, recalled in a 1929 interview that Mugu Lagoon had shrunk considerably over his decades living on the plain:

> Dr. Livingston also tells me that in his time Mugu Lagoon has filled up to a very great extent. Originally it was a large body of water and the probabilities are that it extended in the sixteenth century to the foot of the hills where the principal town was located. Indeed, it is possible that at that time it was open ocean at that point, the lagoon not having formed. Dr. Livingston states that one time the Santa Clara River emptied into the ocean in this neighborhood, the old channel being still plainly visible. (Wagner 1929, in King 2005)

This remark is corroborated by a member of an outing to Point Mugu in March 1902, who stated that "there are indications that the marsh extended further inland, and it is claimed that small steamers and boats used to come up to the now tidewater mark" (Wallace Weston Brown, in Brown 1981).

It is possible that these accounts capture early sedimentation and deposition on the marsh plain as a result of the construction of a channel connecting Calleguas Creek to Mugu Lagoon, reducing tidal extent. The initial date of channelization has been widely stated as 1884 (e.g., Steffen 1982, Onuf 1987, Swanson 1994, USACE 2000); while this is possible, the origin of the assertion is unclear and we found no direct evidence to support it. Regardless of the precise timing, however, it is clear that Calleguas Creek did not maintain a defined connection to Mugu Lagoon prior to channelization efforts, which would have likely been initiated sometime during the late 19th or early 20th century (see page 169). If this is the case, shrinking of Mugu Lagoon could have been a result of increased sedimentation from the Calleguas watershed after channelization, as sediments previously deposited on the Oxnard Plain during floods were transported instead to Mugu Lagoon and the ocean. This process is confirmed by sediment transport calculations, which estimate a ten-fold increase in sedimentation rates over geologic levels as a result of the channelization of Calleguas Creek (Warme 1971, Steffen 1982, Capelli and Cave 1983).

Another possibility is that the former extent of Mugu Lagoon before Mission times is not captured fully by the 1857 T-sheet survey and other early sources described above. There is no way to verify this with the available historical data, though early General Land Office survey notes –slightly predating the T-sheet—suggest that this might have been the case (fig. 6.28). Notes from two surveyors in 1853-4 indicate tidal influence above our mapped zone of tidal marsh and high marsh transition

Fig. 6.28. Historical extent of tidal influence at Point Mugu, early 1800s. The Mugu Lagoon wetland complex, including high marsh transition zone areas, extended quite far inland in the 19th century compared to its current extent. Early surveyor's notes hint that the tidal zone may have extended even further inland, as shown by the excerpts above. Excerpts along the survey line refer to a line segment rather than an individual point. (USDA 2009)

zone. Washington (1853) described a mile-long transect "almost entirely overflowed by tide from the Pacific Ocean" crossing the western slough entering Mugu Lagoon, from 500 to 1,600 feet north of our mapped extent of tidal influence. He also noted "mostly rich low prairie…is overflowed by tide water" for nearly a mile west of modern Calleguas Creek, an area mapped by Bard (1870a,b) as "juncal" and largely interpreted in our mapping as high marsh transition zone, and noted "over flow from tide" more than 1,600 feet north of this mapped edge of high marsh transition zone. Hancock (1854) also noted "tide wash" extending 1,200 feet above the mapped edge of the high marsh transition zone above the western arm of the lagoon, differentiating between "tide wash" to the south and "salt weed" (presumably alkali meadow) to the north. We did not consider these points sufficient evidence to extend our mapping, since it is also possible that these areas were non-tidal, salt-affected lands (e.g., alkali meadows and flats) of the lowland Oxnard Plain. These accounts may also reflect flooding induced by perched conditions created by periodic or partial inlet closure (Jacobs pers. comm.).

Despite these changes, Mugu Lagoon has shown significant resilience over time. By the time of the T-sheet resurvey of November-December 1932, though most of the non-tidal lagoons to the north had been (or were in the process of being) drained, the subtidal and salt marsh components of Mugu Lagoon looked largely similar to the 1857 condition: so much so that the 1933 surveyors called the coastal complex "practically unchanged… even the small sloughs in the swamp area were found as shown" (Kelsh and Green 1934a). The major exception was the migration of the lagoon inlet, which had shifted almost 3,000 feet west during the intervening 76 years.

As might be expected, evidence of closure states for Mugu Lagoon indicate that the nature of the lagoon's connection to the ocean was complex, dynamic, and variable. The cyclical migration and closure of Mugu Lagoon's inlet in the 20th century has been well documented. Sources indicate repeated closure of the inlet and migration in response to onshore and longshore wave action balanced with hydraulic forces from the lagoon and the Calleguas Creek watershed (Bascom 1954). The general location of the mouth is governed by the presence of Mugu Canyon offshore, but its location moves from the northwest to southeast over time in response to longshore movement of sand. When the mouth gets to the southeastern portion of this range it is more susceptible to complete closure from the berms built during winter storms (Bascom 1954). The lagoon then breaks through again at the canyon head and repeats the process. In the mid-20th century, this process was documented to occur up to twice a year (Bascom 1954). This closure pattern was also documented by Warme (1971), who noted that "at present the lagoon mouth is naturally sealed off about every six months to one year" before being immediately dredged open.

Many of the above observations date from after significant modifications to the lagoon complex such as road building, diking, dredging, and the construction of a channel between Mugu Lagoon and Calleguas

Creek. These activities would have impacted lagoon processes, reducing tidal prism, restricting tidal access, and altering sediment availability, distribution, and freshwater inputs. As a result, the relationship of these later observations to 18th and 19th century lagoon closure dynamics is uncertain and has been intensively debated. While Warme (1971) stated that Mugu Lagoon experienced a similar cycle of closure and mouth migration prior to the major modifications of the 20th century, Onuf (1987) asserted that even prior to channelization the lagoon's tidal prism "would have been sufficient to keep the mouth open at all times."

Nineteenth century sources accentuate the relatively open character of the lagoon complex. Historical maps consistently show the lagoon with an open inlet, suggesting a direct connection to the ocean (e.g., Johnson 1857, Bard 1870b, Reed ca. 1871, Stow 1877, USGS 1904, Petit 1919). Early descriptions of the lagoon also emphasize its communication with the ocean, in contrast to the other lagoon complexes along the coast: "there are no esteros, lagunas, or salt ponds other than the Estero Grande [Mugu Lagoon] that have outlets to the sea" (Stow 1871). No 19th century source was found that described inlet closure. These data suggest that on the spectrum of Southern California estuaries, Mugu Lagoon likely had a greater degree of tidal connection than neighboring, smaller systems.

However, comparison of the early maps listed above also clearly shows changes in mouth position and width over time. One early surveyor described perceived changes in the nature of the outlet in the mid-19th century, noting that Mugu Lagoon's "outlet to the sea, which is now only 25.00 chains or a little more than ¼ mile wide" had shrunk substantially: "old residents informed me that its width had lessened one half, within the period of their knowledge of it" (Reed 1871). It is not clear whether these data represent cyclical mouth migration and periodic closure as described in the 20th century or change through time in the lagoon's closure dynamics.

Southern California lagoons existed in a range of closure states, and were connected to or closed off from the ocean at different times. Understanding of and terminology to describe these systems is currently in development, as advanced by Jacobs et al. (2010). Unfortunately, the historical record itself is insufficient at this time to resolve degree of closure or the former frequency, timing, and duration of closure patterns. It seems clear from 19th century data that Mugu Lagoon was at least periodically tidally influenced. It is possible that the size of the open water area may have created a sufficiently large tidal prism to maintain connectivity with the ocean for extended periods of time (Onuf 1987, Coats et al. 1989). Nevertheless, it is important to note that though these data emphasize the lagoon's connection to the ocean, they do not preclude occasional or regular cycles of closure, or closure in the subtidal/intertidal by a bar (Jacobs et al. 2010). Further archival and field-based research at Mugu and other sites may provide additional insight into the nature of these early lagoon dynamics.

SUMMARY OF FINDINGS

The following points represent some of the significant findings from our research on the Ventura County shoreline. Along with an understanding of modern conditions, these findings can support scientists and managers working to identify restoration opportunities in these coastal systems.

1. **A diversity of coastal systems characterized the Ventura shoreline,** each with differing habitat patterns and hydrologic dynamics. The overall habitat distribution is well documented, though available historical sources only begin to indicate the range of coastal processes that created these patterns, from Mugu Lagoon to the backbarrier lagoons, dunes, salt flats, and tidal marshes of the Oxnard Plain.

2. **Coastal wetland habitats covered about 4,300 acres,** accounting for a large proportion of former Ventura County wetlands. Differences in freshwater input, extent of vegetative cover, and closure regime led to varying support functions for native fish and wildlife.

3. **Three distinct types of coastal estuarine systems characterized the Ventura County shoreline**: the freshwater-brackish, intermittently or seasonally closed estuaries of the Ventura and Santa Clara rivers; the non-tidal lagoon complexes marking former Santa Clara River mouths; and the large, more tidally-influenced wetland system at Mugu.

4. **The Ventura and Santa Clara River estuaries were periodically open to the Pacific Ocean**. Regular, seasonal cycles of closure were documented for the Santa Clara River mouth. The Ventura River mouth closed only occasionally (less frequently than the Santa Clara River), reflecting its greater historical volume of summer flow in the lowest reach, steeper channel gradient near the mouth, and lesser wave exposure.

5. **The estuaries of both rivers also shared similar habitat mosaics.** Both rivers had fairly compressed estuaries, with the relatively limited saline and brackish wetland habitat near their mouths bordered by extensive freshwater habitats, most notably the willow-cottonwood forest and wetland documented at both mouths.

6. **McGrath Lake is a regionally significant feature,** unique because of its persistence over the past centuries and its freshwater character. Though the lake has persisted, its location has shifted substantially since the mid-1850s; only a small portion of its current area overlaps with its historical extent.

7. **An extensive suite of marsh, salt flats/pannes, and lagoons stretched from south of the Santa Clara River to the western edge of Mugu Lagoon.** Prior to drainage and agricultural expansion, these systems were a significant component of the Ventura County shoreline. They exhibited a range of habitat patterns based on variable salinity gradients and hydrologic inputs, from the spring-fed brackish Laguna Hueneme to the hypersaline Salinas near Point Hueneme.

8. **Mugu Lagoon was the largest wetland complex in Ventura County, and the site of a broad range of coastal wetland habitats,** including salt and brackish marshes, large salt flats, and extensive tidal channel networks. Dominant habitat cover was tidal marsh. There is some indication that the complex formerly extended substantially further inland than currently recognized. Its acreage has been dramatically reduced.

9. **Salt flats and high marsh transition zone were major components of Mugu Lagoon.** These transitional, high elevation habitats were particularly characteristic of the semi-arid climatic setting (Ferren et al. 2007), and have been disproportionately lost from this system. These features likely provided breeding habitat for shorebirds such as least tern and snowy plover (as small present-day remnants still do), as well as an inland migration zone for tidal marsh transgression in response to naturally rising sea level in the past.

Management Implications

- **The preponderance of closed conditions in most lagoons along the Oxnard Plain suggests strategies for habitat rehabilitation in these areas.** Efforts to restore coastal lagoon functions in these areas, for example at Ormond Beach, should consider these historical dynamics in restoration design. Current physical conditions at these sites (e.g., barrier dunes, small watersheds) may not reliably support open marine conditions without regular maintenance, but could potentially provide support functions for a range of native species. Restoration activities could also enhance the ecological functions of existing features. For example, the lagoon at Ormond Beach, though formed at a different location than historical features, currently exhibits similar closure dynamics. Sustaining and augmenting the geomorphic and ecological functions of this feature is an important restoration consideration.

- **Coastal lagoon complexes with high salinity levels and extensive surrounding salt marsh and salt flat were a significant component of the historical Ventura County shoreline.** These complexes, which occurred in areas with extremely small watersheds and limited freshwater input, may be under-represented in Southern California today.

- **Conversely, brackish-freshwater conditions maintained in some coastal complexes may be considered a significant component of coastal habitat restoration strategy.** While most coastal habitats historically exhibited high salinity levels, a few places maintained fresh-brackish conditions. In particular, the Santa Clara and Ventura river mouths and spring-fed lagoons such as Laguna Hueneme were less saline than surrounding systems. Maintenance of contemporary freshwater sources should be considered to restore or maintain such environments, with adequate consideration of water quality concerns.

- **Re-establishing transitional habitats at Mugu Lagoon is an important component of habitat restoration, and may be of regional significance.** Mugu Lagoon is recognized as the biggest coastal wetland complex in Southern California, yet it has lost much of its habitat area, particularly on its landward edge. High marsh ecotone, a transitional habitat between tidal marsh and alkali meadow, was a significant component of Mugu Lagoon and accounted for much of the region's wetland area. Re-establishing portions of this ecotone may be an important component of the lagoon's future persistence and resilience, and could provide room for inland migration in response to sea level rise. This is one of the few places where this is possible in Southern California.

- **Consideration should be given to potential brackish marsh areas within Mugu Lagoon.** Rush stands documented at the northern edge of the complex may have been important historically for light-footed clapper rail, as they are today. Expansion of this habitat may be an important part of species recovery and enhancement plans.

Fig. 6.29. San Jon Road at Highway 101, looking west. Areas of the Pierpont lowland are still susceptible to flooding, as shown in this December 2008 photograph.

RECOMMENDED FUTURE RESEARCH

This study documents historical landscape patterns of the Santa Clara and Ventura river valleys, the Oxnard Plain, and the Ventura County shoreline prior to major Euro-American modification. In particular, it focuses on former habitat distribution, riverine character and processes, and riparian ecology in each of these areas. However, there are a number of additional research directions that would enrich our understanding of the historical landscape and enhance our ability to apply these findings to current local management.

Additional geographic areas of interest

This research focused on the Ventura County portion of the Santa Clara River and valley, with limited investigation on upper (Los Angeles County) river reaches. Additional data on the upper river undoubtedly exists in Los Angeles County archives not visited during the course of this project, such as the Santa Clarita Valley Historical Society, the Los Angeles Public Library, the Braun Research Library, the Los Angeles County Surveyor's Office, and the Los Angeles County Assessor's Office. A more detailed understanding of this portion of the river, in conjunction with other studies (e.g., Stillwater Sciences 2011), would provide insight into the historical hydrogeomorphic processes and riparian patterns across the entire river.

The study area also excluded a few adjacent areas of possible interest. These include the Ojai Valley east of the Ventura River, and the Santa Rosa Valley and Conejo Valley/Thousand Oaks area east of the Oxnard Plain. In addition, while the lowest reaches of major tributaries to the Santa Clara River were included within the study area, they were not the focus of our research. Subsequent data collection and analysis efforts could reveal more details on the historical dynamics of these systems, in particular Santa Paula, Sespe, and Piru creeks.

Future research directions

Though this study covers many aspects of the Ventura County historical landscape, it is not comprehensive. A number of additional topics merit further research, and would contribute to a better understanding of ecological and hydrogeomorphic pattern, process, and function in the region. While we performed limited analysis of historical botanical and ornithological records, the voluminous available data merit more substantial analysis. In addition, we did not explore historical faunal records. A detailed analysis of these wildlife records by regional experts may support interpretation of historical habitats and linkages with species support functions, which is for the most part not covered in this report. This is particularly true for native fisheries use of Ventura County streams.

Future research into processes and dynamics that shaped the historical ecological landscape would further develop our understanding of former conditions. For example, more in-depth investigations of the history of invasive species introduction (such as *Arundo donax*), fire ecology, historical grazing impacts, and Chumash land management would provide important context for interpreting historical conditions.

In addition, future research may further elucidate historical trends and characteristics outlined here. Interviews with long-time county residents would deepen our understanding of local environmental change and persistence. Scientific studies using geoarchaeology, coring, remote sensing, and other techniques could also add additional detail to this picture of early conditions. More extensive field-based assessment of the findings outlined here would also be useful.

Application of report findings

The research presented in this report provides the foundation for supporting local and regional environmental management with detailed historical data. However, the historical record alone is insufficient to apply these findings on the ground. This research must be integrated with contemporary assessments of physical and biological conditions to develop practical, place-specific conservation strategies for use by local organizations. For example, the management implications explored here for floodplain and riparian restoration need to undergo feasibility analysis before application to particular sites. Partnerships between local residents, managers, and scientists is a crucial component of determining how and where to apply these data.

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Strategic Plan for Arundo Treatment and Post-treatment Revegetation

September 2011

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1 INTRODUCTION

1.1 Background

The 116-mile-long Santa Clara River flows from the San Gabriel Mountains in Los Angeles County, through Ventura County, and eventually into the Pacific Ocean near the City of Ventura (Figure 1-1). The river and its floodplain have been significantly altered due to flood protection infrastructure, water diversions and flow regulation, roads, agriculture, aggregate mining, urbanization, and invasion by non-native plants. These impacts have constrained or disrupted natural geomorphic and hydrologic processes, often causing riparian and aquatic habitat loss or degradation. Despite the alterations to the riparian system, the lower Santa Clara River presents a unique opportunity to conserve and restore riparian functions and ecosystems compared with other coastal southern California rivers, most of which are highly degraded. As the watershed is one of the least altered rivers in southern California, it continues to support a variety of natural aquatic and terrestrial communities and native species. It also provides a regionally important north-south corridor between protected terrestrial wildlife areas in the southern California coastal ecoregion, and the river itself provides an important aquatic habitat linkage from the coast and estuary to upstream habitats in the mainstem channel and tributaries.

The Santa Clara River Parkway (Parkway) project, which is lead by the California State Coastal Conservancy (Coastal Conservancy) and The Nature Conservancy (TNC), seeks to ameliorate historical ecological impacts in the lower 33 miles of the river, from the Los Angeles County line to the Pacific Ocean, and conserve existing riparian habitats by acquiring and restoring existing habitat and flood-prone property from willing sellers. The primary goal of the Parkway project is to create, protect and restore 33 miles of continuous river and floodplain corridor from the mouth of the mainstem Santa Clara River to the Ventura/Los Angeles County line. Other goals of the Parkway project are to: 1) conserve and restore aquatic and riparian habitat for native species, 2) provide enhanced flood protection, and 3) provide public access and environmental education within the Parkway. The Parkway is being created through the acquisition of river channel, floodplain, and agricultural lands vulnerable to flooding, and conversion of those lands back to riparian and upland habitats. Land acquisition is being conducted on a willing seller basis and is focused on the lower river, where a number of parcels have already been acquired (Figure 1-2).

The Santa Clara River Parkway Floodplain Restoration Feasibility Study (Stillwater Sciences 2008) was undertaken for the Coastal Conservancy to assist with the acquisition, management, and eventual restoration of lands within the Parkway. The Feasibility Study identified non-native invasive species removal as one of the six primary restoration strategies for the Parkway, and the treatment of arundo (giant reed; *Arundo donax*) in particular. Arundo is a highly aggressive, naturalized landscape plant that is a relative of bamboo and invades riparian zones by establishing dense, monospecific clonal stands (DiTomaso and Healy 2007). It is widely distributed in the watershed, spreads quickly (it establishes by vegetative propagules, most often rhizomes that wash downstream from eroded banks [DiTomaso and Healy 2007]), and severely impacts the ecology of the riparian corridor (Stillwater Sciences and URS 2007).

- Dry and dead arundo stems, or canes, create a thick, dry fuel source and are highly flammable. Arundo has been shown to increase the likelihood and intensity of fire in Southern California riparian corridors, and in the Santa Clara River specifically (Coffman 2007, Coffman et al. 2010, Geissow et al. 2011). In addition, arundo is shade-tolerant and has established under the canopy of native vegetation.

Figure 1-1. The Santa Clara River watershed.

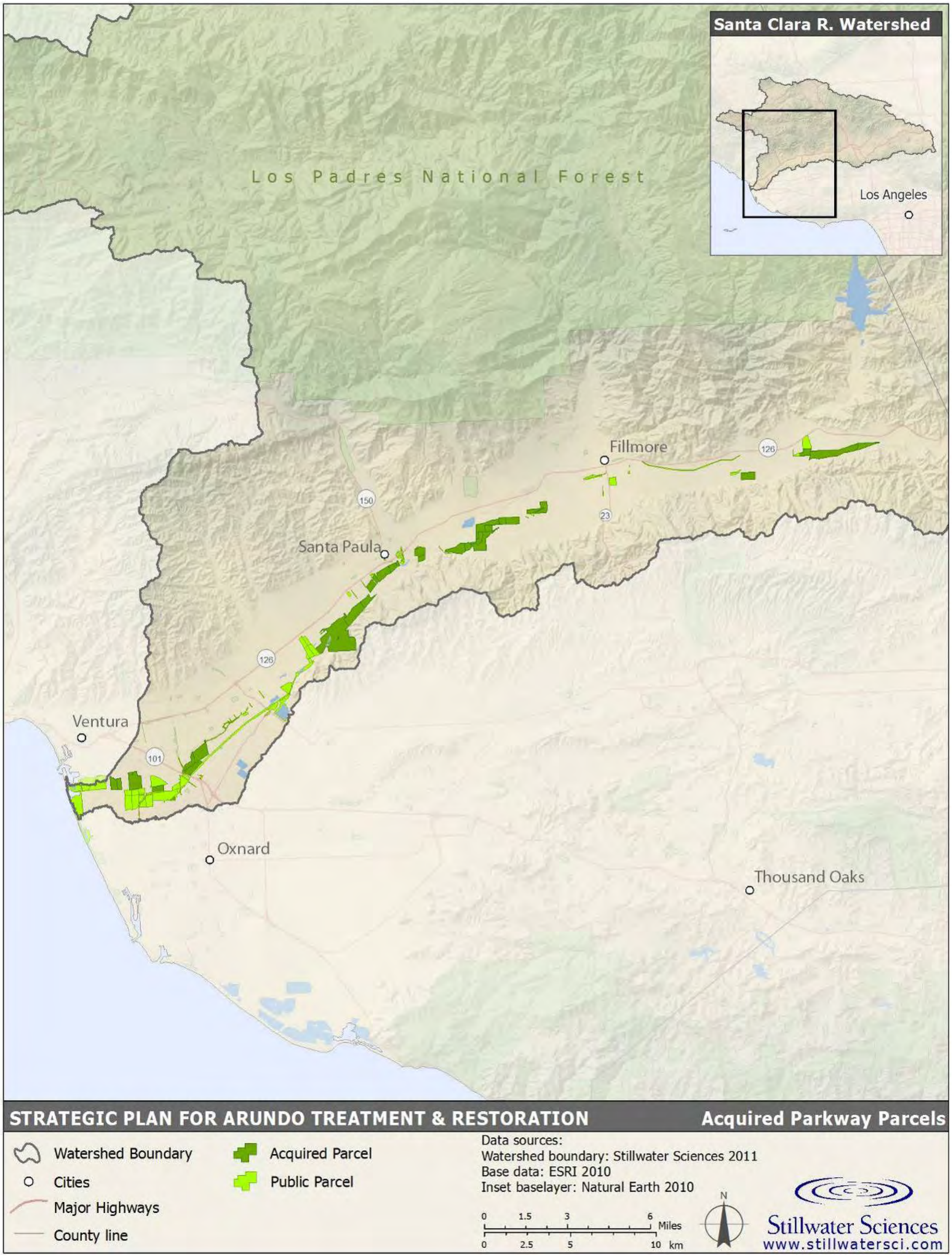

Figure 1-2. Santa Clara River Parkway parcels.

This exposes native riparian trees, which are much less tolerant of fire, to increased fire threat, contributes to the spread of wildfires from and between drier upland vegetation communities, and reduces the function of the riparian corridor as a natural barrier to fire. Arundo also re-sprouts vigorously after fire by quickly exploiting released nutrients, allowing it to outcompete and replace native plant species (Coffman 2007, Coffman et al. 2010). Past and potential future fires along the Santa Clara River, such as the ones that burned approximately 11% of the watershed in 2003, are likely to increase the cover and extent of arundo along the riparian corridor and exacerbate the arundo-fire cycle (Stillwater Sciences 2007b, Lambert et al. 2011).

- Arundo is a hydrophyte and uses a large amount of water to supply its very high rate of growth (Bell 1997, Geissow et al. 2011). A variety of studies in the arid west have demonstrated that, based on its evapotranspiration rate, arundo uses anywhere from three to 110 times more water than native riparian plant species (see Coffman and Ambrose 2011).
- Large stands of arundo obstruct river flow, increase stream roughness, and create debris dams at bridge crossings, thereby increasing the risk of flooding, bank erosion, and damage to infrastructure (DiTomaso 1998, Coffman and Ambrose 2011). In a recent study of several modeled Southern California stream channels, large stands of arundo were found to significantly reduce flood capacity and alter river geomorphology (NHC 2011).
- Arundo is a strong competitor in systems with increased nutrient supply, and heavy fertilizer use may be an important factor aiding its dominance over native riparian plant species in the Santa Clara River watershed (Coffman 2007). It outcompetes native plant species such as willows, mulefat, and cottonwoods, which provide bird nesting habitat for protected least Bell's vireo (*Vireo bellii pusillus*) and southwestern willow flycatcher (*Empidonax traillii eximus*) (Bell 1997, Kisner 2004, Coffman and Ambrose 2011). Silica in arundo leaves and stems reduces herbivory by many native insects and grazers, and its dense growth form can physically restrict wildlife movement through the riparian corridor (Jackson and Nunez 1964 and Kisner 2004, as cited in Coffman and Ambrose 2011).

In the same way that arundo has a multitude of impacts on riparian ecology, treatment of arundo can have a variety of benefits. Reducing the amount of arundo in and adjacent to the riparian corridor can help disrupt the arundo-fire cycle and reduce the risk, extent, and intensity of wildfires. Studies have estimated that treatment of arundo can increase the amount of water available for both ecosystem and human uses, and that the cost of arundo treatment is far outweighed by the benefit in water savings (Seawright et al. 2009, Geissow et al. 2011). Treatment of arundo in the Parkway will provide the opportunity for native vegetation to reestablish and improve the quality of riparian habitat for various wildlife species. At the Hedrick Ranch Nature Area on the lower Santa Clara River, an increase in the abundance and diversity of riparian and special-status bird species has been documented following arundo treatment and riparian restoration activities (WFVZ 2010). This has included numerous pairs of least Bell's vireo and observations of southwestern willow flycatcher and yellow-billed cuckoo (*Coccyzus americanus*).

The Feasibility Study broadly defined the strategy for non-native invasive plant removal and provided guidelines for prioritizing arundo removal projects in the Parkway:

- Projects should generally be conducted from upstream to downstream and in tributaries. These areas have lower risk of reinfestation and reduce the supply of propagules to downstream areas.
- Upland or transition zones between riparian areas and upland areas should be priority areas for removal projects to reduce the supply of propagules to lower areas and to reduce the fire risk to the riparian corridor and adjacent vegetation types.

- Watersheds with low nutrients should be priority areas for removal projects, as these areas would be less likely to favor the reestablishment of arundo over native species.
- Projects should be conducted in the summer following flood event when biomass has already been washed downstream and it is easier to access, cut and treat the plants.
- Projects should be conducted after fires to take advantage of the loss of biomass and to suppress rapid arundo regrowth following fires.
- Projects should be done outside the breeding season (mid-March to late September) of bird species that may use arundo as nesting habitat. In addition, where large tracts of arundo are removed and reduce nesting habitat availability, projects should be quickly followed by revegetation with native riparian species to replace structural habitat for scrub-nesting birds.

While the Feasibility Study broadly defined a strategy for arundo treatment, the lack of a detailed and spatially explicit strategy has made it difficult for the Coastal Conservancy and TNC to know where to start in selecting and acquiring funding for specific treatment projects. The Coastal Conservancy wanted a comprehensive look at the arundo problem in the Parkway, as well as a strategy and a sense of the magnitude of the cost as it pursues funding opportunities. The Coastal Conservancy also recognized that too many arundo removal proposals it receives are piecemeal, uninformed, and would be unsuccessful without a scientifically supported and pragmatic strategy. Fortunately, the Feasibility Study included the development of a number of spatial data sets, including flood frequency mapping, riparian vegetation mapping, and arundo percent cover mapping, which can be used to inform a more detailed and spatially explicit strategy for arundo treatment. Contributing to this difficulty are wide ranging cost estimates for arundo treatment and uncertainty in permitting requirements and costs.

This report summarizes the objectives, methods, and results of a strategic plan for arundo treatment and post-treatment revegetation to restore native riparian habitat for parcels in the Parkway, along with permit and cost information and treatment priorities.

1.2 Goals and Objectives

The primary goal of this strategic arundo plan is to provide the information necessary for the Coastal Conservancy and TNC to select and acquire funding for specific arundo treatment and native riparian habitat revegetation/restoration projects in the Parkway. Specific objectives to support this goal are to:

- Identify effective and appropriate arundo treatment approaches for Parkway lands.
- Identify maintenance requirements, costs, and permits associated with those methods.
- Identify specific areas for the application of treatment methods and priorities for treatment on existing Parkway parcels, using existing spatial data sets (e.g., arundo percent cover, riparian vegetation, and flood frequency) and field reconnaissance.

While the Coastal Conservancy and TNC need cost estimates and specific strategies for the lands that they own or will acquire soon as part of the Parkway, they are also interested in using this strategy and subsequent studies to engage other public agencies that own river lands as well as private landowners as partners in the arundo treatment effort. Hence, while the focus of this study is on current Parkway parcels, cost estimates are provided that include other public and private lands infested with arundo in the lower Santa Clara River.

Subsequent phases of this strategic plan may expand this effort to potential, but not yet acquired Parkway parcels and/or other relevant lands in the Santa Clara River watershed. It is also important to note that areas in the Parkway that do not contain arundo are not addressed in this plan, which is focused on strategies and priorities for arundo treatment and subsequent post-treatment revegetation. Although there are a number of Parkway parcel areas that are suitable for or high priority for revegetation or other restoration strategies (such as removing or setting back levees or developing water quality treatment wetlands), it is recommended that these be addressed at the site-scale (e.g., as parcel-specific restoration plans) or as a separate strategic planning effort.

1.3 Study Area

The Santa Clara River Parkway focuses on the lower 33 miles of the mainstem Santa Clara River, downstream of the Los Angeles/Ventura County Line (Figure 1-1). This strategic arundo plan is specifically for existing parcels in the Parkway, and is organized by the 13 Parkway parcel complexes (i.e., smaller adjacent parcels have been merged into one complex name in some cases): Totlcom, McGrath, Strathmore, Santa Clara Ranch, Hanson-Villanueva, City of Santa Paula, Prairie Pacific, Peto, Hedrick Ranch, Valley View, Aflalo, Lago Marcino, and Vulcan (Figure 1-2).

The Santa Clara River originates on the northern slopes of the San Gabriel Mountains in Los Angeles County (approximately 9,000 ft above mean sea level). It flows through the Santa Clara River Valley and the Oxnard Plain in Ventura County before emptying into the Pacific Ocean near the City of Ventura (Figure 1-1). The river is one of the largest watersheds on the southern California coast, draining an area of approximately 1,600 mi^2. Consistent with other rivers in the region, the Santa Clara River watershed experiences highly variable annual rainfall and peak river flows. During the dry summer season, flows in the mainstem and tributaries are intermittent or non-existent, depending primarily on areas of rising groundwater or inflows from dam releases or other anthropogenic sources, such as irrigation runoff and treated wastewater effluent (Stillwater Sciences 2007a). During winter rainfall events, however, flows can increase, peak, and subside rapidly, with the potential for severe flooding under saturated or near-saturated watershed conditions. In planform, the lower Santa Clara River is characterized by a wide, relatively straight floodway with one or more low-flow channels that are reconfigured after each flood event. The full mainstem channel bed is occupied only during higher magnitude floods, typically larger than a 5-year event. As floods recede, the river becomes more braided in character, with multiple flow courses. There is insufficient perennial flow to retain multiple flowing channels in a majority of the lower Santa Clara River and, in general, a single dominant channel defines the channel thalweg (Stillwater Sciences 2007a).

Arundo is abundant and well distributed throughout the 500-year floodplain of the lower river (Figure 1-3). Arundo-specific vegetation mapping indicates that the species occurs at varying levels of percent cover on 5,242 ac of the lower river corridor (Stillwater Sciences and URS 2007). There are approximately 216 ac with 80–100% arundo cover, where the vegetation generally has a dense, continuous shrub layer completely dominated by arundo (Figure 1-3). Another 1,290 ac have 20–79% arundo cover, where mulefat (*Baccharis salicifolia*) or various willow species (*Salix* spp.) are generally co-dominant species, and another 3,736 ac have 1–19% arundo cover, where arundo is generally a component of the shrub or understory layers of mixed riparian forest and scrub communities (Figure 1-3). Figure 1-3 is based on conditions and arundo levels in 2005 and 2006 and there is the potential that some areas may have been invaded or reinvaded by arundo (particularly riverwash areas that were bare in 2005 as a result of a recent flood). Remapping arundo on Parkway parcels was, however, beyond the scope of this plan. As such, updated mapping of arundo, and tailoring the arundo treatment and post-treatment revegetation types and priorities accordingly, to capture current conditions is likely to be necessary at the site-scale before proceeding with arundo treatment implementation.

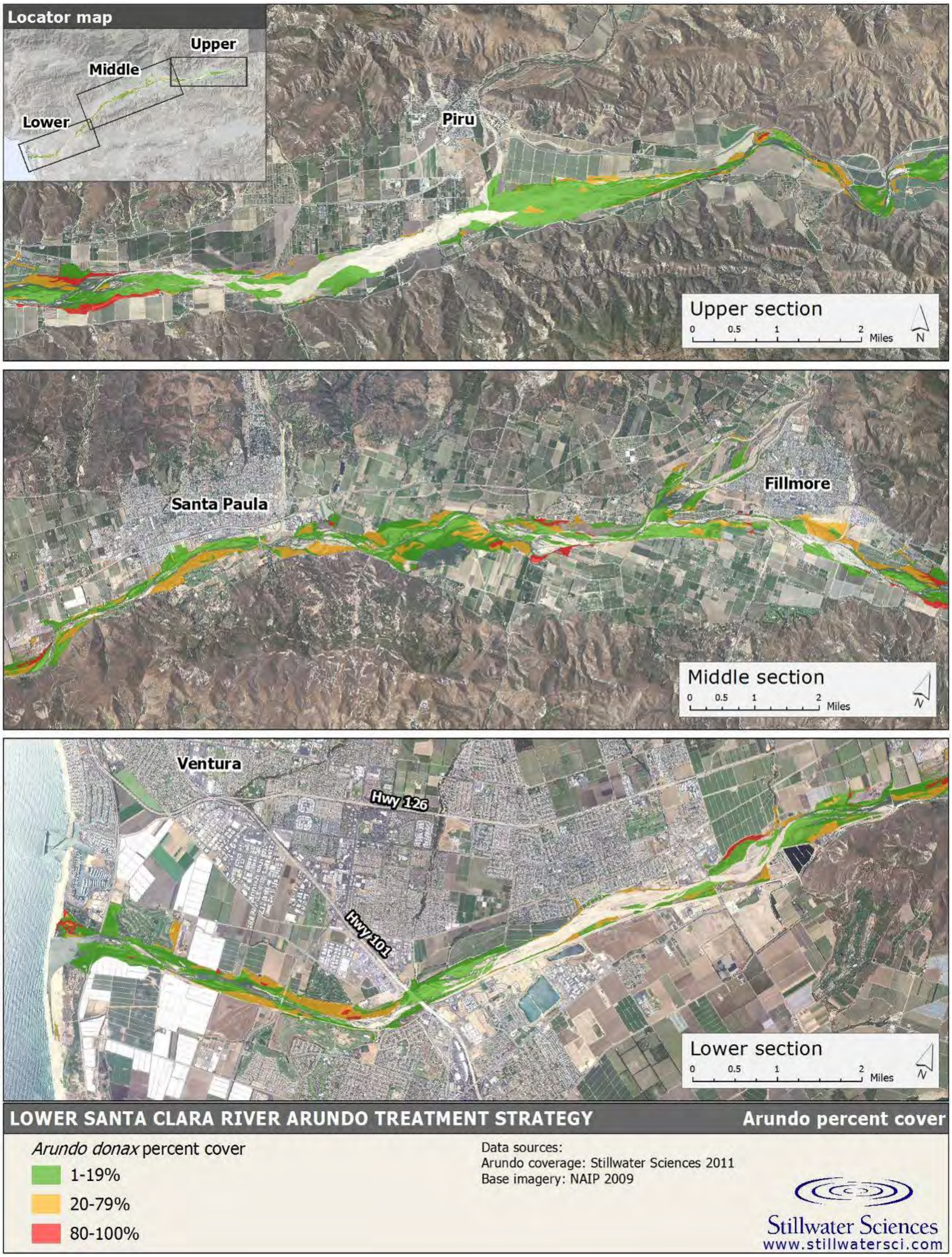

Figure 1-3. Percent cover of arundo in the lower Santa Clara River 500-year floodplain.

2 ARUNDO TREATMENT METHODS AND COSTS

Initial investigations into arundo treatment costs revealed a very wide range of costs/acre, depending on the project region, project size, methods, permitting effort, degree of arundo infestation, and other factors (Appendix A). Several arundo treatment experts with experience in the region were interviewed to identify the most effective treatment methods, the most important determinants for cost, and costs per acre for treatment methods and site conditions that would be characteristic of the lower Santa Clara River. Application of approved herbicides (e.g., imazapyr and glyphosate) and associated adjuvants (materials such as surfactants, dyes, and oils that aid in the application of herbicides), whether on standing arundo, cut arundo stumps, or regrowth after cutting, was unanimously considered the most effective method for treating arundo under the kinds of conditions in the Parkway. The cutting and removal of arundo stems, whether prior to or following herbicide treatment, is the most expensive component of arundo treatment projects. Cutting arundo stems prior to herbicide treatment (also referred to as biomass removal) can be accomplished using mechanical (e.g., mowing and/or mulching) and/or hand techniques, with hand methods being much more time consuming and expensive. Arundo treatment projects may be required to remove or dispose of cut or dead arundo stems from the river or floodplain after herbicide treatments to reduce the perceived risk of fire and/or flooding to adjacent lands and infrastructure and the potential for arundo propagules to be transported downstream. Depending on the disposal method, for example whether stems can be mulched on site or must be disposed of at a landfill, this greatly increases the cost of arundo treatment projects and can easily make many projects financially unfeasible.

The most common methods for arundo treatment in Southern California, and their associated costs, are summarized below and in Table 2-1. Appendix A lists the various cost estimates gathered, considered, and used to develop the estimates provided in Table 2-1.

- **Spray only.** This method has been shown to be effective in Southern California areas where leaving dying and dead arundo stems is appropriate (e.g., in areas with low arundo cover and/or where dead material will not increase fire risks) (Giessow 2010, Neill 2010). Approved herbicides are sprayed directly onto standing arundo stems, either via backpack sprayers or vehicle-mounted spray tanks (Katagi et al. 2002). Because this method does not involve biomass removal it is one of the more cost-effective and straightforward methods to implement (Table 2-1).
- **Contingency.** This method is a variation on spray only. Herbicide is sprayed onto the regrowth of arundo that has recently been scoured by floods or burned by fire. Under these conditions, much of the arundo biomass and surrounding vegetation has been removed, which facilitates access, reduces the amount of regrowth that must be sprayed, and is the cheapest treatment method to implement (Table 2-1).
- **Bend-and-spray.** This method requires minimal crews and equipment and minimizes the risk of herbicide application to non-target vegetation. As such, it is one of the most suitable methods for remotely located, small to moderately sized infestations, with interspersed native vegetation (Newhouser 2008, Coffman and Ambrose 2011). The bend-and-spray method involves at least one worker bending arundo stems away from native vegetation and an herbicide applicator spraying the bent stems with an approved herbicide (Coffman and Ambrose 2011). The hook-and-spray method is a variation of this method that involves only an applicator, who hooks and bends arundo stems with one hand and sprays the bent stems with herbicide with the other (Coffman and Ambrose 2011). These methods are described in more detail by Coffman and Ambrose (2011). If dead arundo stems treated with these methods can be left in place, these methods are similar in cost to spray only, although slightly more expensive due to the increase in

labor hours (to bend or hook the stems) (Table 2-1). If dead arundo stems must be mulched or removed, then the cost is significantly higher (Table 2-1).

- **Cut-and-daub/cut-and-spray.** Depending on the method with which arundo stems are cut, this method can be appropriate in a wide variety of conditions. Both methods include cutting arundo stems at or near the ground surface. Using cut-and-daub, cut arundo stumps are immediately painted with an herbicide (Coffman and Ambrose 2011). Using cut-and-spray, cut stems are allowed to regrow for a season or two and then sprayed with herbicide. In dense arundo infestations that can be accessed by vehicles, arundo stems can be cut with modified mowers and/or mulchers. In less dense infestations or where access is constrained, arundo stems can be cut with a chainsaw or hand tools. Because cut arundo stems can sprout into new arundo plants, it is important that cut stems not be allowed to fall in or near waterways. These methods are described in more detail by Coffman and Ambrose (2011). As with bend-and-spray methods, the cost of this method is significantly less if cut arundo stems can be left in place rather than mulched or removed (Table 2-1).
- **Maintenance/retreatment.** Arundo treatment projects should plan for approximately five years of follow-up treatments or maintenance to ensure that all arundo biomass is killed (Giessow 2010, Neill 2010). Since retreatment is done on previously cut and/or treated arundo, it generally consists solely of herbicide application and is relatively cost effective to conduct (Table 2-1).

The timing of these methods is critical to their success, but is constrained by arundo life history (i.e., when it is growing and would most effectively translocate herbicide into the root system), seasonal climate conditions (when herbicides can be safely and effectively applied), and the bird nesting season (March to September). Late summer through early fall (August to October) is frequently when herbicides are applied to standing arundo stems, or to stems that have been cut the previous winter. This timing avoids the bird nesting season and can maximize the efficacy of glyphosate herbicide, but can also allow for significant arundo regrowth (in which case access is constrained and more herbicide is necessary). Herbicide application to standing or previously cut arundo stems in spring or early summer, when arundo is actively growing, can maximize the translocation of herbicide, particularly imazapyr, into the root system (and more quickly kill the plant) and reduces the potential for significant arundo regrowth, but must be monitored and managed carefully to avoid nesting birds. All methods will most certainly require annual maintenance for several years to ensure that treated arundo is killed. The contingency method is likely to be most appropriate in the summer following a flood or fire, and should not interfere with bird nesting, as the flood or fire will have presumably removed any potential bird nesting habitat in the immediate vicinity.

The costs in Table 2-1 are applied to the acres of arundo both within and outside of existing Parkway parcels to develop total cost estimates for treating arundo in the Parkway and in the entire lower Santa Clara River in Section 4.

Table 2-1. Arundo treatment cost/acre ranges.

Treatment type	Description	Cost/acre range*	Notes
Contingency/ Maintenance/ Retreatment	Herbicide application on scoured, burned, or previously treated regrowth	$1,000-2,000	This includes annual retreatment for all treatment types.
Spray only/bend-and-spray	Foliar herbicide application on standing biomass (i.e., no biomass removal)	$3,000-6,000	Biomass density and protection of native plants increases cost relative to Contingency-level treatment; also more herbicide and labor hours are necessary. Spray only is captured by lower end of cost range, while bend-and-spray is captured by higher end of cost range. This report combines these two treatment types into "spray only".
Cut-and-daub/cut-and-spray	Herbicide application on cut stumps or regrowth; biomass left on site	$4,000-9,000	Cost depends on biomass removal method (e.g., mechanical, by hand, or a combination). This report refers to these methods as "mechanical", "hand", or "mixed".
Cut-and-spray with disposal	Herbicide application on cut stumps or regrowth; biomass removed from site	$7,000-150,000	Cost depends on biomass removal method (e.g., mechanical, by hand, or a combination). Stem removal is estimated to cost an additional $3,000/acre, if a flail mower is used, to $150,000/acre if hand crews are used to mulch stems (Neill 2010). This report refers to these methods as "mechanical", "hand", or "mixed".

*cost estimates based on treatment of 50-acre site, with gentle gradients, and available site access.

3 ARUNDO TREATMENT PERMITS

A programmatic permitting effort for arundo treatment, such as what is already in place for the upper Santa Clara River watershed (Ventura County Resource Conservation District 2006), is underway for the lower watershed. At this time it is unknown when the programmatic permitting effort will be completed, when the permits will be acquired, and when and under what conditions individual projects may be covered under the programmatic permits. While the programmatic permits will presumably be a great asset to arundo treatment projects throughout the entire lower watershed once they are in place, the Coastal Conservancy sought to better understand individual project permitting requirements in the interim.

Regional permitting guidelines were reviewed, and relevant regulating agencies, as well as individuals experienced in arundo treatment permitting were interviewed to identify the range of potential permit requirements for arundo treatment projects in the Parkway. Table 3-1 summarizes the permits, regulating agencies, and triggers that are most relevant to arundo treatment projects in the Parkway, given the location, likely methods, and incorporated conservation measures. Much more exhaustive descriptions of these and other potential permit requirements are available from Katagi et al. (2002), Ventura County Planning Division (2006), Ventura County Resource Conservation District (2006), and Wildscape Restoration (2010).

Table 3-1. Potential permit requirements for arundo treatment projects.

Regulation	Regulating agency	Trigger for permit	Likely permit type
Clean Water Act Section 404	USACE	Working in floodway and building roads, placing thick mulch, etc	Regional General Permit 41
Endangered Species Act Section 7 or 10	USFWS and/or NOAA Fisheries	Working near federally endangered or threatened species or their critical habitat	No-take-concurrence letter, Biological Opinion, or Safe Harbor Agreement
California Fish and Game Code Section 1600	CDFG	Working in floodway and riparian zone	Streambed Alteration Agreement
Ventura County	Ventura County Watershed Protection District	Working in red-line stream in Ventura County	Encroachment/water course permit

3.1 Clean Water Act Section 404 Regional General Permit

Under Section 404 of the Federal Clean Water Act (CWA), the U.S. Army Corps of Engineers (USACE) has jurisdiction over the area between any levees on the Santa Clara River and the cross-sectional extent of high-flow debris lines, as well as any adjacent wetlands that meet USACE criteria. Projects within this jurisdiction that require the excavation of stumps, building of roads, and potentially the placement of thick mulch in this area would require a Section 404 permit. Many arundo treatment projects in the Parkway are not likely to include actions or be conducted in area that are under the USACE's jurisdiction and, therefore, will not require a Section 404 permit. Those that are determined to be under the USACE's jurisdiction (e.g., when mulch is left in place) should qualify for a Section 404 Regional General Permit (RGP) 41, which covers weed removal in areas with densities greater than 50%. RGP 41 includes CWA Section 401 certification from the Regional Water Quality Control Board, but will trigger the need for

Section 7 consultation with U.S. Fish and Wildlife Service (USFWS) and/or National Marine Fisheries Service (NOAA Fisheries). A Section 404 RGP can take a few months to complete and acquire.

3.2 Endangered Species Act consultation

Whether or not a Section 404 permit is required, federal Endangered Species Act (ESA) consultation (under either Section 7 or 10) with USFWS and/or NMFS is likely to be required given the presence of federally listed species in and around the Parkway. For most treatment projects in the Parkway, No Take Concurrence from USFWS and/or NMFS should suffice, so long as projects incorporate take avoidance measures and are not so large that listed bird species may need to nest elsewhere. No Take Concurrence typically takes approximately 30 days. If these conditions do not apply, then a Biological Opinion (if a Section 404 permit is required) or a Safe Harbor Agreement (if a Section 404 permit is not required) may be necessary. These processes can take several months to a year.

3.3 Fish and Game Code Section 1600 Streambed Alteration Agreement

All arundo treatment projects in the Parkway will likely require a Section 1600 Streambed Alteration Agreement from the California Department of Fish and Game (CDFG). In fact, a Section 1600 permit may be the only permit required for many arundo treatment projects in the Parkway, since many of these projects are unlikely to trigger federal or local permits due to their location and magnitude. The programmatic Section 1600 permit recently acquired by TNC (Notification No.1600-2010-0196-R5) should cover most arundo treatment projects in the Parkway, as additional parcels can be easily added to the TNC permit. There are, however, several requirements of the TNC Section 1600 permit that will affect the cost and schedule of treatment projects, including:

- Pre-project surveys for special-status species must be done three weeks before start of project;
- All project field staff must attend environmental training sessions(s);
- A biological monitor must be on-site during all treatment work; and
- Development and implementation of mitigation and/or restoration plans may be required.

3.4 Ventura County Watershed Protection District Encroachment Permit

An encroachment permit from the Ventura County Watershed Protection District (VCWPD) is required for any project within the 100-year floodplain of the red-line stream. The permit application requires a $215 fee, a $2,000 trust deposit (against which VCWPD permit staff charge their time), and proof of insurance. It may also require a hydraulic assessment report if the project would leave a notable amount of mulch within the stream channel or includes extensive revegetation.

4 ARUNDO TREATMENT AND POST-TREATMENT REVEGETATION TYPES AND PRIORITIES

4.1 Methods

4.1.1 Primary flood reset zone

One of the most important aspects of this study is the identification of the primary flood reset zone. The identification and use of this zone may provide the single biggest cost saving opportunity in planning and implementing arundo treatment projects on the lower Santa Clara River, particularly when compared to conventional site-specific bottom-up arundo removal programs that do not take landscape-scale processes into consideration. The primary flood reset zone was defined to identify areas suitable for arundo treatment projects, the type of arundo treatment methods that will be appropriate, and the level of revegetation that may be necessary. The primary flood reset zone was defined by the combined extents of scoured or partially scoured areas from the 1995 and 2005 floods in GIS (see Stillwater Sciences 2007a), which were 13- and 16-year flood events, respectively. As such, the primary flood reset zone is an estimation of the area that is likely to be reset via scour and/or deposition in the next 10- to 20-year flood event.

The physical removal of arundo biomass greatly increases the cost of arundo treatment projects. Floods, as well as fires, are effective at clearing large swaths of arundo biomass, and present obvious opportunities for cost effective treatment, since treatment would consist only of herbicide application (see Table 2-1). The flood reset zone provides an estimate of the arundo-infested areas that are highly likely to be scoured and have arundo biomass removed naturally during a high-flow event. In addition, arundo treatment in this zone will require only limited herbicide application to treat new growth from those rhizomes that do remain after a high-flow event. The primary flood reset zone is also the area that is most likely to be successfully revegetated through natural recruitment, rather than expensive active planting, which could be scoured away by a subsequent high-flow event. Major arundo treatment or revegetation expenditures in the primary flood reset zone could be undone quickly by the introduction and reinfestation of arundo from upstream sources in the watershed, further limiting the utility of treatment methods that require biomass removal or revegetation that requires active planting.

4.1.2 Arundo treatment types

Outside the primary flood reset zone, arundo percent cover and vegetation composition (Stillwater Sciences and URS 2007) were the primary variables used to identify areas suitable for arundo treatment projects and the treatment approach that may be appropriate on Parkway parcels. In addition, a field reconnaissance was conducted to evaluate opportunities and constraints to various methods of arundo treatment in the Parkway.

Arundo percent cover outside the primary flood reset zone was divided into three categories that, based on our experience mapping arundo in the watershed, we believed would be indicative of the range of site conditions and type of treatment methods that may be appropriate in the Parkway: 1–19%, 20–79%, and 80–100%. Arundo percent cover was overlaid with vegetation mapping of the lower Santa Clara River in GIS to determine the degree and type of native vegetation that may be interspersed with arundo in different areas. Whether or not arundo biomass removal would likely be required was also evaluated to determine appropriate treatment types and associated costs. In some areas, it may be feasible and appropriate to spray arundo biomass directly with herbicide and leave the dead stems standing in place (i.e., spray only). Due to the fire risk associated with dead arundo biomass, however, the spray only treatment type was no considered suitable in areas with very large tracts of arundo or near developed areas. Table 4-1 summarizes the evaluation process used to identify arundo treatment types for Parkway parcels (these treatment types correspond to one or more of the treatment methods described in Section 2). These decision rules were applied in a GIS to identify the arundo treatment types for specific areas of Parkway parcels, and modified as necessary to reflect opportunities and constraints in specific parcel areas.

Table 4-1. Decision rules to identify arundo treatment types.

Decision rule	Treatment type
1. Arundo inside primary flood reset zone	Flood contingent (foliar herbicide application following floods, and potentially fire)
1’ Arundo outside primary flood reset zone	
2. No biomass removal required	Spray only (foliar herbicide application on standing stems)
2’ Biomass removal required	
3. Arundo % cover > 80	Mechanical (mowing as lone or primary biomass removal method prior to foliar herbicide application)
3’ Arundo % cover <80, >20	Mixed (combination of mowing and hand removal of biomass prior to foliar herbicide application)
3’’Arundo % cover <20	Hand (hand removal of biomass prior to foliar herbicide application)

4.1.3 Post-arundo treatment revegetation types

Revegetation of native plants follow arundo treatment can increase the extent and improve the quality of riparian habitat and contribute to ecosystem functioning (Stillwater Sciences 2008). The type of post-treatment revegetation – passive, active, or limited active - appropriate for arundo treatment areas on Parkway parcels was identified based on the selected arundo treatment type, the proximity of the area to native propagule sources, the potential for inundation by high-flows, the elevation and landscape position of the area, and nearby vegetation types. Arundo treatment and revegetation types were then modified as necessary to reflect opportunities and constraints in specific parcel areas. As mentioned previously, it is important to note that there are a number of Parkway parcel areas that are suitable for and/or high priority for revegetation or other types of restoration, but that are not addressed in this plan because they do not contain arundo. These areas will have to be addressed at the site-scale (e.g., as parcel-specific restoration plans) or as a separate strategic planning effort.

In areas where floodplain inundation occurs across a wide area and/or groundwater levels are high, revegetation should rely primarily on natural recruitment, or passive revegetation. These areas are well represented by the primary flood reset zone (Section 4.1.1). Vegetation mapping in 2005 and 2006 and experiments on Hedrick Ranch confirm that natural seed sources are adequate for passive revegetation in many reaches of the lower Santa Clara River (Stillwater Sciences and URS 2007, Coffman and Ambrose 2011). Passive revegetation is generally ill suited where flood flows do not inundate at least once every year or two, or where groundwater levels are documented or suspected of being inadequate to sustain plants during the growing season (Stillwater Sciences 2008). In addition to flood inundation frequency, the extent of arundo treatment (i.e., a relatively small area) and the occurrence of a diverse assemblage and/or large extent of native plants on-site or nearby that could serve as a seed or propagule source was used to determine where passive revegetation will be appropriate and effective on Parkway parcels. These types of areas are generally considered the most appropriate for passive revegetation (Katagi et al.

2002, Coffman and Ambrose 2011).

Where passive revegetation is not expected to achieve restoration goals, perhaps because of a lack of upslope or upstream seed supply, less reliable surface inundation, or shallow groundwater levels, active revegetation should be implemented. Active revegetation consists of planting, and potentially irrigating, native species seedlings, cuttings and/or seeds. Active revegetation in the most active or dynamic portions of the floodway (*i.e.*, those portions of the river that are scoured by floods every one to two years), should generally be avoided. Passive revegetation is likely to occur in these areas without any intervention, and subsequent floods are likely to scour active revegetation efforts. In addition to areas with infrequent flood inundation, active revegetation was recommended for areas on Parkway parcels where:

- a relatively large area of arundo has been treated;
- there is a lack of native plants on-site or nearby that could serve as a seed or propagule source;
- there is a high level of site disturbance by humans or the presence of other site conditions (such as depth to groundwater) that are likely to limit natural revegetation processes; and/or
- accelerated revegetation is necessary (e.g., highly disturbed or former agricultural areas, and to replace the structural habitat needed for least Bell's vireo and southwestern willow flycatcher, both endangered bird species found in the lower Santa Clara River, during breeding season).

Lower cost active revegetation actions (*e.g.*, planting cuttings without irrigation in areas of high groundwater) might also be appropriate in some passive and/or active revegetation areas (e.g., small areas immediately adjacent to the primary flood reset zone). Planting cuttings of willow and cottonwood, which are relatively inexpensive, is more appropriate in areas that receive intermediate levels of scour from flood flows to replace the loss of structure following arundo removal (Stillwater Sciences 2008). This report refers to this as limited active revegetation.

In areas designated as appropriate for active to limited active revegetation following arundo removal, a general vegetation type potentially suitable for active revegetation in the area was recommended. Vegetation types were selected based on the on-site and/or adjacent vegetation type, flood inundation frequency, presumed groundwater levels, and landscape position. For example, willow, cottonwood, and mixed riparian forest and scrub vegetation types are located in areas outside the active floodway (i.e., where significant and frequent scouring would not be expected) and in gaining reaches of the river, where active revegetation is most likely to be successful (Briggs 1996, Stillwater Sciences 2008, Orr et al. 2011). More upland vegetation types, such as oak savanna, giant wildrye, and coastal scrub, were located in areas outside the active floodway and in drier, losing reaches (Stillwater Sciences 2007b, Orr et al. 2011). Guidance for the suite of native species to include in these active revegetation types is provided by Stillwater Sciences (2007b and 2008). Since vegetation type recommendations were based primarily on GIS information, they will need to be evaluated and refined at the site-scale (e.g., as parcel-specific restoration plans) prior to implementation.

While planting just prior to the rainy season can reduce the need for irrigation (although it may increase the chances for scour by winter floods), given the semi-arid climate and lowered groundwater table in some portions of the lower Santa Clara River corridor, irrigation is likely to be necessary for most active revegetation areas (which will not be inundated frequently). In these instances, drip irrigation should be considered as it helps conserve water and limit the establishment of weedy species that can compete with planted seedlings, cuttings, and seeds (Stillwater Sciences 2007b).

4.1.4 Arundo treatment priorities

As discussed previously, the Feasibility Study described a number of general criteria used to prioritize arundo treatment projects. Coffman and Ambrose (2011) also describe criteria for arundo treatment projects, including:

- Remove arundo under mature riparian forests, especially adjacent to fire-prone shrublands;
- Remove the largest arundo propagule sources;
- Control arundo on a watershed scale; and
- Remove arundo immediately after fires or floods.

Several of the Feasibility Study and Coffman and Ambrose (2011) criteria have already been incorporated into this plan, such as the inclusion of a contingency method to treat arundo immediately after fires and floods. While removing arundo on a watershed scale (as recommended by Coffman and Ambrose [2011]) or from upstream to downstream (as recommended in the Feasibility Study) is the ultimate goal of arundo treatment efforts in the Santa Clara River, it is unfeasible, unwise, and unnecessary to wait until arundo is eradicated from the upper watershed before beginning arundo treatment in the lower watershed. It may not be possible to ever eradicate arundo from the upper watershed, and in the meantime arundo would continue to invade and degrade native habitats. In addition, there is a significant amount of arundo in the lower watershed, such as on floodplain terraces and along tributaries, that can be treated and significantly improve habitat conditions with low risk of reinfestation from upstream.

While these general arundo treatment prioritization criteria are useful, additional criteria were necessary to prioritize arundo treatment efforts on specific Parkway parcel areas. Any arundo inside the primary flood reset zone was designated as a low priority, unless a flood or fire that removes arundo biomass from the area occurs. The priority for arundo treatment in these areas, which would be limited to herbicide application, would then be increased to high priority.

To prioritize arundo treatment areas outside the flood contingency zone, the following criteria were considered qualitatively for each Parkway parcel. Responses to these questions were used to rank treatment priorities as high, medium, or low.

- On-site habitat quality – if treated, would the area protect or contribute to any on-site areas of high habitat quality?
- Adjacent habitat quality – if treated, would the area protect or contribute to any adjacent areas of high habitat quality?
- Risk of reinfestation – if treated, could the area become easily or quickly reinfested by arundo?
- Fire risk – if treated, would the area reduce the risk of fire to adjacent infrastructure (e.g., Stillwater Sciences 2008, Coffman and Ambrose 2011)?
- Special features – if treated, would the area protect or contribute to any nodes of high quality habitat or unusual vegetation types?
- Amount of surrounding arundo – if treated, would the area make a significant or strategic reduction in any surrounding arundo (e.g., Coffman and Ambrose 2011)?

4.1.5 Arundo treatment costs

The costs/ac in Table 2-1 were applied to the acres of arundo both within and outside of existing Parkway parcels to develop total cost estimates for treating arundo in the Parkway and in the entire lower Santa Clara River. For Parkway parcels, the treatment methods and acres of individual arundo areas developed in Section 4.1.2 were used to identify and apply the appropriate cost/ac range from Table 2-1 (see Table 4-

2). For example, $1,000–2,000 was used for areas identified for flood contingent arundo treatment; $3,000–6,000/ac was used for areas identified for spray only arundo treatment; and $4,000–9,000/ac was used for areas identified for cut-and-daub/cut-and-spray arundo treatment with hand, mixed, or mechanical biomass removal (see Table 4-2). The lower end of cost ranges from Table 2-1 were used to estimate best-case scenario costs, while the higher end of the ranges were used to estimate worse-case scenario costs, where arundo stem removal and disposal may be required (Table 4-2). A cost estimate for arundo treatment maintenance was also calculated using a cost/acre of $1,500 (Table 4-2).

Table 4-2. Cost/acre estimates for arundo treatment methods on Parkway parcels.

Arundo treatment type	Cost/acre		
	Best-case Scenario	Worse-case Scenario	Maintenance
Flood contingent	$1,000	$2,000	$1,500
Spray only	$3,000	$6,000	
Manual	$9,000	$150,000	
Mixed	$6,500	$78,500	
Mechanical	$4,000	$7,000	

Outside of Parkway parcels, any arundo within the primary flood reset zone was assumed to be treated on a flood contingent basis, with a cost/ac range of $1,500. Outside the primary flood reset zone, arundo percent cover was used to estimate a potentially suitable treatment method and associated cost/ac. Half of areas with 1–19% arundo cover were assumed to require arundo biomass removal by hand prior to herbicide application ($9,000/ac), with the other half assumed to be appropriate for spray only treatment ($3,000/ac). Areas with 20–79% and 800–100% arundo cover were assumed to require arundo biomass removal using mixed and mechanical techniques, respectively, prior to herbicide application ($6,500 and $4,000/ac, respectively).

Due to the assumptions and generalities included in both the cost/acre estimates (Tables 2-1 and 4-2) and the selected treatment methods, these costs should be considered rough estimates only.

4.2 Results and Discussion

4.2.1 Primary flood reset zone

The primary flood reset zone, which was defined by the combined extents of scoured and partially scoured areas from the 1995 and 2005 floods, is depicted in Figure 4-1. Of the 5,242 ac of arundo mapped at varying levels of percent cover in the lower Santa Clara River, 3,093 ac, or 60%, occurs in the primary flood reset zone. Again, arundo treatment, which would be limited to herbicide application, inside this zone would be contingent upon a flood scouring the area and removing arundo biomass naturally. In addition, natural recruitment of native riparian plant species would be the means of revegetating arundo treatment areas inside the flood contingency zone. The primary flood reset zone should be a low priority for arundo treatment, unless a flood or fire that removes arundo biomass from the area occurs, in which case the arundo herbicide treatment should be a high priority.

Again, the primary flood reset zone is only an estimate; there is likely to be scour/reset in areas outside the primary flood reset zone during 10- to 20-year flood events, and most certainly during larger flood events. In addition, floods of these magnitudes will inundate a much larger area that estimated by the primary flood reset zone, but only a portion of the area inundated is likely to be reset by scour and/or deposition.

4.2.2 Arundo treatment and post-treatment revegetation types

Following the decision rules in Table 4-1 and criteria described in Section 4.1.3, five primary arundo treatment types were identified. Table 4-3 summarizes these types and incorporates the cost estimates and permitting requirements from Sections 2 and 3. Figures 4-2 through 4-9 depict the arundo treatment and revegetation types suitable for specific areas on Parkway parcels. Since arundo treatment and revegetation type recommendations were based primarily on GIS information, they will need to be evaluated and refined at the site-scale (e.g., as parcel-specific restoration plans) prior to ultimate implementation.

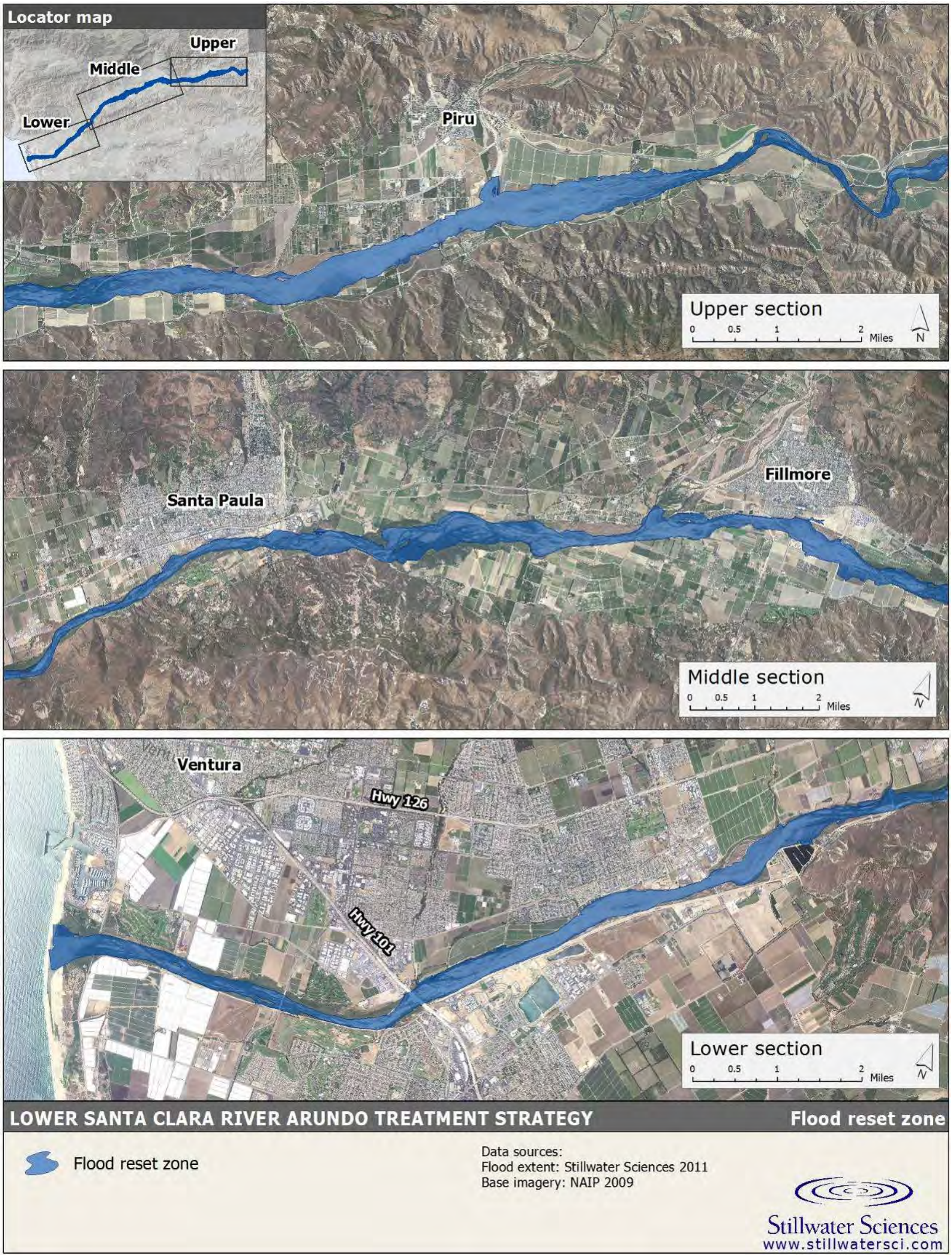

Figure 4-1. Lower Santa Clara River primary flood reset zone.

Table 4-3. Arundo treatment type descriptions.

Decision rule	Treatment type
1. Arundo inside primary flood reset zone	Flood contingent (foliar herbicide application following floods, and potentially fire) • Year 1* price estimate: $1,000–$2,000/acre • Revegetation: passive • Permitting: 1600 & USFWS/NMFS no take concurrence
1′ Arundo outside primary flood reset zone	
2. No biomass removal required	Spray only (foliar herbicide application on standing stems) • Year 1 price estimate: $3,000–$6,000/acre • Revegetation: consider passive if arundo % cover is low, active likely required if arundo % cover is high • Permitting: 1600 & USFWS no take concurrence
2′ Biomass removal required	
3. Arundo % cover > 80	Mechanical (mowing as lone or primary biomass removal method prior to foliar herbicide application)
4. No post-treatment cane removal	• Year 1 price estimate: $4,000–$6,000/acre • Revegetation: active likely required • Permitting: 1600 & USFWS no take concurrence
4′ Post-treatment cane removal required	• Year 1 price estimate: $7,000–$150,000/acre • Revegetation: consider passive • Permitting: 1600, USFWS no take concurrence, and potential USACE RGP
3′ Arundo % cover <80, >20	Mixed (combination of mowing and hand removal of biomass prior to foliar herbicide application)
5. No post-treatment cane removal	• Year 1 price estimate: $7,000–$8,000/acre • Revegetation: active likely required • Permitting: 1600 & USFWS no take concurrence
5′ Post-treatment cane removal required	• Year 1 price estimate: $10,000–$150,000/acre • Revegetation: consider passive • Permitting: 1600, USFWS no take concurrence, and potential USACE RGP
3′′Arundo % cover <20	Hand (hand removal of biomass prior to foliar herbicide application)
6. No post-treatment cane removal	• Year 1 price estimate: $8,000–$9,000/acre • Revegetation: active likely required • Permitting: 1600, USFWS no take concurrence, and unlikely USACE RGP
6′ Post-treatment cane removal required	• Year 1 price estimate: $11,000–$150,000/acre • Revegetation: consider passive • Permitting: 1600, USFWS no take concurrence, and potential USACE RGP

*Subsequent years would presumably be maintenance/retreatment only with an estimated cost of $1,000–$2,000/acre

Several Parkway parcels provide good examples of the decision rules used to identify arundo treatment and revegetation types:

- Santa Clara Ranch (Figure 4-3) is an example of where there is an obvious topographic break, in this case levees, below which active arundo treatment and revegetation is not appropriate. All of the arundo on this parcel is within the primary flood reset zone, and is highly likely to be inundated and scoured by the next high-flow event, which will likely remove arundo biomass, but could also reintroduce arundo from upstream and scour away actively revegetated areas.

- The Strathmore property (Figure 4-2) demonstrates how percent cover of arundo determines appropriate treatment types. There is over 50 acres of arundo with greater than 75% cover. This area will be suitable for mechanical removal of arundo biomass prior to herbicide application, since there are very few interspersed native trees and shrubs that would have to be protected during biomass removal. Following arundo biomass removal and treatment, active revegetation is likely to be necessary to re-establish native vegetation, since mechanical removal would be done over a relatively large area, would leave little to no native trees and shrubs remaining behind, and the area is not likely to be inundated by high flows that would reintroduce native tree and shrub propagules. Given the elevation and position of the Strathmore property and adjacent vegetation types, cottonwood and willow vegetation types are likely the most suitable for revegetation.
- The Peto parcel complex (Figure 4-6) is an example of where spray only arundo treatment methods are likely to be appropriate. In several areas, arundo is at relatively low percent cover, although there are interspersed native species that would need to be avoided. Spray only methods in these areas would no leave behind large, dense stands of dead arundo that could increase fire risk to nearby developed areas. Given the amount of native vegetation that is likely to remain following arundo treatment, passive or only limited active revegetation is likely to be required for post-treatment revegetation.
- The streambank of the McGrath property (Figure 4-2) is as an example of where hand removal of arundo biomass is likely to be required prior to herbicide application. Arundo in this area is located on a steep bank and is interspersed with native riparian trees that would need to be avoided. However, because the native trees will be retained and the area is expected to support relatively high groundwater levels, passive revegetation should be sufficient to restore habitat quality following arundo treatment.

4.2.3 Arundo treatment and post-treatment revegetation priorities

Along with the arundo treatment and revegetation type, Figures 4-2 through 4-9 depict the arundo treatment priorities for Parkway parcels. Table 4-4 summarizes the acreage of different arundo treatment and revegetation types for Parkway parcels, as well as the priority for arundo treatment.

Table 4-4. Arundo treatment and revegetation type acreages and priorities for Santa Clara River Parkway parcels.

Parkway Parcel Complex	Priority	Treatment Type	Revegetation Type	Acres
Aflalo View Complex	Low	Flood contingent	Passive to active (scale broom/alluvial scrub)	27.20
		Manual	Passive to active (scale broom/alluvial scrub)	9.41
		Mixed	Active (cottonwood/mixed riparian forest)	0.42
City of Santa Paula Complex	Low	Flood contingent	Passive	12.86
	Medium	Mixed	Limited to active (mixed willow/cottonwood-willow forest)	30.42
Hanson-Villanueva Complex	Low	Flood contingent	Passive	58.76
	High	Manual	Active (mixed willow scrub/oak savanna)	13.55
		Mechanical	Passive to limited active (mixed willow/cottonwood forest)	14.84
		Mixed	Active (coastal sage scrub/oak savanna)	24.36
			Active (mixed willow forest)	0.89
			Passive to limited active (giant wildrye)	12.01
			Passive to limited active (mixed riparian scrub)	11.32
			Passive to limited active (mixed willow/cottonwood forest)	51.70
		Spray only	Passive	13.79

Parkway Parcel Complex	Priority	Treatment Type	Revegetation Type	Acres
Hedrick Ranch-Valley View Complex	Low	Flood contingent	Passive	210.46
	High	Mixed	Passive	6.99
			Passive to active (mixed willow/cottonwood forest)	53.54
Lago Marcino Complex	Low	Flood contingent	Passive	19.77
		Spray only	Passive	2.77
McGrath	Low	Flood contingent	Passive	1.21
	Medium	Manual	Active (coastal sage scrub)	5.35
			Passive	8.79
		Mixed	Passive to limited active (mixed riparian scrub/cottonwood-willow forest)	22.12
Peto Complex	Low	Flood contingent	Passive	45.02
	High	Manual	Passive to limited active (oak savanna/mixed riparian)	3.33
		Spray only	Passive to limited active (oak savanna)	10.07
Prarie Pacific Complex	Low	Flood contingent	Passive	88.02
	Medium	Mixed	Limited to active (cottonwood-willow forest)	51.79
		Spray only	Passive	0.50
Santa Clara Ranch Complex	Low	Flood contingent	Passive	112.09
		Mixed	Passive	10.97
Strathmore	Low	Flood contingent	Passive	9.78
	Medium	Mechanical	Limited active (cottonwood-willow forest)	6.81
		Mixed	Passive	27.01
Totlcom	Low	Flood contingent	Passive	3.28
Vulcan Complex	Low	Flood contingent	Passive	306.25
		Spray only	Passive	2.36
TOTAL				1,289.83

Several Parkway parcels provide good examples of the criteria used to prioritize arundo treatment areas on Parkway parcels:

- The Hedrick Ranch-Valley View parcel complex (Figure 4-7) is an example of high priority arundo treatment to conserve and restore high on-site habitat quality. Arundo treatment and revegetation in many areas of this parcel complex will expand the extent and increase the habitat value of one of the largest remaining riparian forest complexes on the Santa Clara River.
- The Peto parcel complex (Figure 4-6) is an example of high priority arundo treatment to protect or contribute to adjacent areas of high habitat quality. Arundo treatment and revegetation on this parcel complex will expand the extent of the high-quality habitat on the Hedrick Ranch property, although there are still a number of unprotected parcels between the two.
- The entire primary flood reset zone is a prime example of an area that is low priority for arundo treatment due to the fact that it could become easily or quickly reinfested by arundo. On the other hand, the floodplain terrace on the north bank of the Hanson-Villanueva parcel complex (Figure 4-4) is an example of an area that is high priority for arundo treatment since it is at low risk for flood inundation and arundo reinfestation.
- The southern portions of the Hanson-Villanueva and Prairie Pacific parcel complexes (Figure 4-4 and 4-5) are examples of high priority arundo treatment to reduce the risk of fire. Arundo treatment in these areas could help reduce the risk of fire spreading from more fire-prone upland vegetation types on South Mountain, through the riparian corridor, and toward developed areas on the northern side of the river.

- The Peto parcel (Figure 4-6) is an example of where arundo treatment is of high priority because it would protect or contribute to nodes of unusual vegetation types. This parcels supports vegetation types such as elderberry and live oak savanna and desert riparian scrub that are relatively rare in the lower Santa Clara River and broader region and that could be degraded if arundo is left to invade.
- Due to their large extents, the Hedrick Ranch-Valley View and Hanson-Villanueva parcel complexes (Figures 4-7 and 4-4) are examples of high priority arundo treatment that would make a significant or strategic reduction in surrounding arundo.

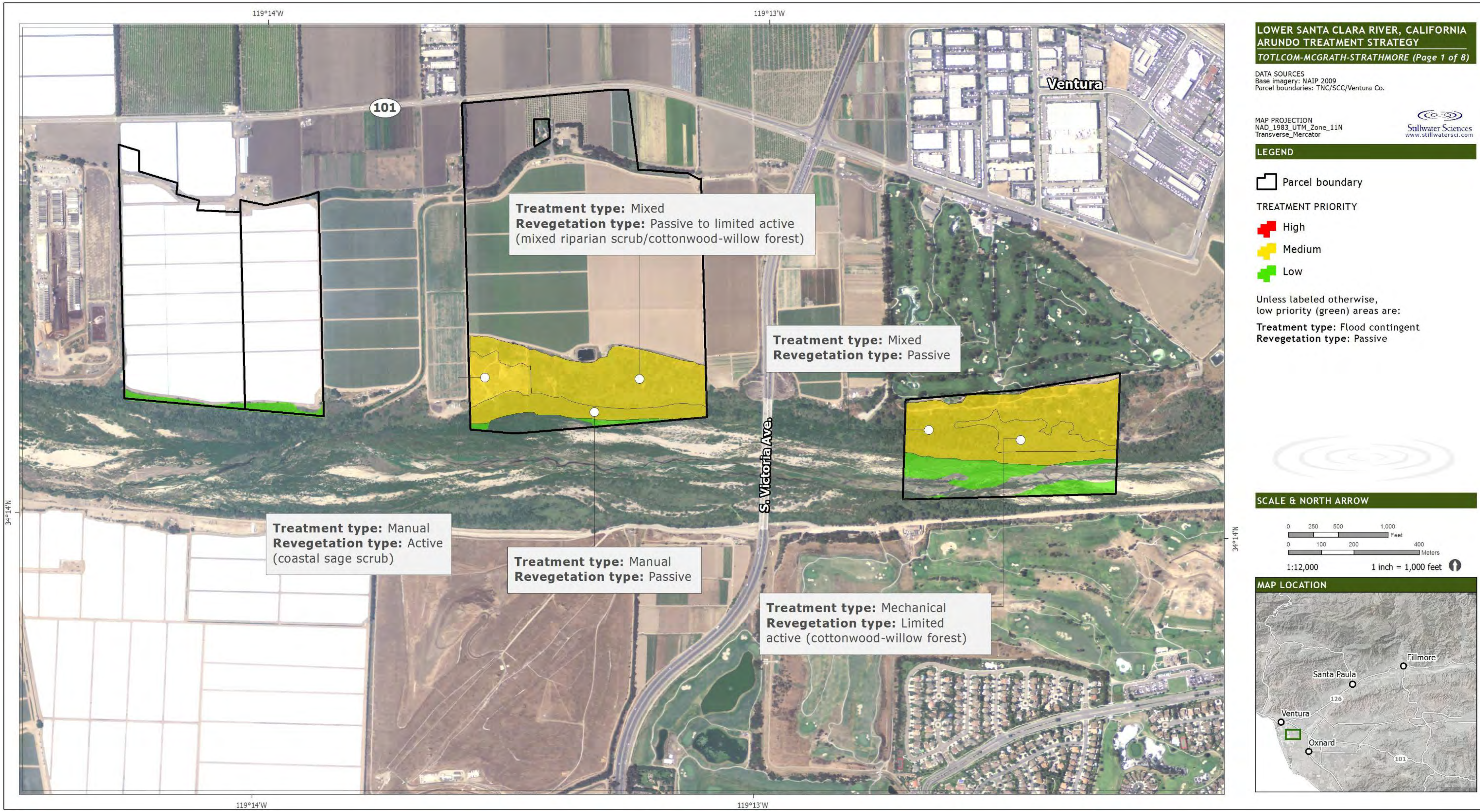

Figure 4-2. Arundo treatment types, revegetation types, and priorities for the Totlcom, McGrath, and Strathmore parcels.

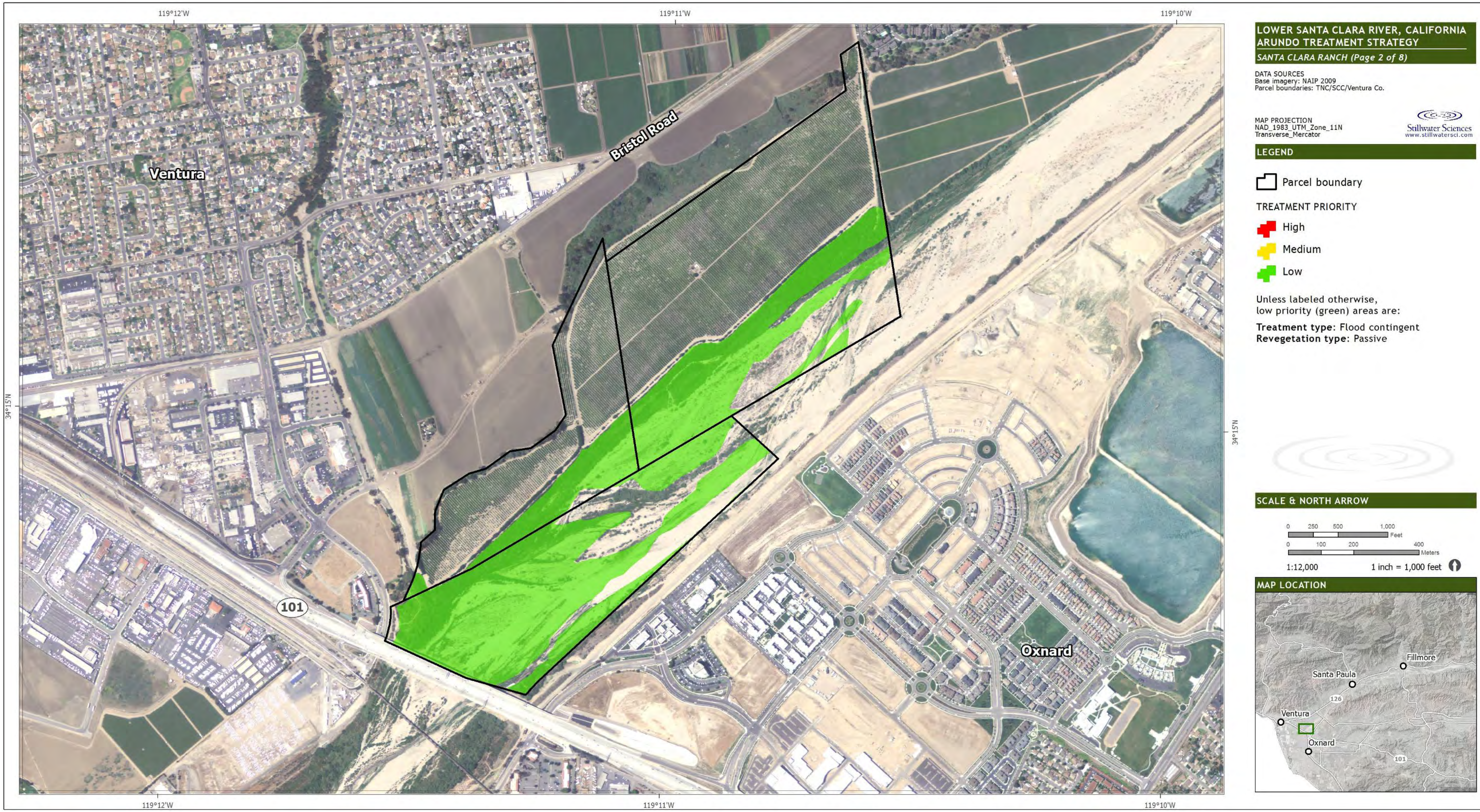

Figure 4-3. Arundo treatment types, revegetation types, and priorities for the Santa Clara Ranch parcels.

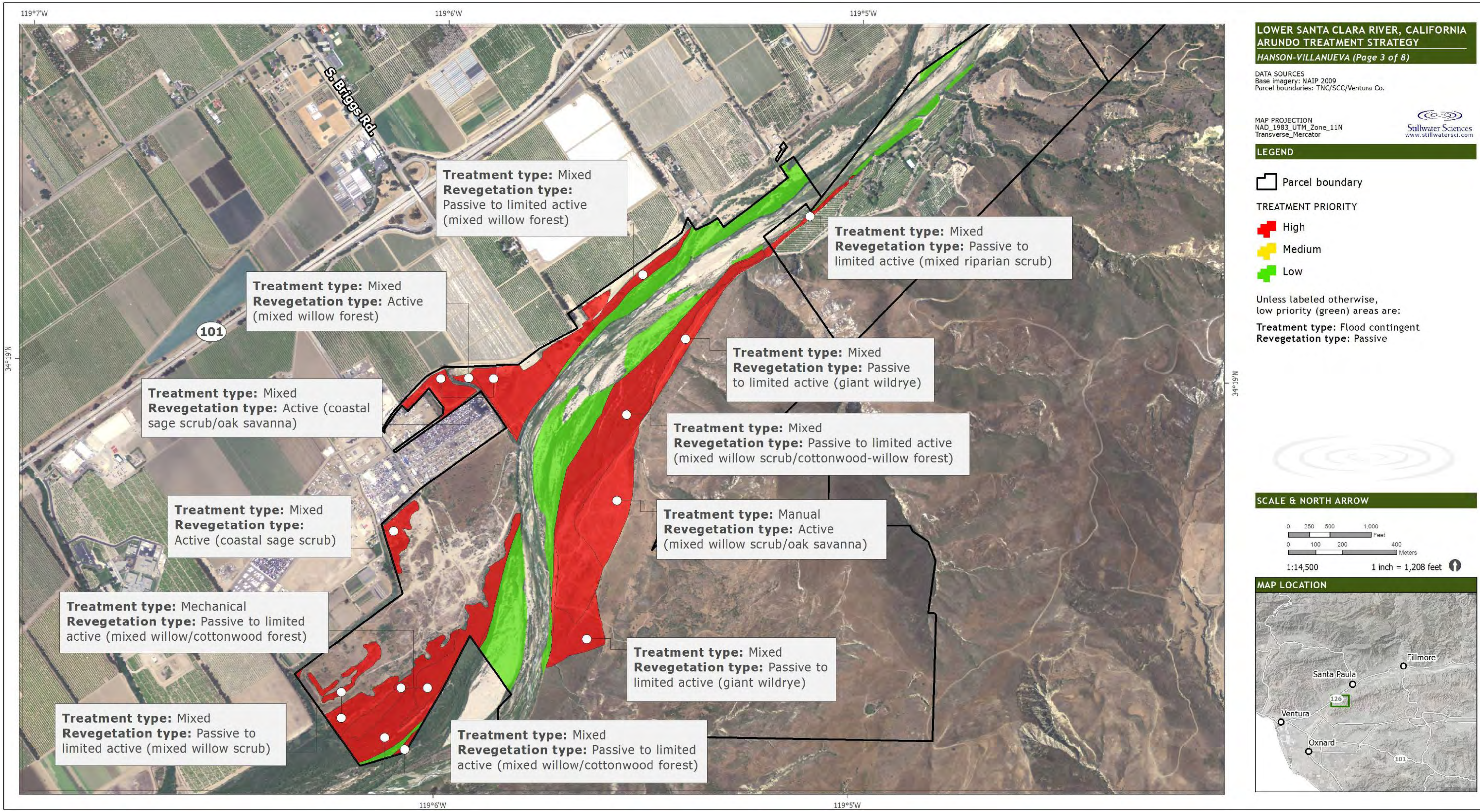

Figure 4-4. Arundo treatment types, revegetation types, and priorities for the Hanson-Villanueva parcels.

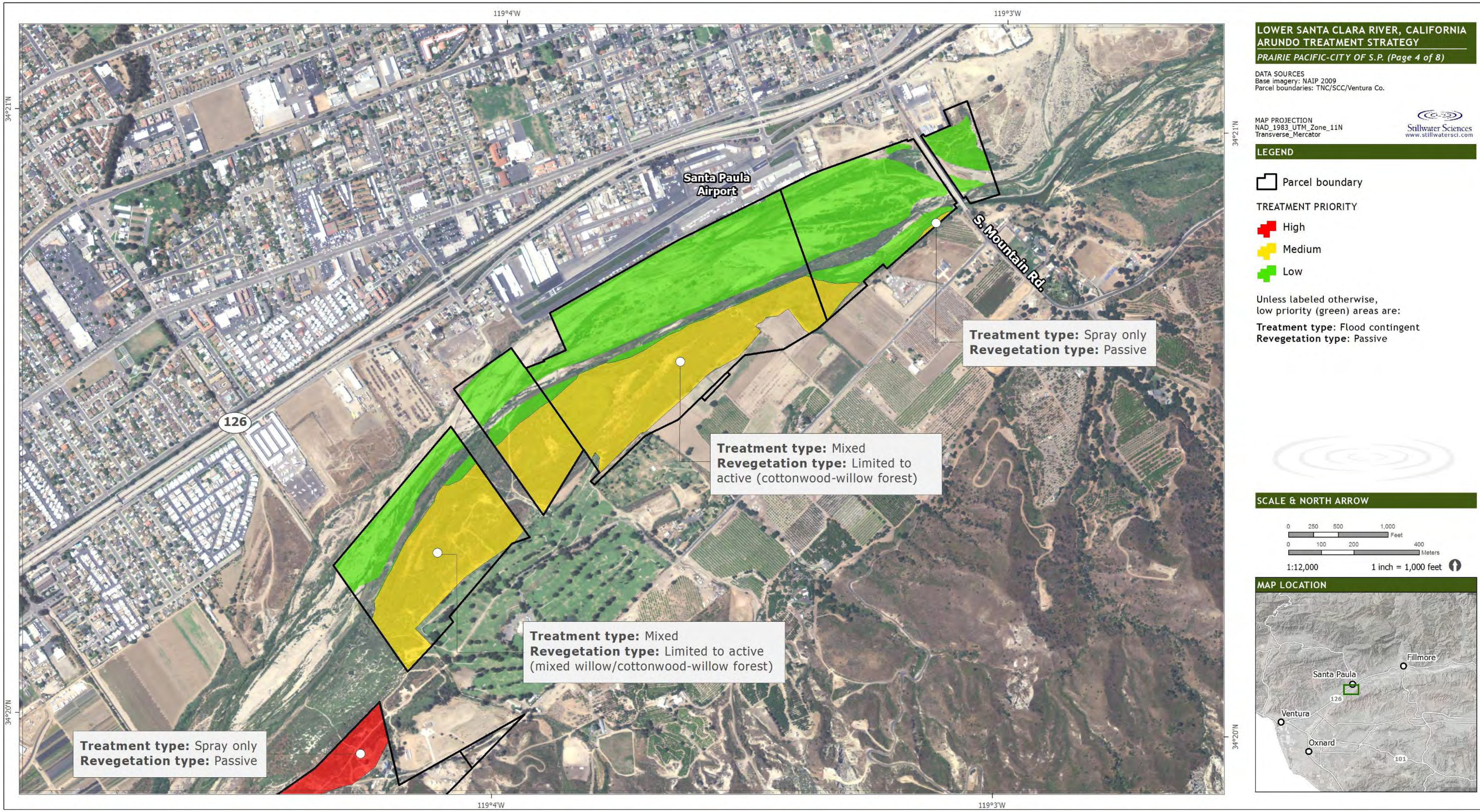

Figure 4-5. Arundo treatment types, revegetation types, and priorities for the Prairie Pacific and City of Santa Paula parcels.

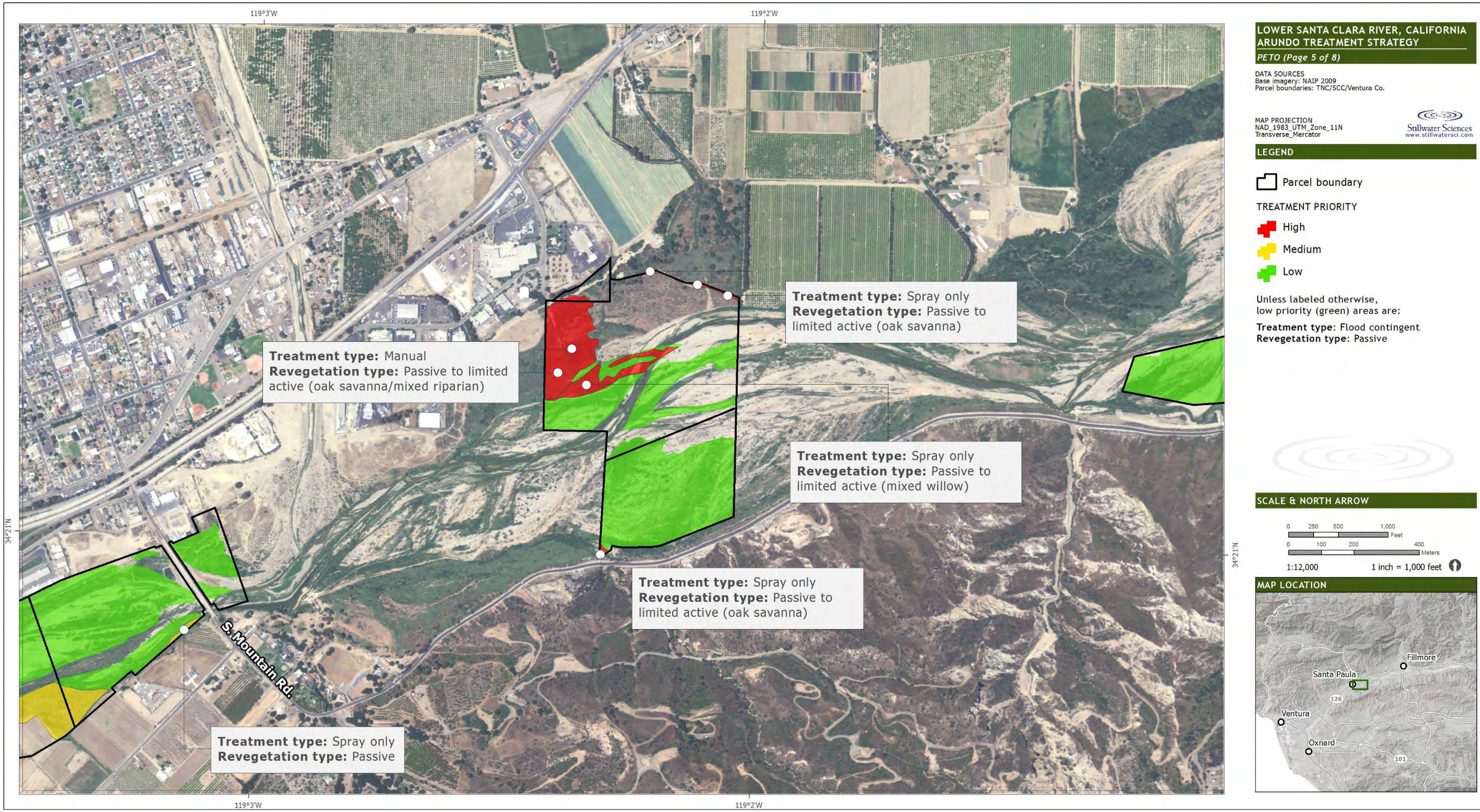

Figure 4-6. Arundo treatment types, revegetation types, and priorities for the Peto parcel.

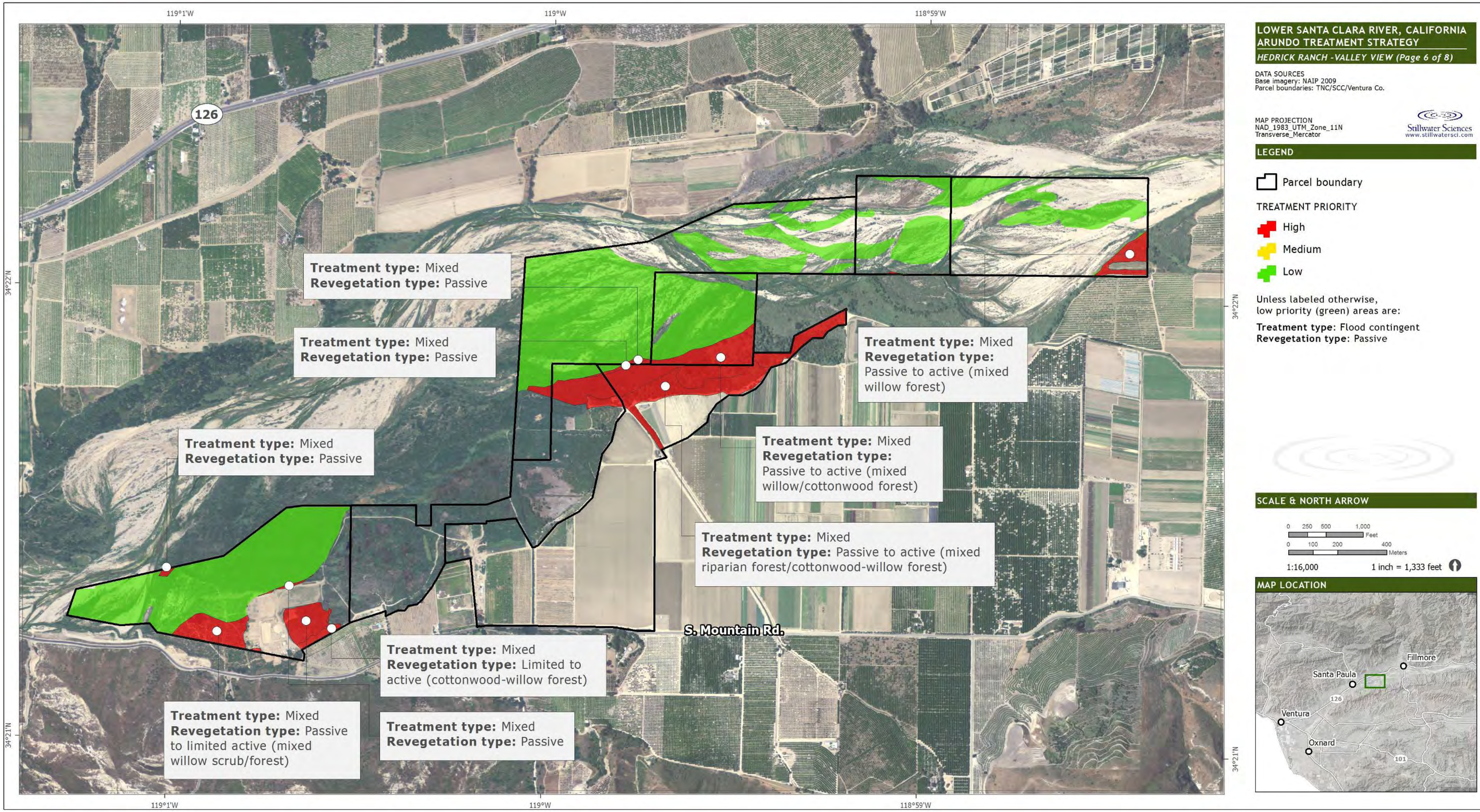

Figure 4-7. Arundo treatment types, revegetation types, and priorities for the Hedrick Ranch and Valley View parcels.

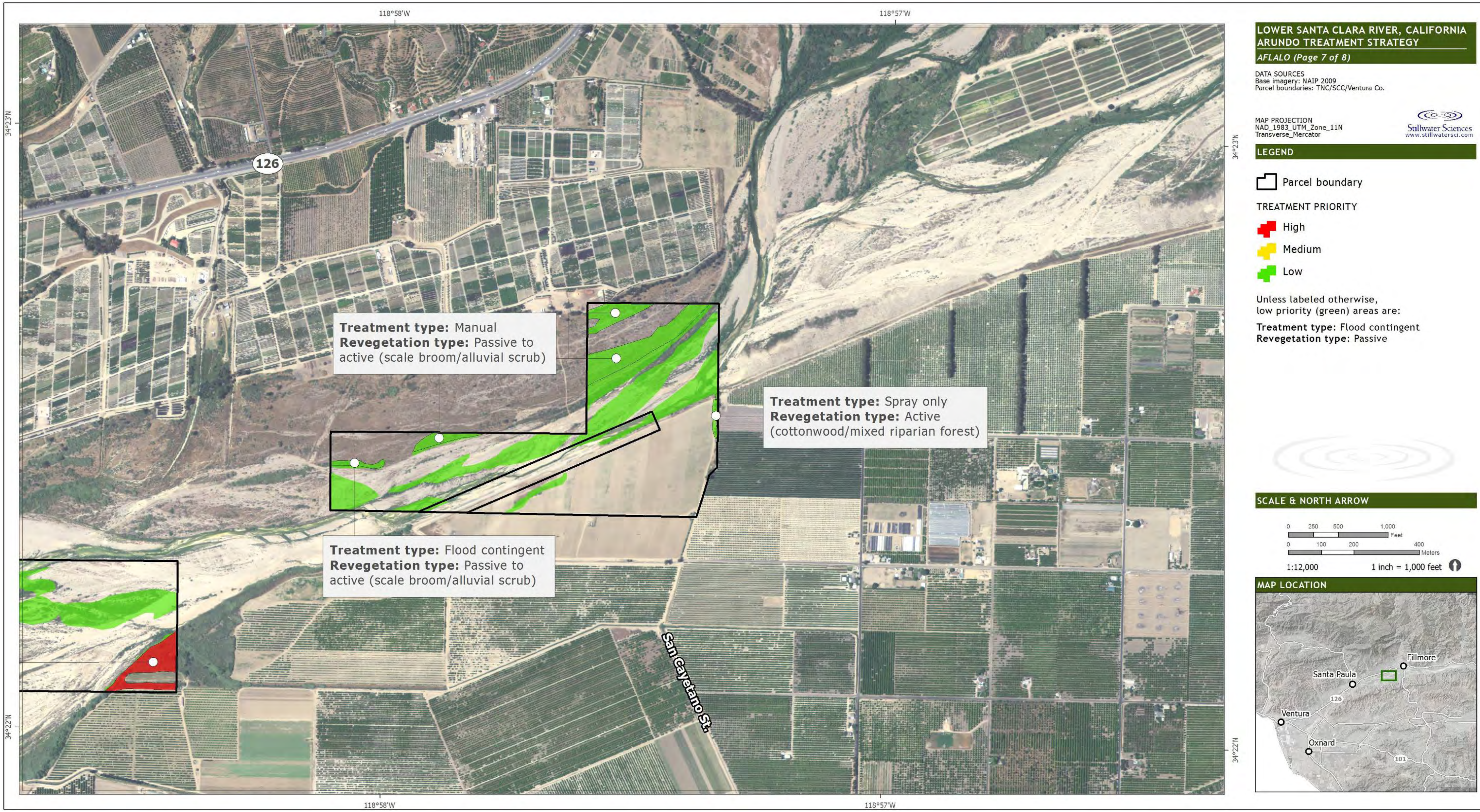

Figure 4-8. Arundo treatment types, revegetation types, and priorities for the Aflalo parcel.

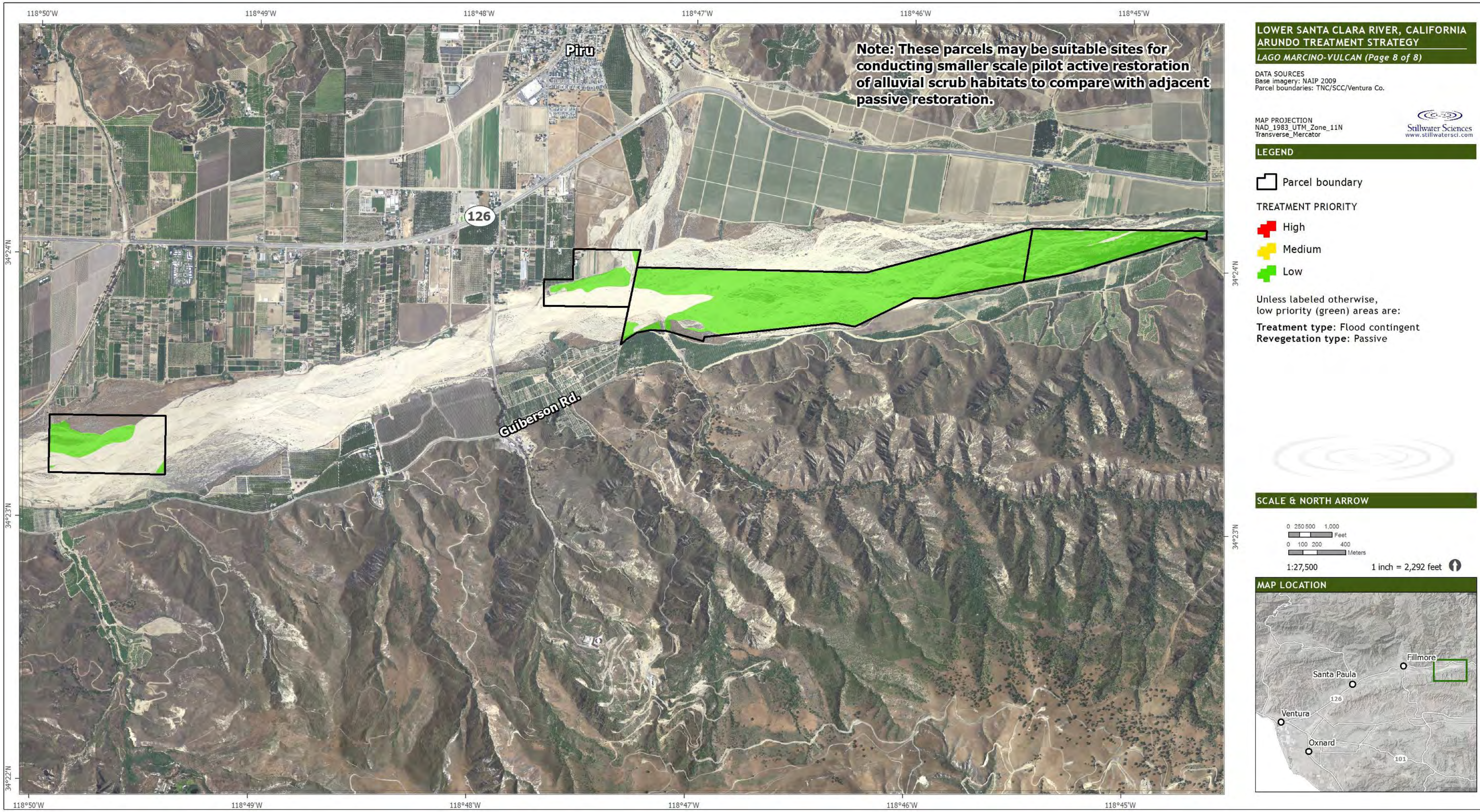

Figure 4-9. Arundo treatment types, revegetation types, and priorities for the Lago Marcino and Vulcan parcels.

4.2.4 Arundo treatment costs

Table 4-5 summarizes the estimated costs for arundo treatment on current Parkway parcels, based on the treatment methods and acres of individual arundo areas in Table 4-4 and costs/ac in Table 4-2. The total cost for arundo treatment on current Parkway parcels, under a best-case scenario, is estimated to be $3.4 million. Under a worse-case scenario, where arundo biomass removal and disposal is required, treatment of arundo on current Parkway parcels is estimated to be $32 million. The cost of arundo treatment maintenance on current Parkway parcels is estimated to be just under $2 million/year, or $9.5 million for five years of maintenance.

Table 4-5. Arundo treatment cost estimates for Santa Clara River Parkway parcels.

Parkway Parcel Complex	Treatment Type	Acres	Best-case Cost	Worse-case Cost	Maintenance Cost
Aflalo View Complex	Flood contingent	27.20	$ 27,200	$ 54,400	$ 40,800
	Manual	9.41	$ 84,700	$ 1,411,800	$ 14,100
	Mixed	0.42	$ 2,700	$ 32,900	$ 600
City of Santa Paula Complex	Flood contingent	12.86	$ 12,900	$ 25,700	$ 19,000
	Mixed	30.42	$ 197,700	$ 2,387,900	$ 45,600
Hanson-Villanueva Complex	Flood contingent	58.76	$ 58,800	$ 117,500	$ 88,100
	Manual	13.55	$ 121,900	$ 2,031,800	$ 20,300
	Mechanical	14.84	$ 59,400	$ 103,900	$ 22,300
	Mixed	100.28	$ 651,800	$ 7,872,300	$ 150,400
	Spray only	13.79	$ 41,400	$ 82,700	$ 20,700
Hedrick Ranch-Valley View Complex	Flood contingent	210.46	$ 210,500	$ 420,900	$ 315,700
	Mixed	60.53	$ 393,400	$ 4,751,600	$ 90,800
Lago Marcino Complex	Flood contingent	19.77	$ 19,800	$ 39,500	$ 29,700
	Spray only	2.77	$ 8,300	$ 16,600	$ 4,200
McGrath	Flood contingent	1.21	$ 1,200	$ 2,400	$ 1,800
	Manual	14.13	$ 127,200	$ 2,120,000	$ 21,200
	Mixed	22.12	$ 143,800	$ 1,736,800	$ 33,200
Peto Complex	Flood contingent	45.02	$ 45,000	$ 90,000	$ 67,500
	Manual	3.33	$ 30,000	$ 499,800	$ 5,000
	Spray only	10.07	$ 30,200	$ 60,400	$ 15,100
Prarie Pacific Complex	Flood contingent	88.02	$ 88,000	$ 176,000	$ 132,000
	Mixed	51.79	$ 336,600	$ 4,065,500	$ 77,700
	Spray only	0.50	$ 1,500	$ 3,000	$ 700
Santa Clara Ranch Complex	Flood contingent	112.09	$ 112,100	$ 224,200	$ 168,100
	Mixed	10.97	$ 71,300	$ 861,000	$ 16,500
Strathmore	Flood contingent	9.78	$ 9,800	$ 19,600	$ 14,700
	Mechanical	6.81	$ 27,300	$ 47,700	$ 10,200
	Mixed	27.01	$ 175,600	$ 2,120,700	$ 40,500
Totlcom	Flood contingent	3.28	$ 3,300	$ 6,600	$ 4,900
Vulcan Complex	Flood contingent	306.25	$ 306,300	$ 612,500	$ 459,400
	Spray only	2.36	$ 7,100	$ 14,200	$ 3,500
TOTAL		1,289.83	$ 3,406,700	$ 32,010,000	$ 1,934,700

Table 4-6 summarizes the estimated costs for arundo treatment outside of current Parkway parcels, based on the primary flood reset zone, arundo percent cover, and the costs/ac described in Section 4.1.5. The total cost for arundo treatment outside current Parkway parcels is roughly estimated to be just under $14 million (Table 4-6). Combining the totals from Table 4-5 and 4-6, the estimated cost for arundo treatment of the entire lower Santa Clara River, under a best-case scenario, is roughly $17 million, while under a worse-case scenario, it is roughly $46 million. Again, due to the assumptions and generalities included in both the cost/acre ranges and the selected treatment methods, these costs should be considered rough estimates only.

Table 4-6. Arundo treatment cost estimates for the lower Santa Clara River outside of Santa Clara River Parkway parcels.

Area	Treatment Type	Acres	Cost
Within Primary Flood Reset Zone	Flood contingent	2209.74	$ 3,314,600
Outside Primary Flood Reset Zone			
1-19% arundo cover	Spray only	460.54	$ 1,381,600
	Hand	460.54	$ 4,144,900
20-79% arundo cover	Mixed	649.43	$ 4,221,300
80-100% arundo cover	Mechanical	170.25	$ 681,000
Grand Total		**3950.50**	**$13,743,400**

5 ARUNDO TREATMENT AND POST-TREATMENT REVEGETATION MONITORING

Long-term monitoring of restoration sites and high-quality reference sites for both aquatic and riparian habitat was recommended in the Feasibility Study to increase the understanding of the lower Santa Clara River system and assist in developing more detailed restoration plans. In particular, monitoring of the effectiveness of different types of restoration and revegetation strategies relative to environmental conditions in the Parkway area (*e.g*., gaining versus losing reaches, time since last disturbance from flood or fire) could help guide and increase the success rate of future restoration efforts.

A selection of the arundo treatment and revegetation projects specified in this plan would make excellent restoration monitoring sites. Coffman and Ambrose (2011) identify a number of appropriate arundo treatment project success criteria, monitoring methods, and statistical analyses for projects on the Santa Clara River. These methods can be easily adapted to individual, select Parkway arundo treatment projects to maximize the contribution of these projects to the collective understanding of the most effective arundo treatment and revegetation methods for the lower Santa Clara River and broader Southern California region, and associated costs.

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Appendix A
Documented arundo treatment project costs

Description	Cost/acre	Notes	Source
Permits	$2,387	For arundo removal and revegetation of an approx. 1-acre site on the beach in Santa Barbara County	Chang 2010
Glyphosate applied to hand-cut stumps	$25,765	Involved approximately 500 man-hours for an approx. 1-acre site in Santa Barbara County	Chang 2010
Biomass disposal	$2,318	21.3 tons of arundo disposed of at Santa Barbara County landfill	Chang 2010
Retreatment	$1,442	Involved approximately 68 man-hours for an approx. 1-acre site in Santa Barbara County	Chang 2010
Low-volume application of imazapyr to small clumps without cutting	$1,000-1,500	Restricted to clumps smaller than 40 ft across, treated by applicators using backpack sprayers; assumes 12 hr labor @ $60/hr for initial treatment and 2-3 follow-up visits over 2 years plus $250 for 3 qt imazapyr herbicide and adjuvant	Neill 2006
High-volume application of glyphosate to large stands without cutting	$3,000-7,000	Suitable for arundo stands as large as 1 acre, treated by 4-man crew using gasoline-powered pump, ladders and long hoses to apply 60-100 gln dilute glyphosate herbicide mixture; high end of price range includes labor to compact arundo and trim native trees where intermixed	Neill 2006
Large flail mower for biomass reduction followed by resprout spraying	$4,000-6,000	Suitable for dense stands larger than 1 acre on relatively open, level terrain; assume $3000-5000/acre for biomass reduction by flail mower and $1000/acre for low volume foliar treatment of resprouts using imazapyr herbicide	Neill 2006
Small flail or rotary mower biomass reduction followed by resprout spraying	$7,000-10,000	Suitable for steep slopes and stands intermixed with trees; assume $6000-$9000/acre for biomass reduction by smaller flail or rotary mower and $1000/acre for low volume foliar treatment of resprouts using imazapyr herbicide	Neill 2006
Chainsaw crew with portable shredder for biomass reduction followed by resprout spraying	$20,000-150,000	Suitable for locations requiring biomass reduction but not accessible to mower tractors; price range depends on stand density, accessibility, amount of dead thatch, etc.	Neill 2006
Herbicide application (single treatment)	$850		Simmons and Berry, no date
Biomass removal and mulching	$3,116		Simmons and Berry, no date
Maintenance	$2,000	Cost per year	Simmons and Berry, no date
None provided	$9,333	Cost per acre for 1,500 acres on the Santa Ana River	Simmons and Berry, no date
None provided	$15,000	Cost per acre for 290 acres on the San Luis Rey	Simmons and Berry, no date

Description	Cost/acre	Notes	Source
None provided	$1,000	Cost per acre for 1,000 acres on the Russian River	Simmons and Berry, no date
None provided	$34,000	Cost per acre for 0.25 acre on the Trabucho Creek	Simmons and Berry, no date
None provided	$20,000-80,000	Includes five-years of retreatments	Russell 2010

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Prepared by: **California Invasive Plant Council**

Arundo donax (giant reed): Distribution and Impact Report

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Submitted by: California Invasive Plant Council (Cal-IPC)

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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).

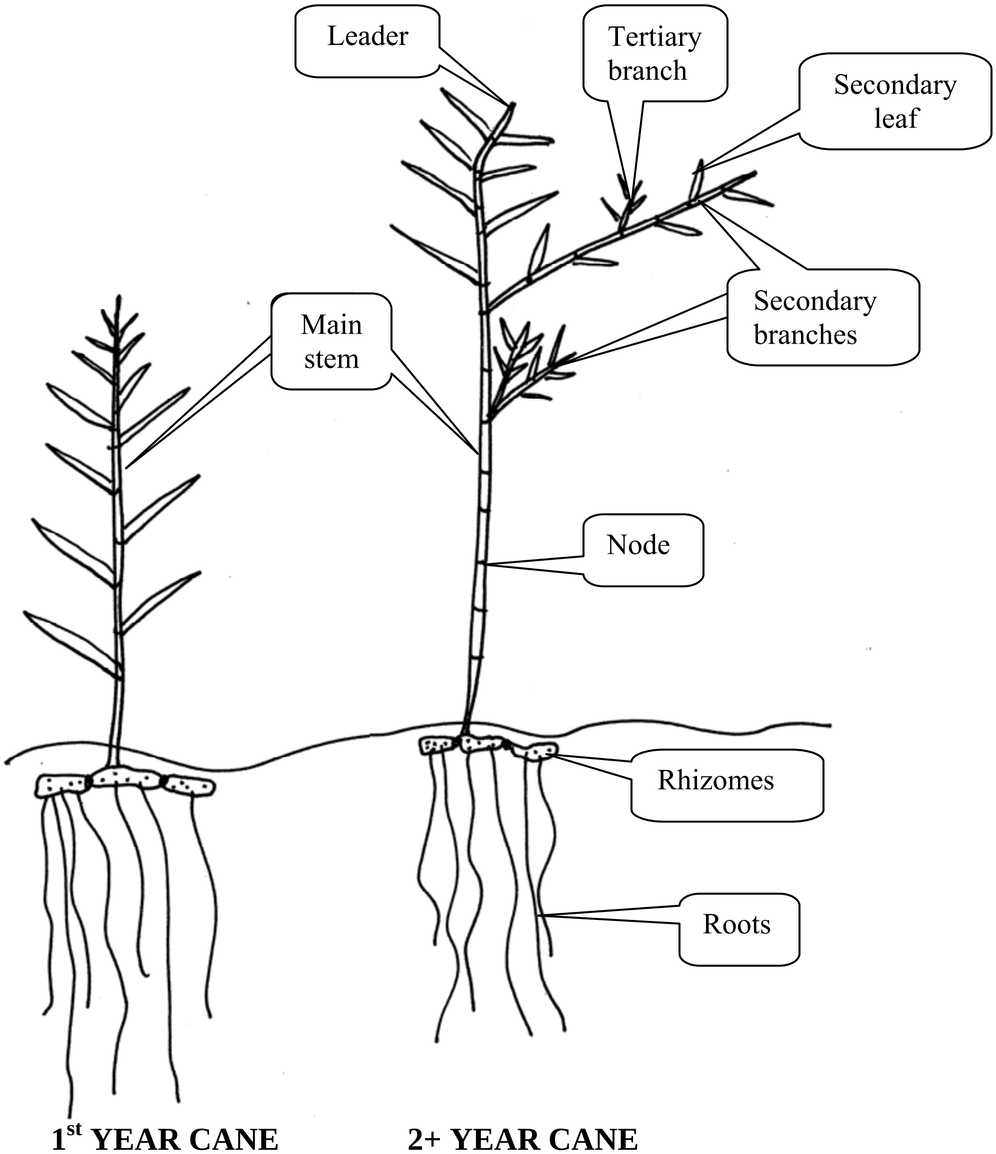


Figure 2-2. Illustration of *Arundo* structure for first year and 2+ year old stems. Older canes would have many secondary braches. Drawing by J. Giessow.

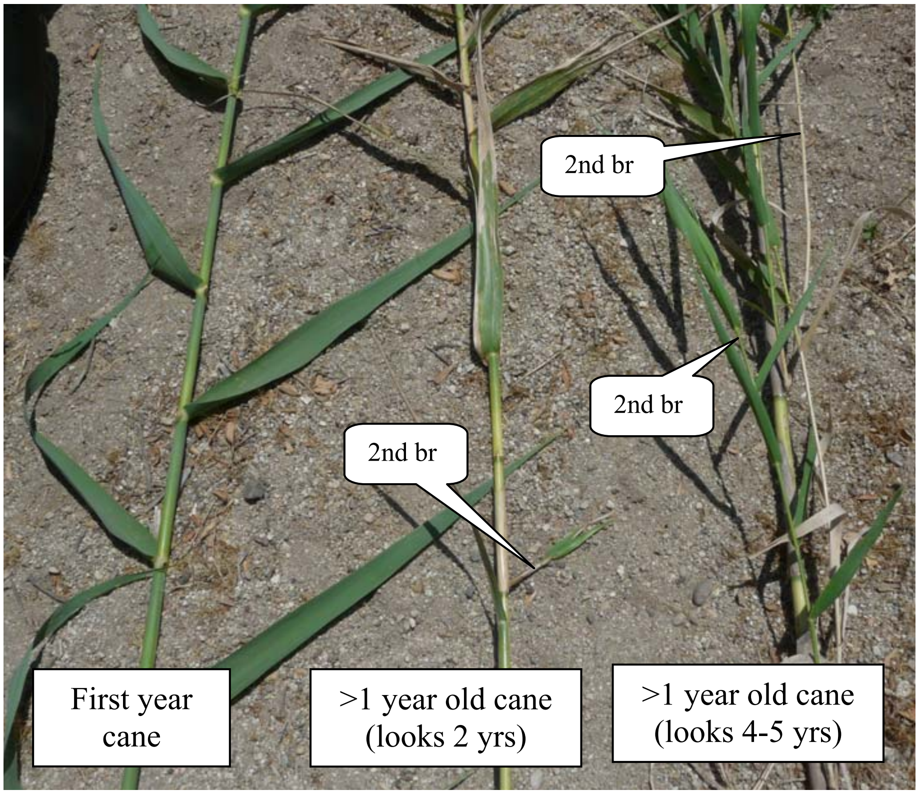


Figure 2-3. First year and >1yr year old *Arundo* canes, showing leaf and branching structure. First year canes have only cauline leaves. Older canes have an increasing number of secondary branches with leaves on them, and leaves on the old leader are often damaged and dying.

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.

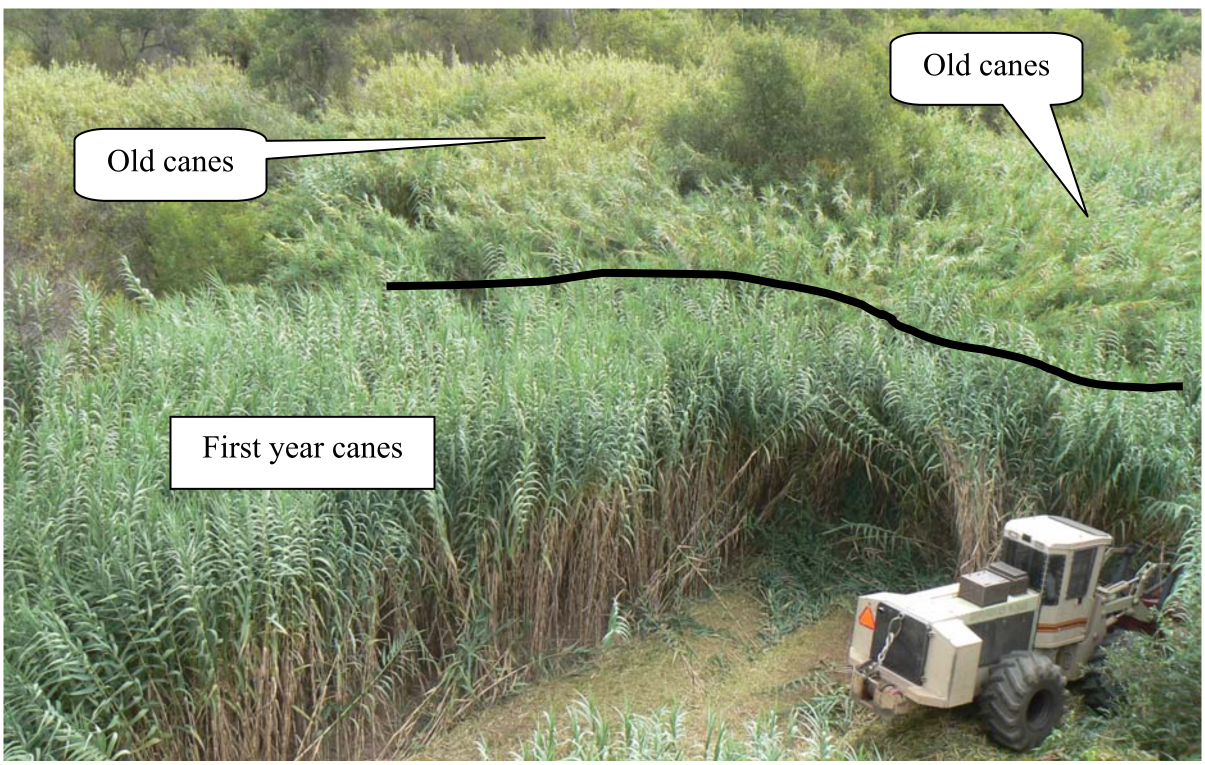


Figure 2-6. First year *Arundo* canes at full height (6+ m).
The tractor is 10' high. This area had been cut as a fuel break the year before and is being cut again. Energy stored in rhizomes underground allow this rapid regrowth after cutting or fire events. Note simple unbranched vertical structure, 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

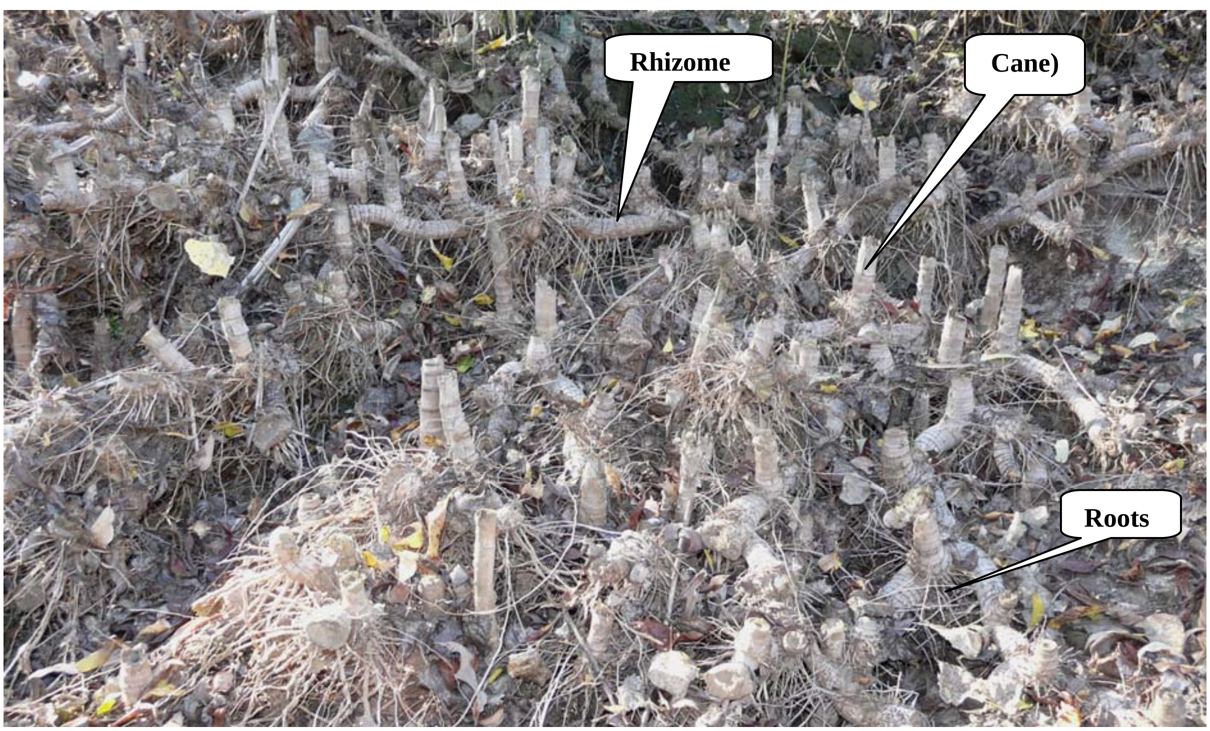


Figure 2-7. Dense rhizome and root network of an *Arundo* clump that was scoured during a flow event, removing the upper soil matrix and canes.

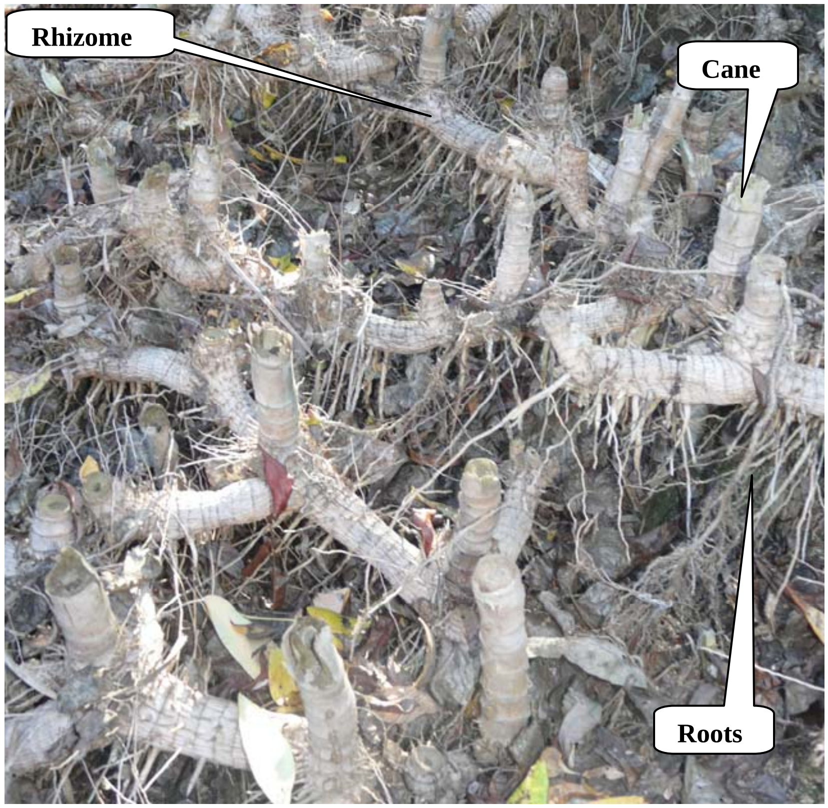


Figure 2-8. Close up of rhizomes showing emerging canes and roots.

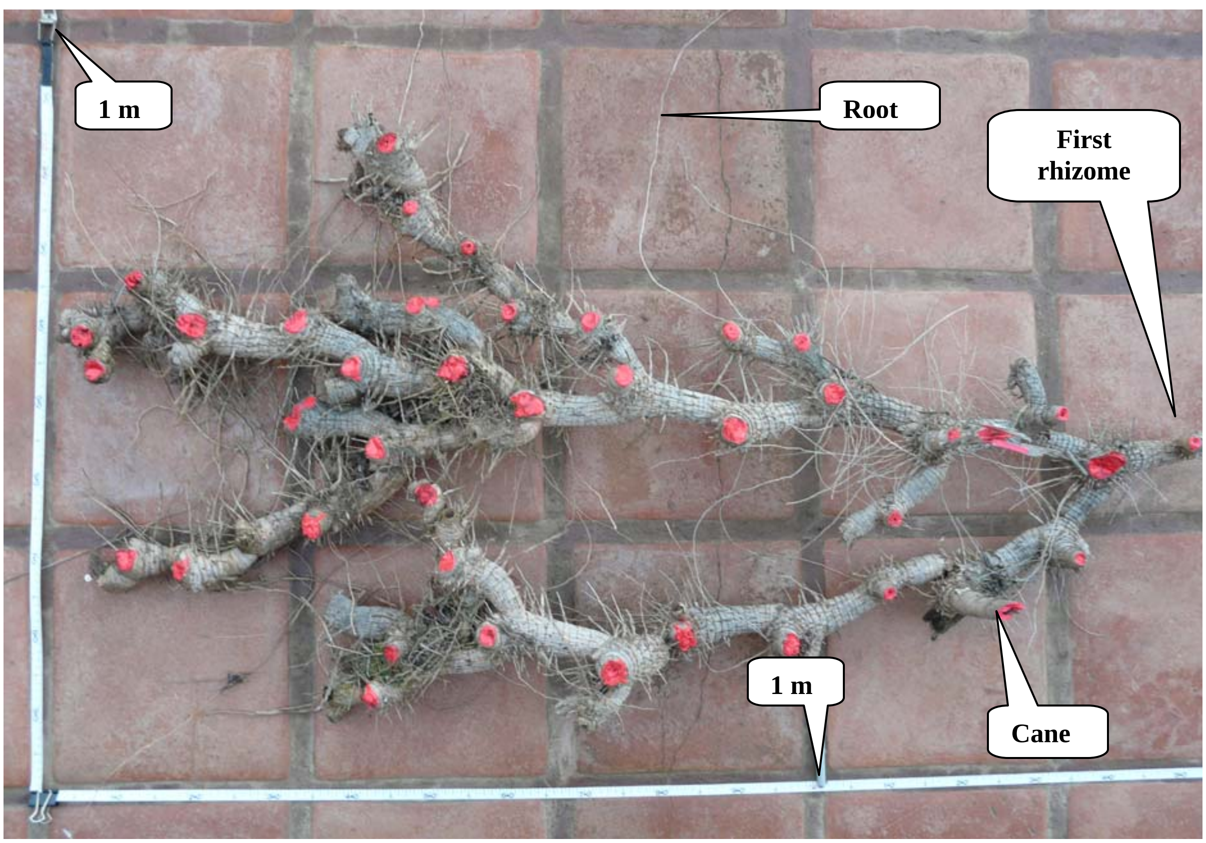


Figure 2-9. Rhizome network arising from a single growth point.
33 canes emerged from the marked 1 x 1m area (painted red).

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.

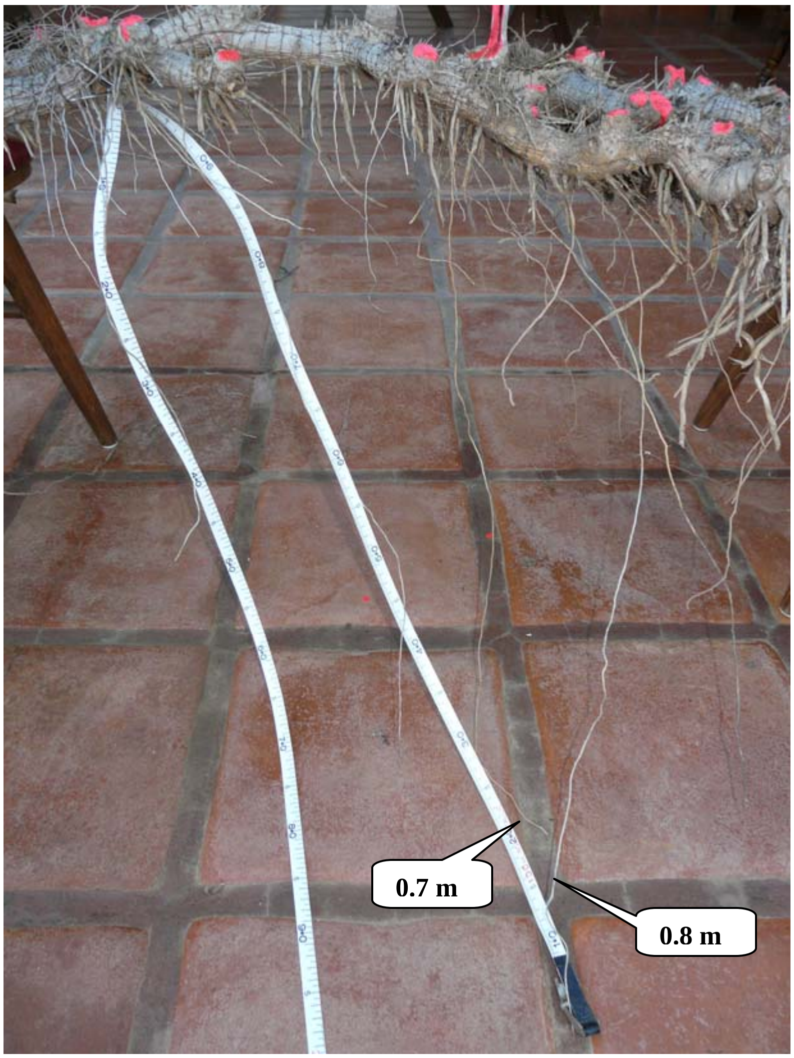


Figure 2-11. Rhizome network showing root length of up to 80 cm.
This was a dislodged rhizome network scoured out by flood action, so many of the roots have already been broken off, but it gives an idea of root density (near the rhizome) and length.

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.

<u>The stand or clonal mass:</u>

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.

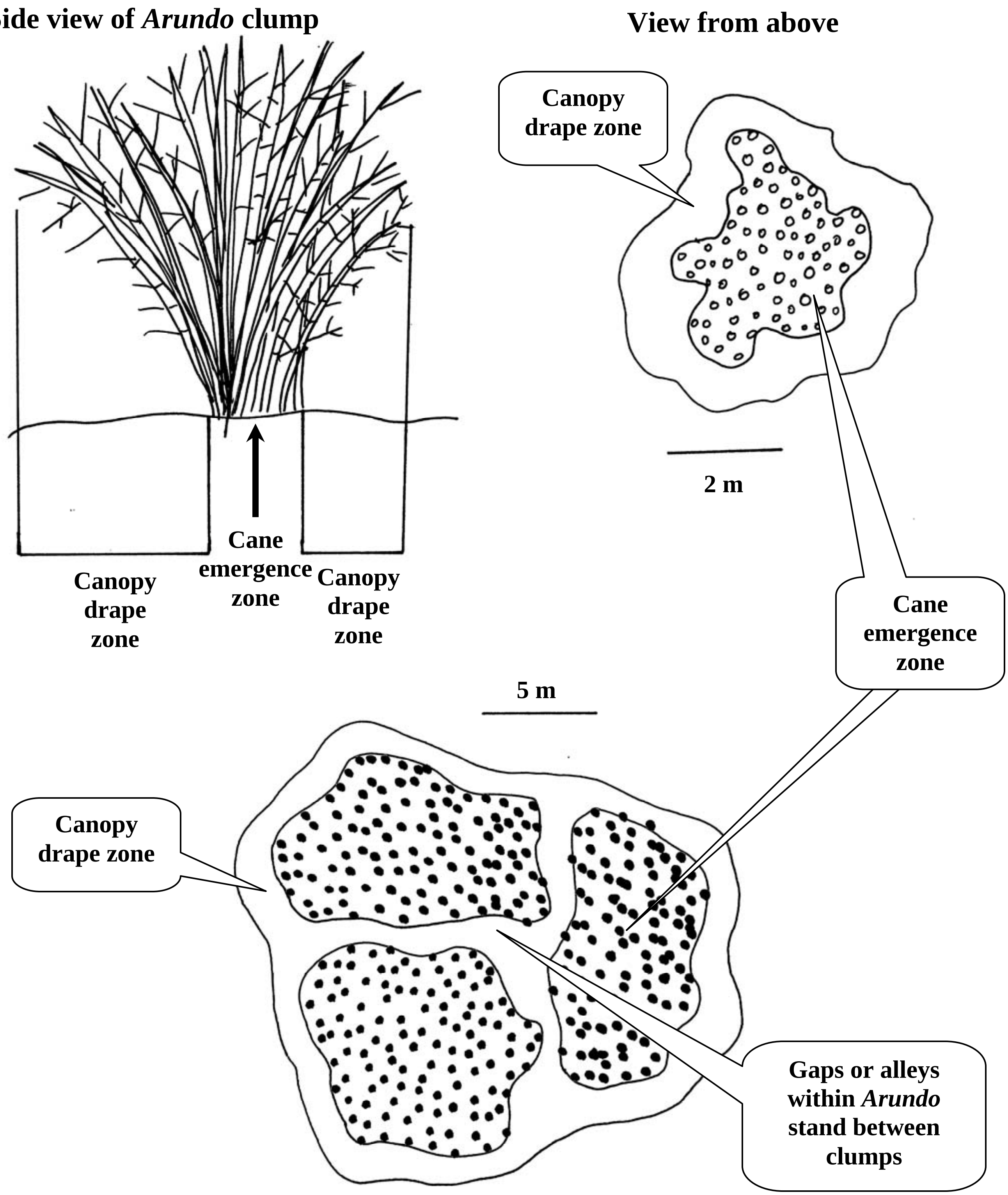


Figure 2-12. Draping effect of *Arundo* on the edge of the stand and gaps between clumps within a stand.
Drawing by J. Giessow.

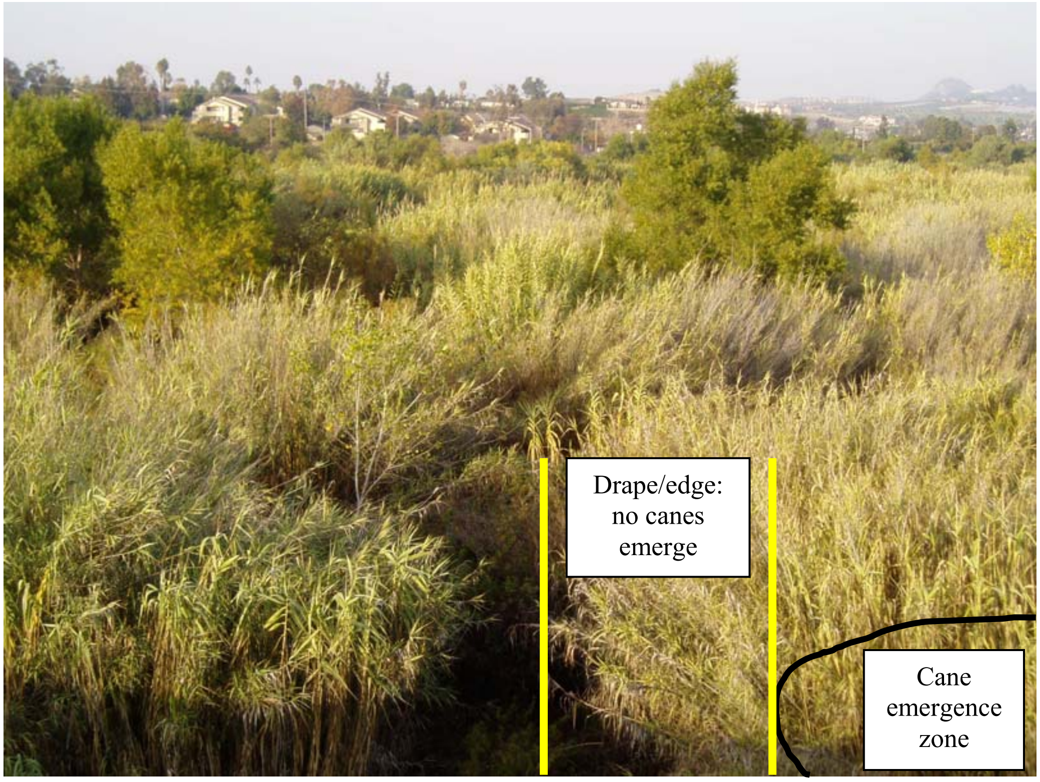


Figure 2-13. A mature *Arundo* stand showing draping of *Arundo* canes along an edge.

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

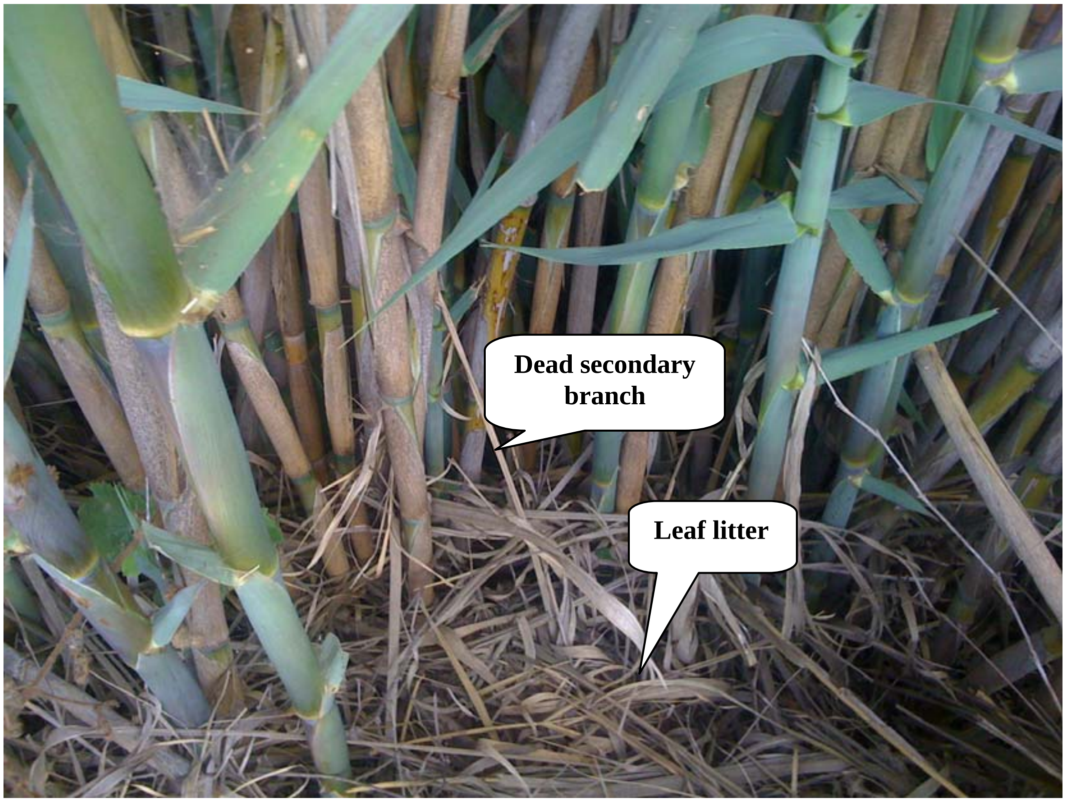


Figure 2-18. Cane density and dead leaf litter within a dense *Arundo* stand.

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.

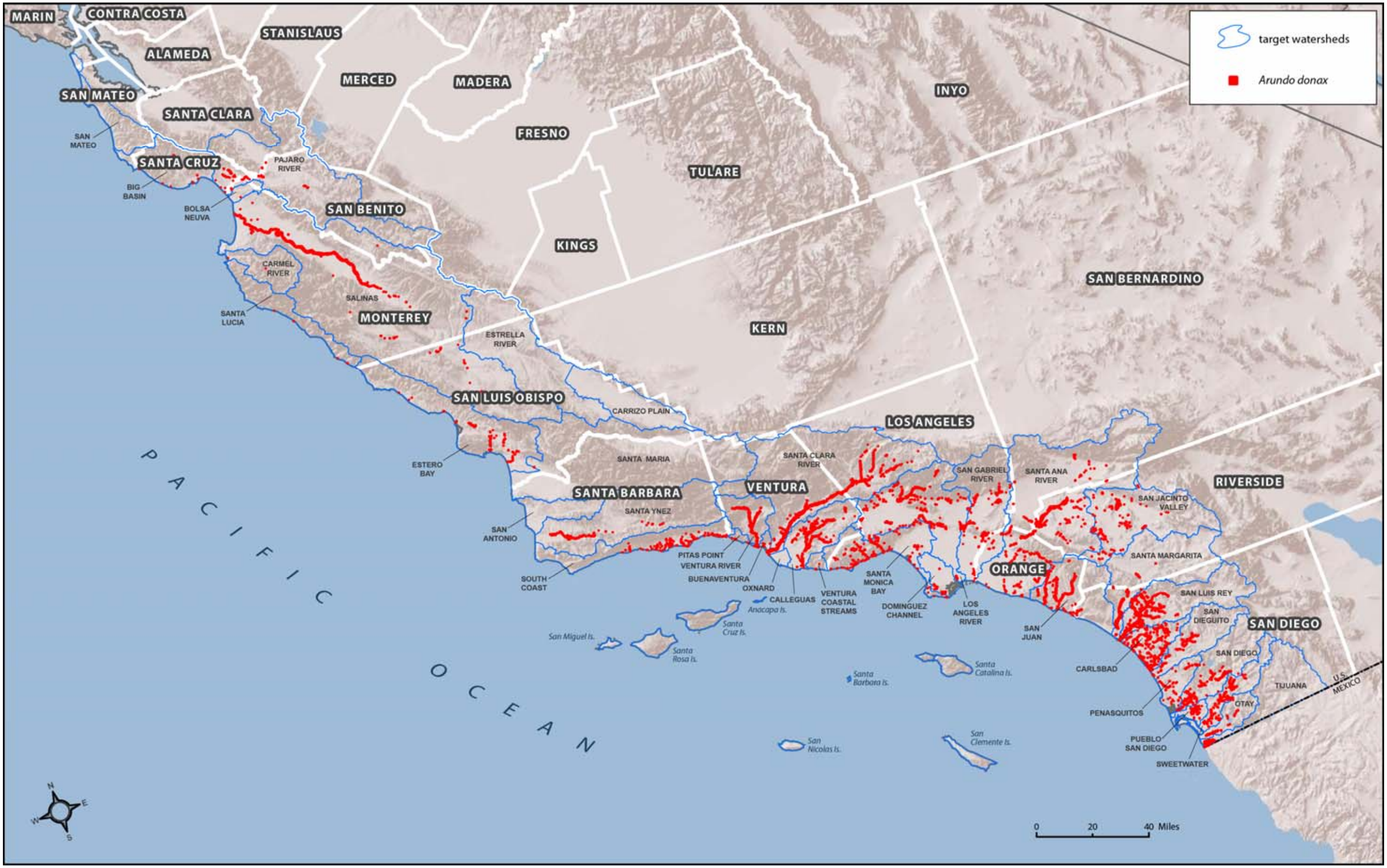


Figure 3-1. Distribution of *Arundo* mapped within the study area from Monterey to San Diego, CA.

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.

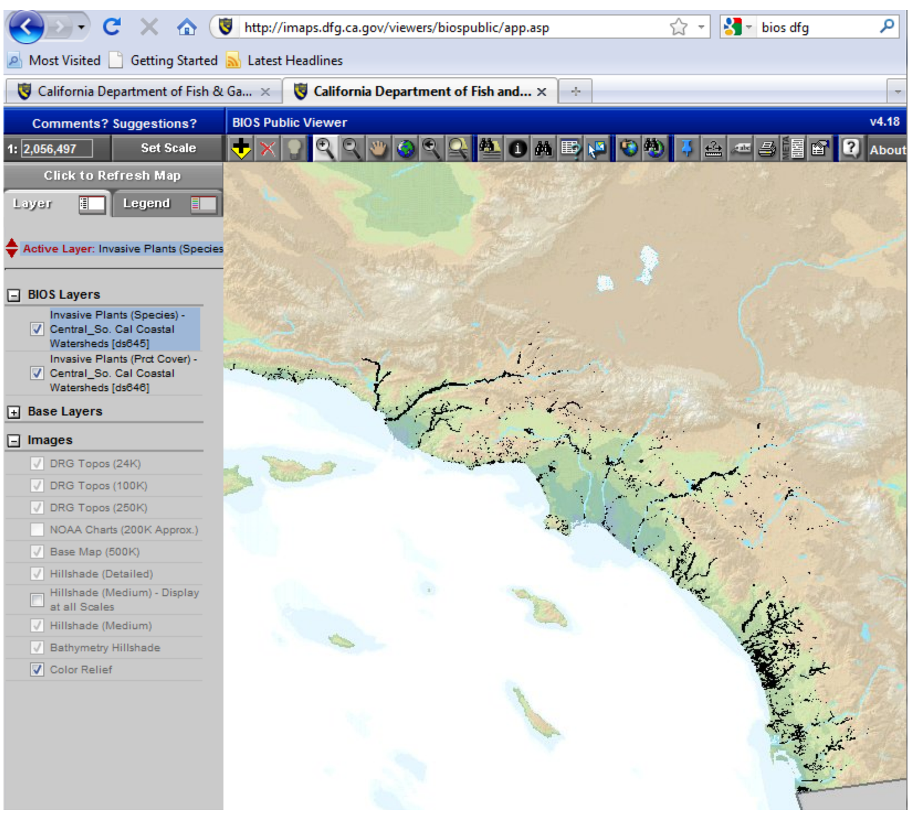


Figure 3-5. DFG BIOS data viewer with invasive plant data set active.

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	-	-	-	-

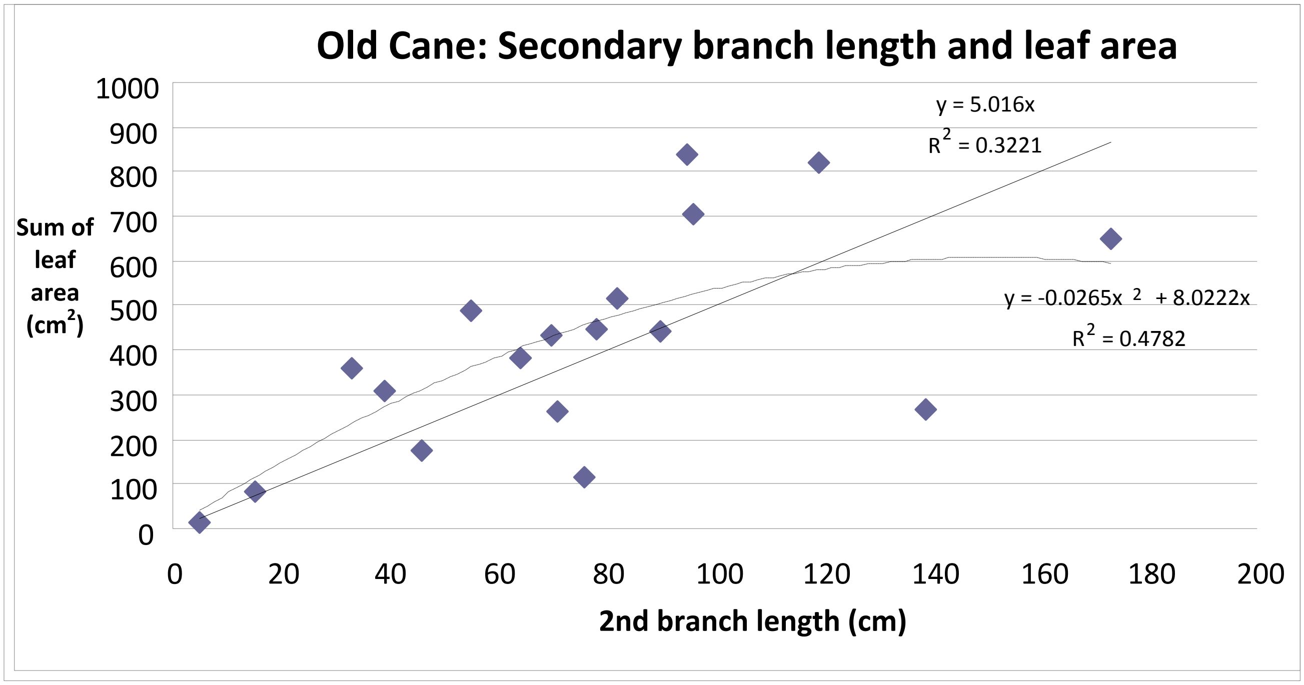


Figure 4-1. Secondary branch leaf area to length relationship.

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	1[st] 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)

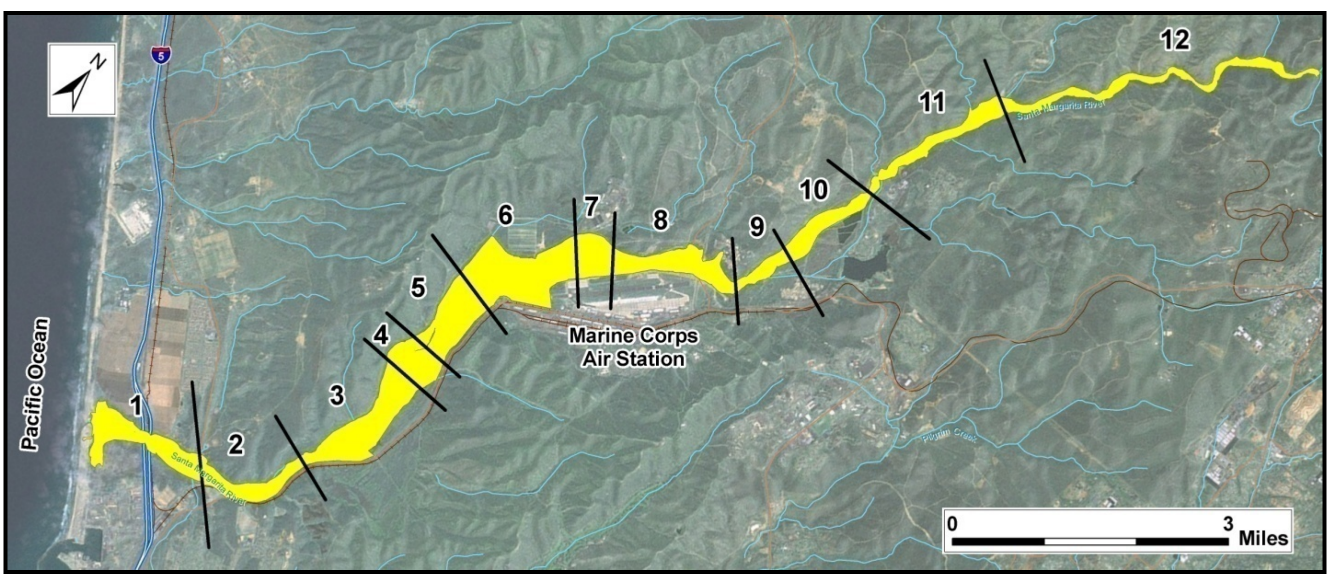


Figure 5-1.1. Santa Margarita River study reaches, with yellow denoting extent of mapped floodplain.

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)

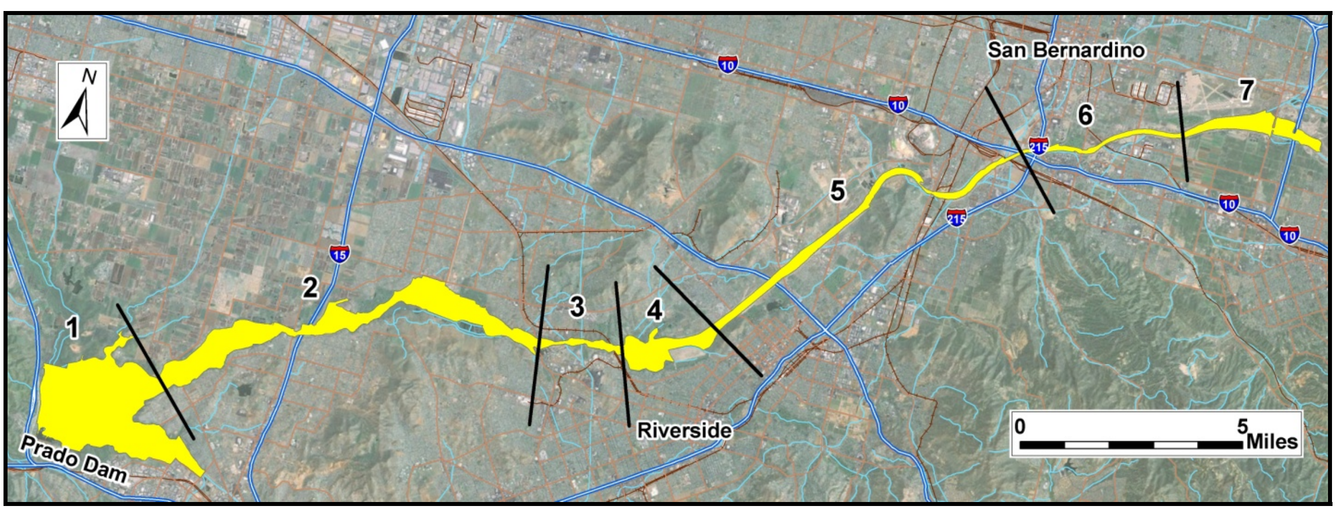


Figure 5-1.2. Santa Ana River study reaches with extent of mapped floodplain denoted in yellow.

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)

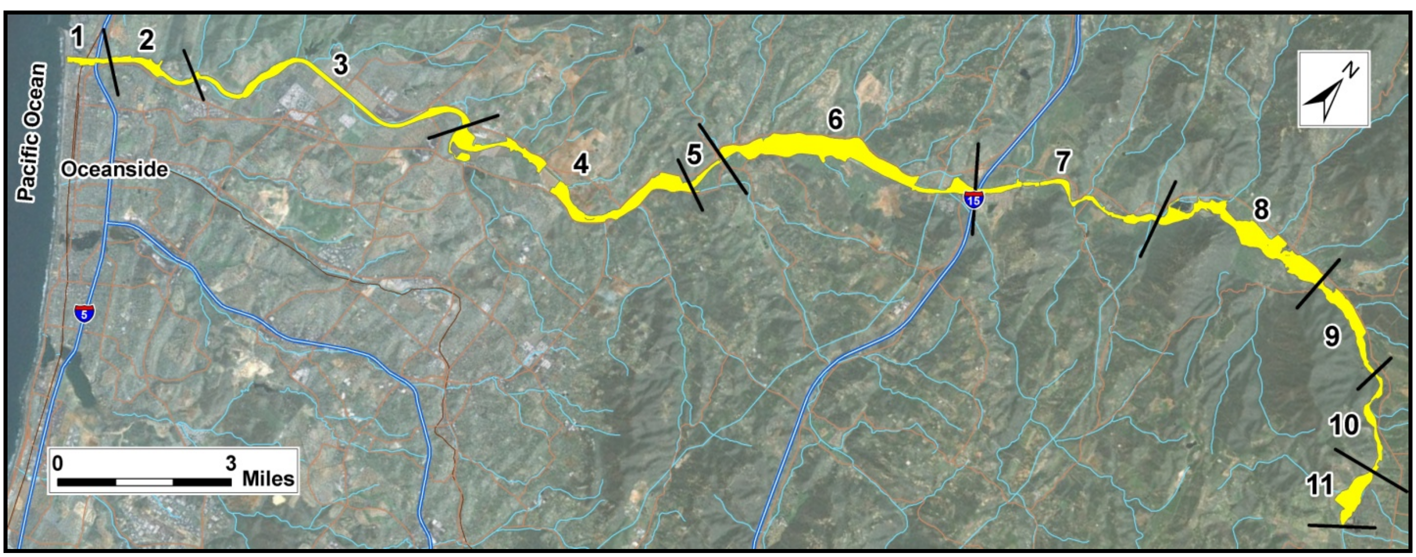


Figure 5-1.3 San Luis Rey River study reaches with extent of mapped floodplain denoted in yellow.

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).

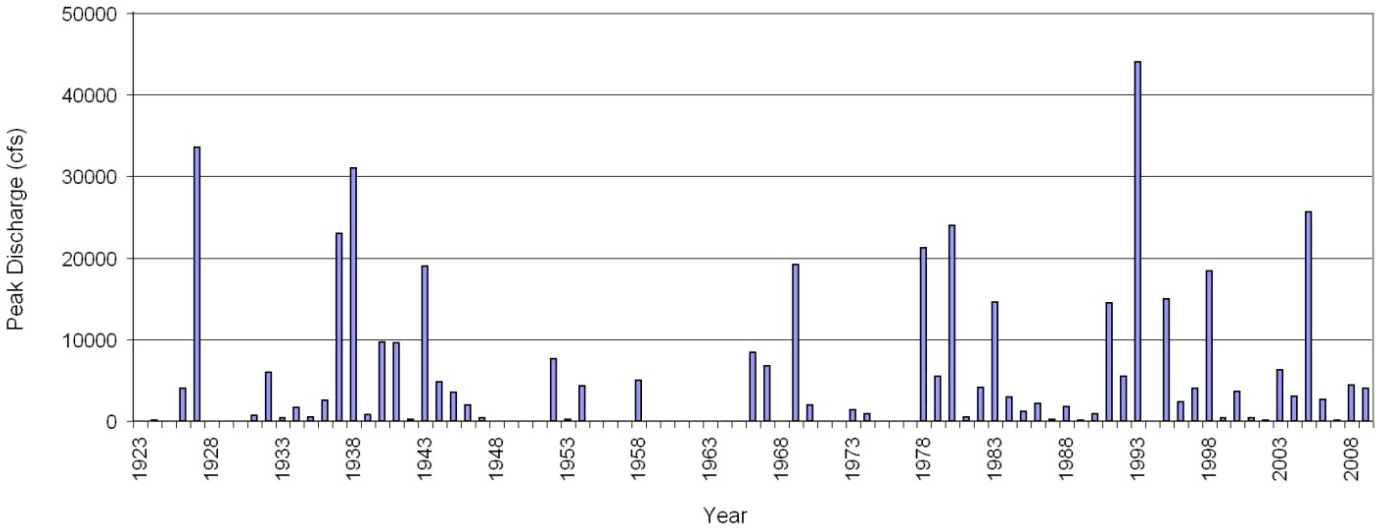


Figure 5-1.4. Annual peak discharges recorded at USGS stream gage 11046000 on Santa Margarita River near Ysidora.
Years with zero values or no data are shown as blank.

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).

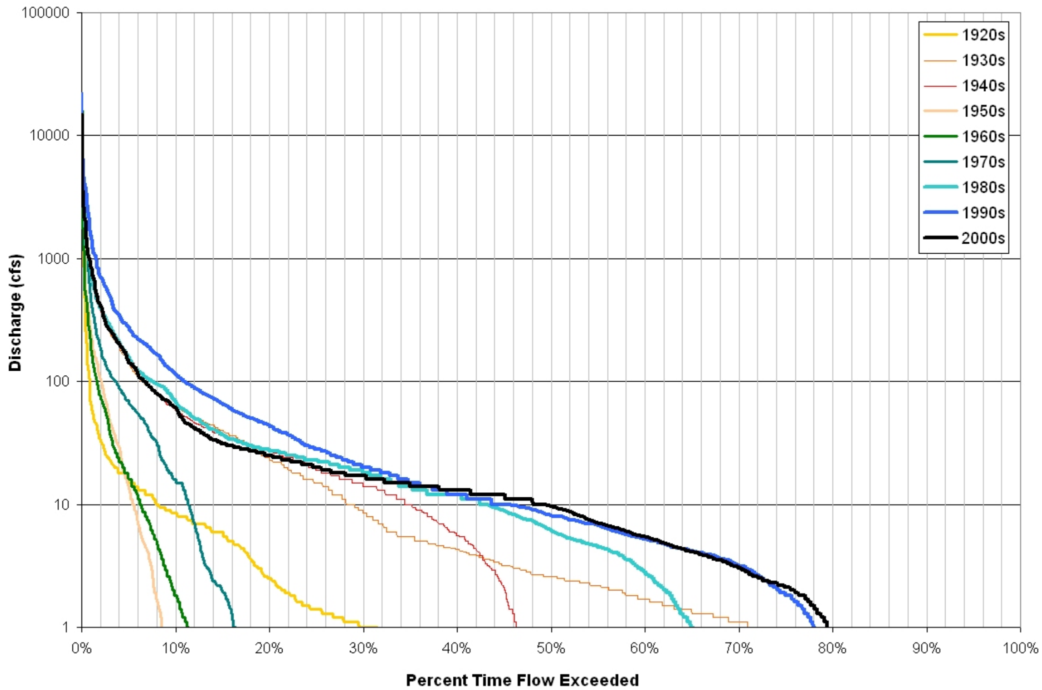


Figure 5-1.5. Flow duration curves plotted by decade at the Ysidora gage (11046000).

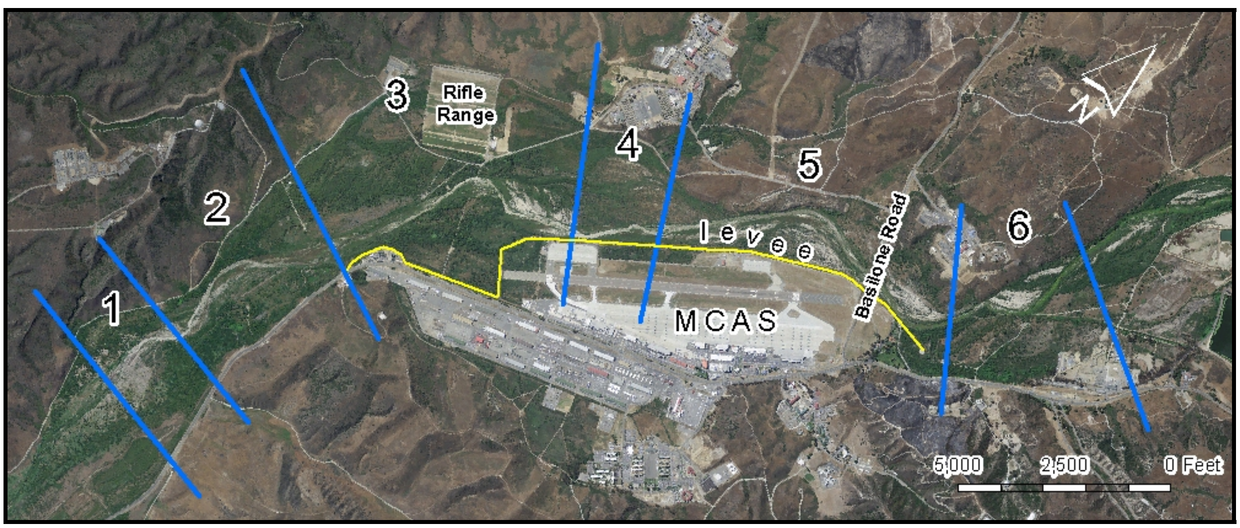


Figure 5-1.6. Sub-reaches (numbers 1 through 6) in the lower Santa Margarita River project reach.

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).

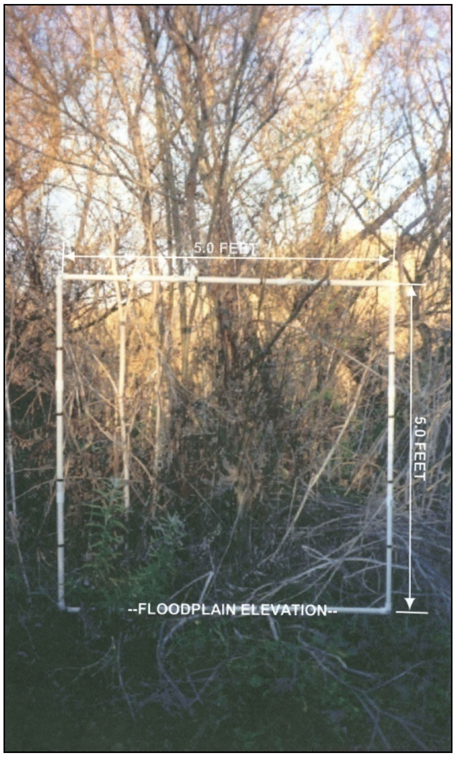
Model Calibration

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.

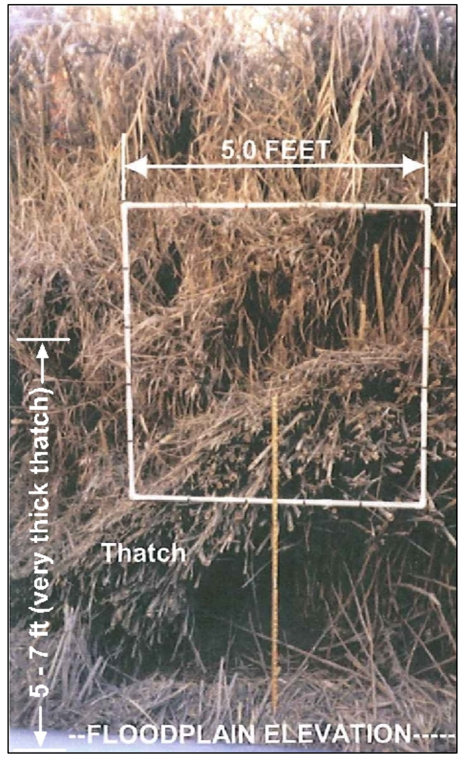
Field observations of mature *Arundo* stands showed an extremely dense thatch of interlocking plant stems that extended 5 to 7 feet above the ground surface that effectively blocked conveyance on the floodplain (Figure 5-1.10). Above that elevation, the *Arundo* stems were not as interlocked or densely 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.



(a) Native Riparian Vegetation



(b) Mature Stand of *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.

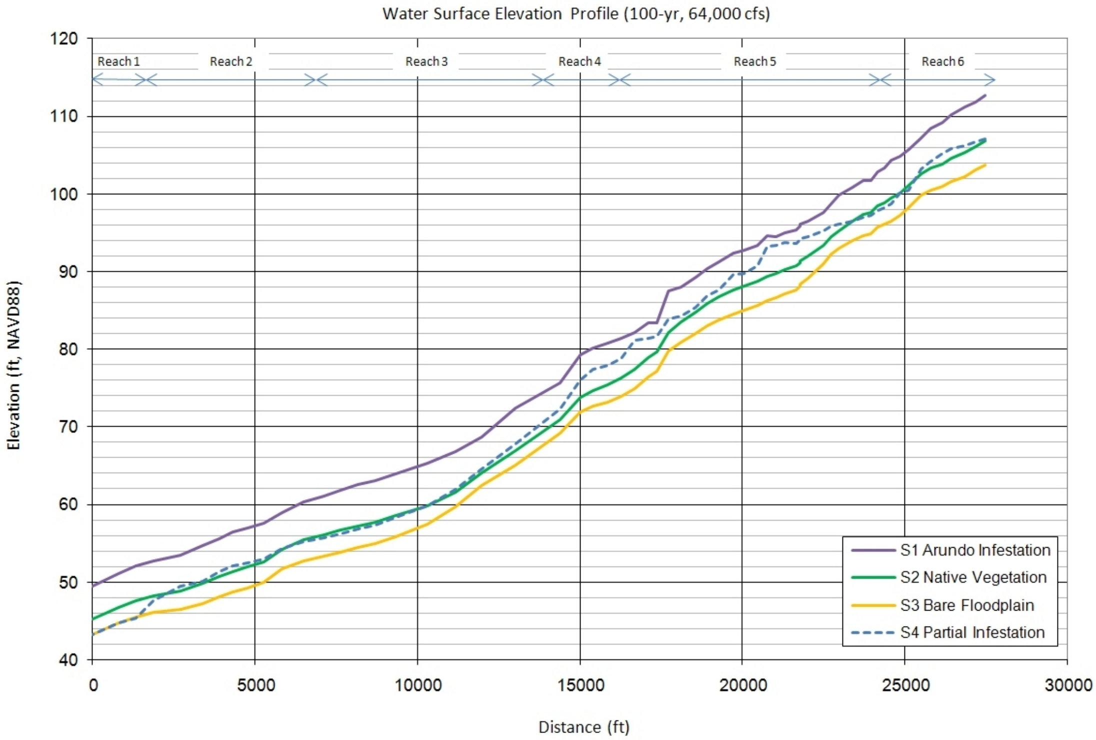


Figure 5-1.11. Project reach water surface profiles for scenarios 1 to 4: 100-year peak flow.

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.

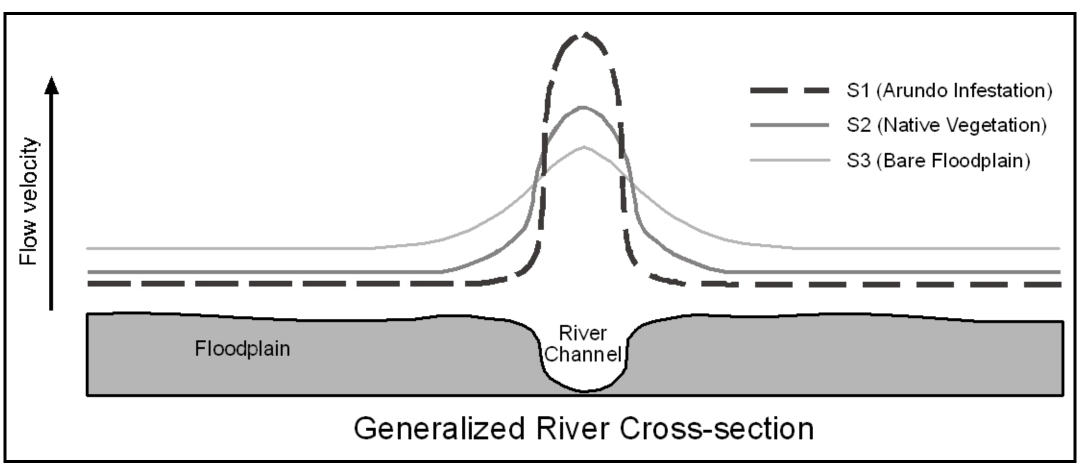


Figure 5-1.12. Generalized illustration of the effects of floodplain roughness (dense vegetation) on velocity across the section for Scenarios 1, 2, and 3.

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:

$$Sediment_{Out} = Sediment_{In} \pm \Delta Storage \qquad (1)$$

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

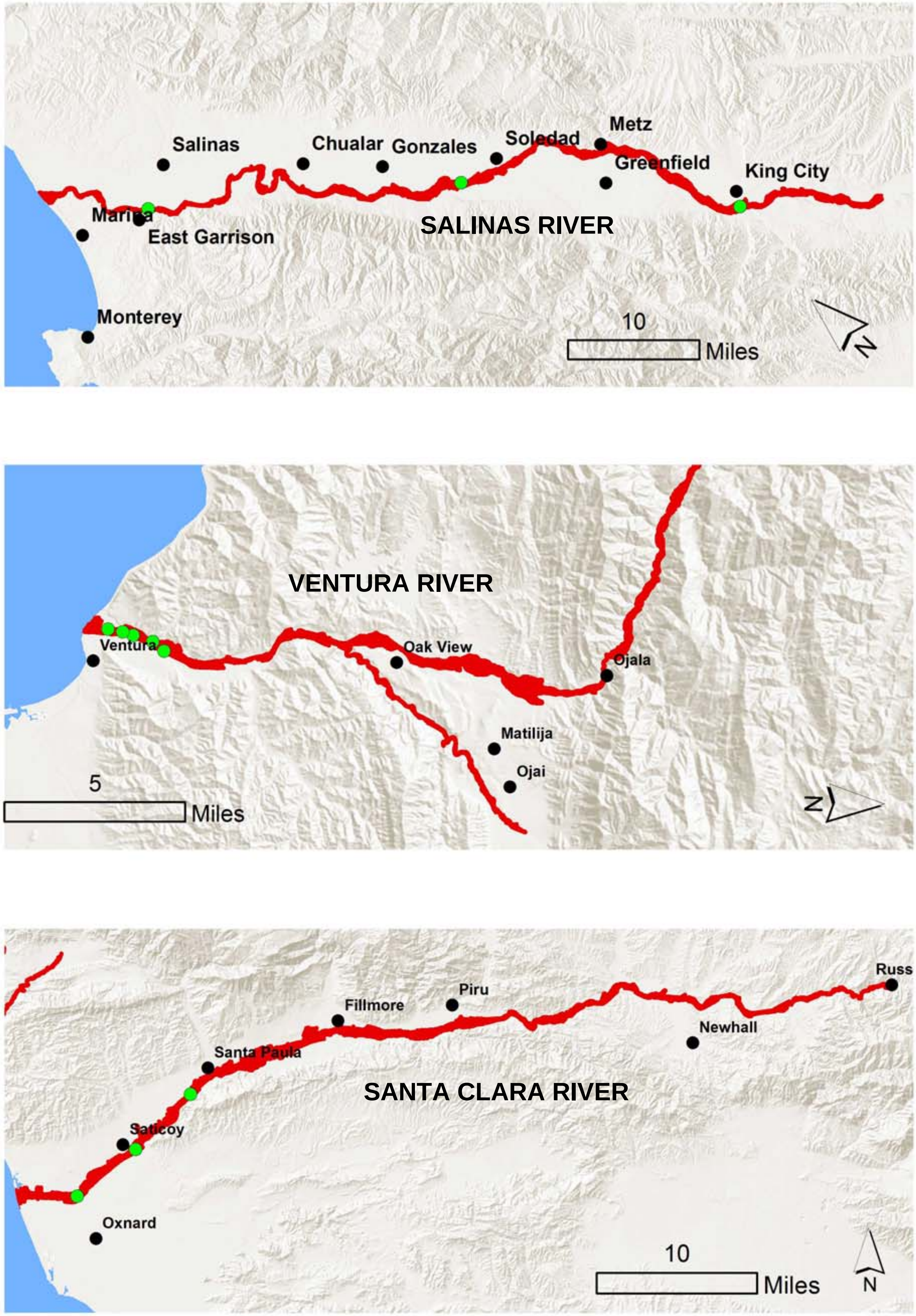


Figure 5-2.1. Location of the Area of Interest and cross-sections (northern watersheds).

Figure 5-2.2. Location of the Area of Interest and cross-sections (southern watersheds).

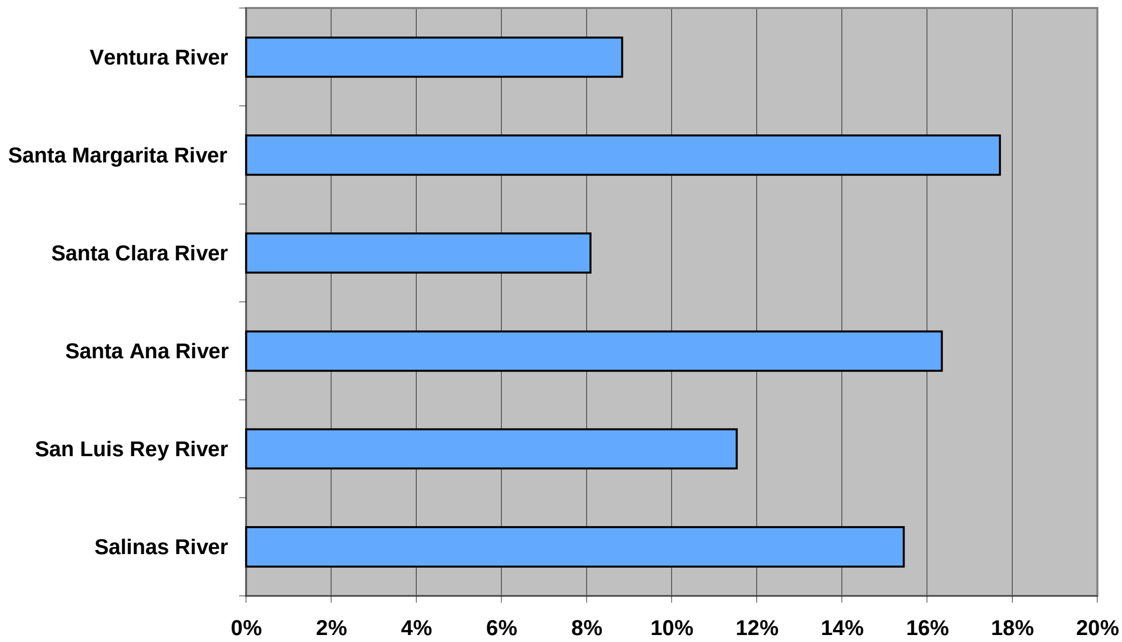


Figure 5-2.3. *Arundo* acreage as a percent of system acreage within the Area of Interest (AOI).

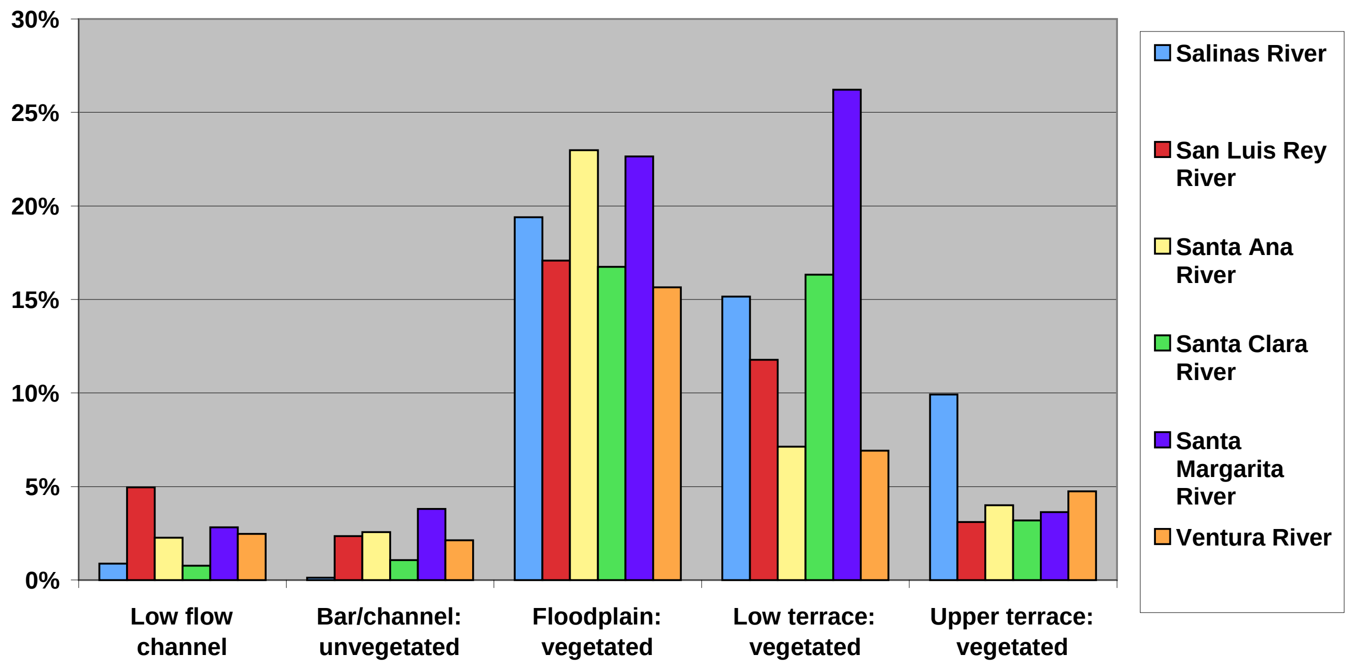


Figure 5-2.4. Percent of geomorphic form invaded by *Arundo* for the Area of Interest (AOI). This shows that the highest levels of invasion are in the floodplain and low-terrace geomorphic forms, regardless of the acreage of the geomorphic form itself.

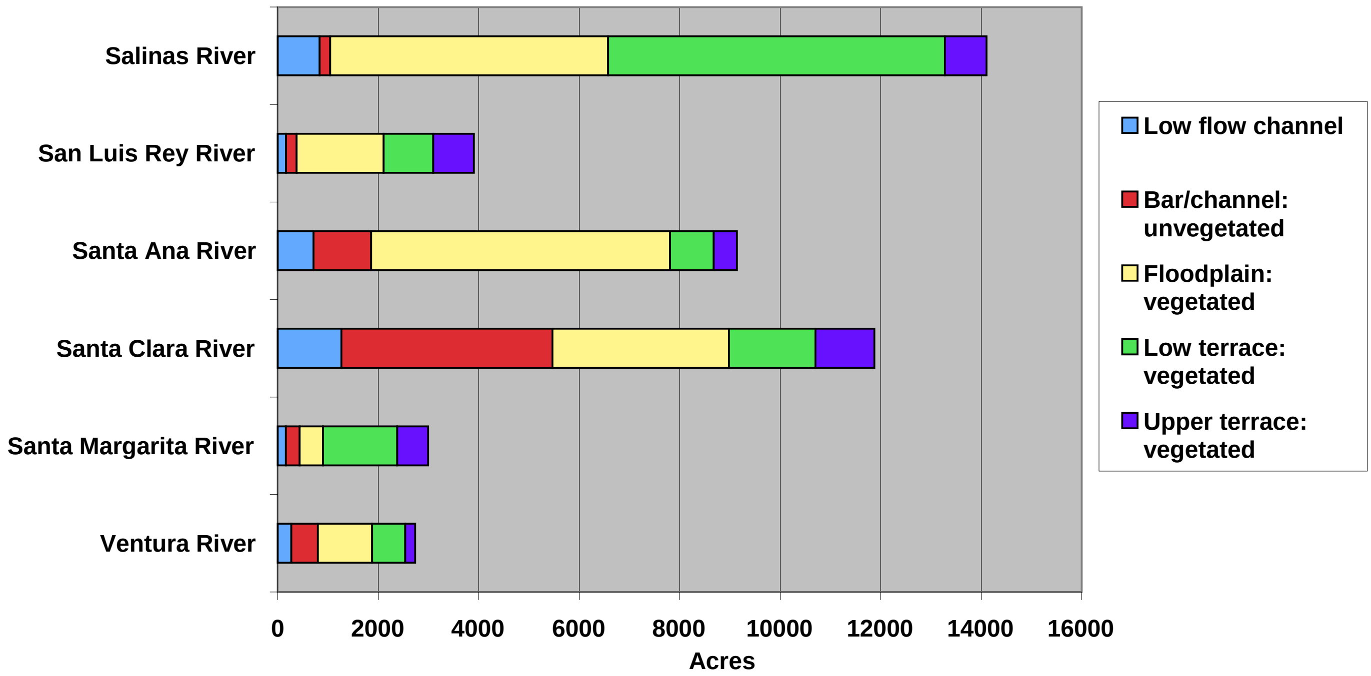


Figure 5-2.5. Acreage of geomorphic forms mapped within the Area of Interest (AOI). This shows that the floodplain and terrace forms dominate most systems (within the AOI).

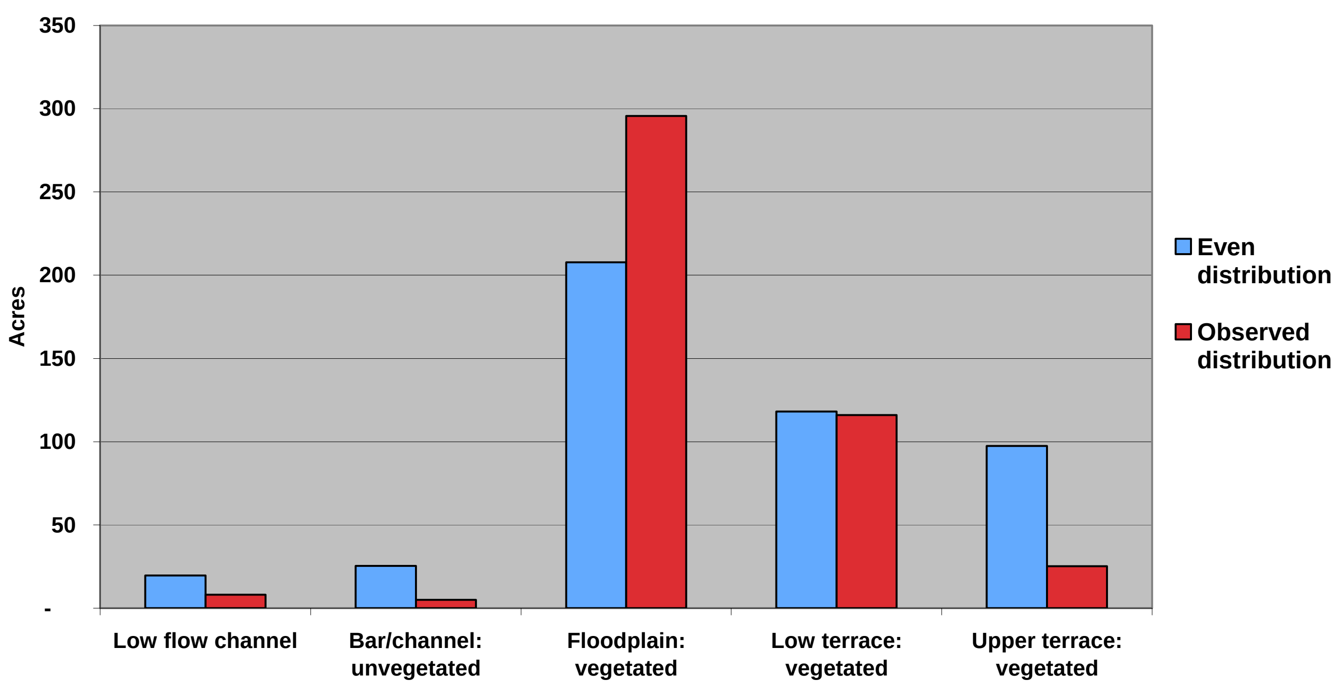


Figure 5-2.6. Observed and expected even distribution of *Arundo* acreage on the San Luis Rey watershed by geomorphic class.

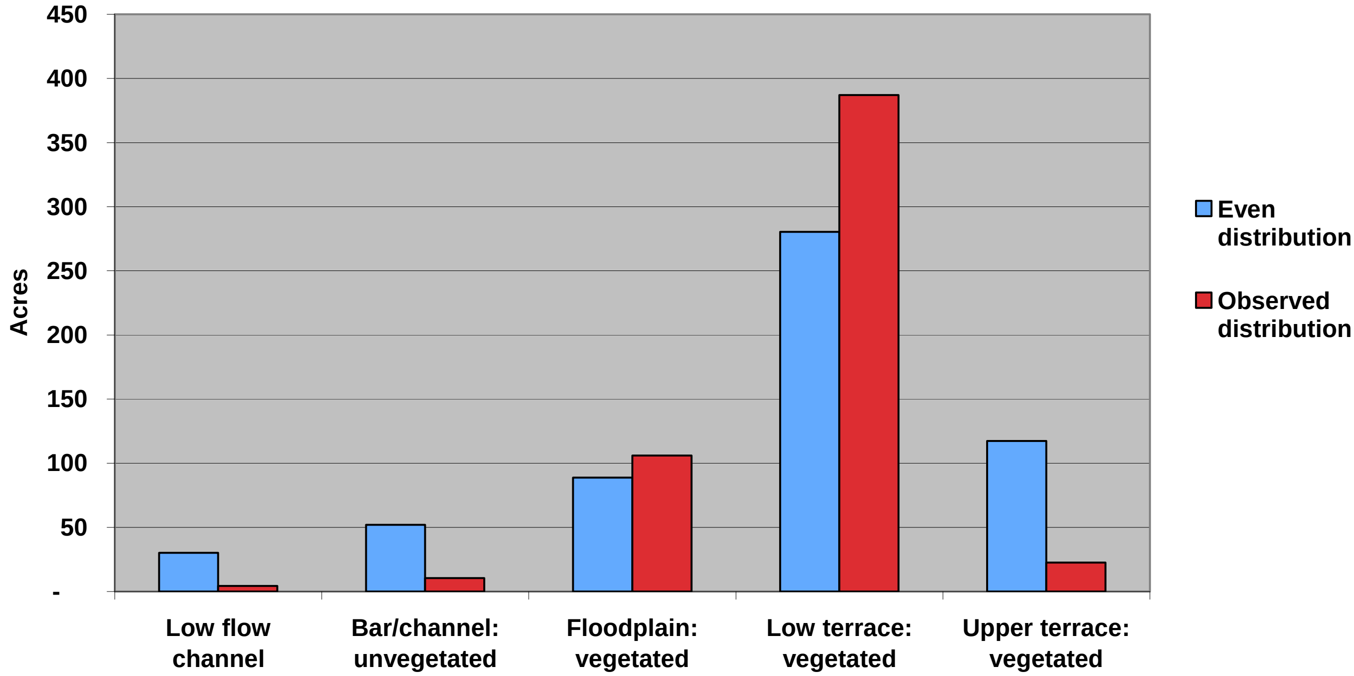


Figure 5-2.7. Observed and expected even distribution of *Arundo* acreage on the Santa Margarita watershed by geomorphic class.

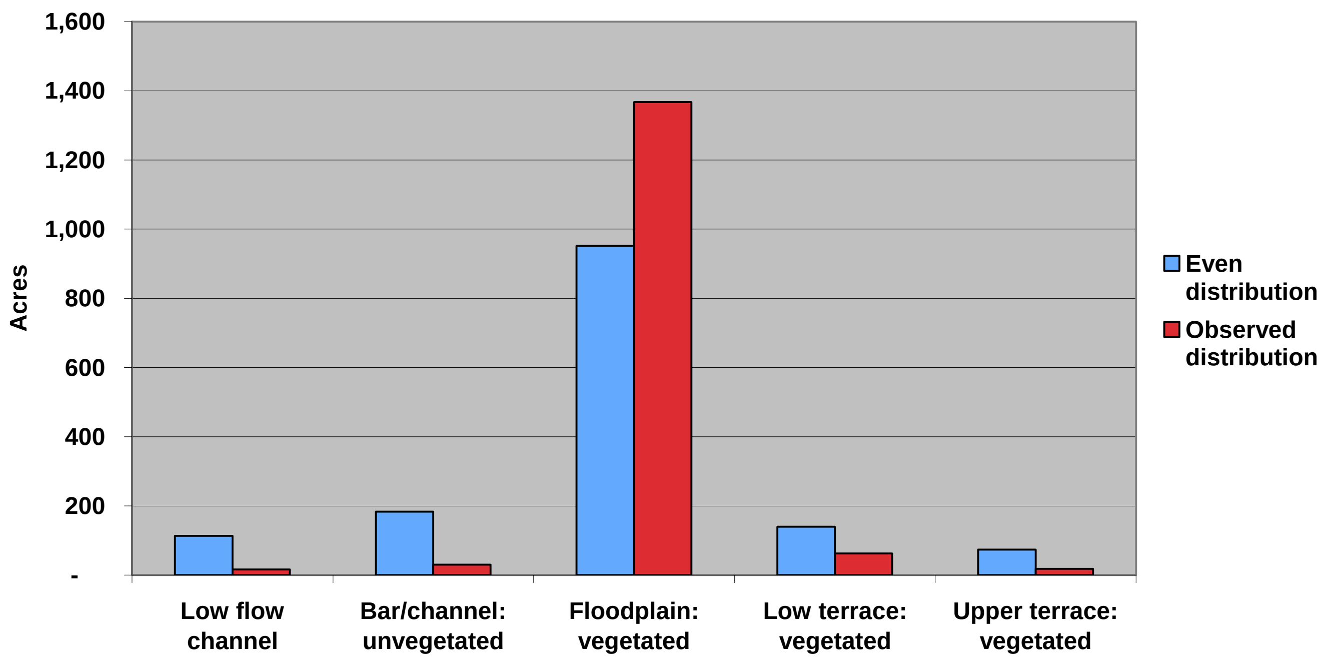


Figure 5-2.8. Observed and expected even distribution of *Arundo* acreage on the Santa Ana watershed by geomorphic class.

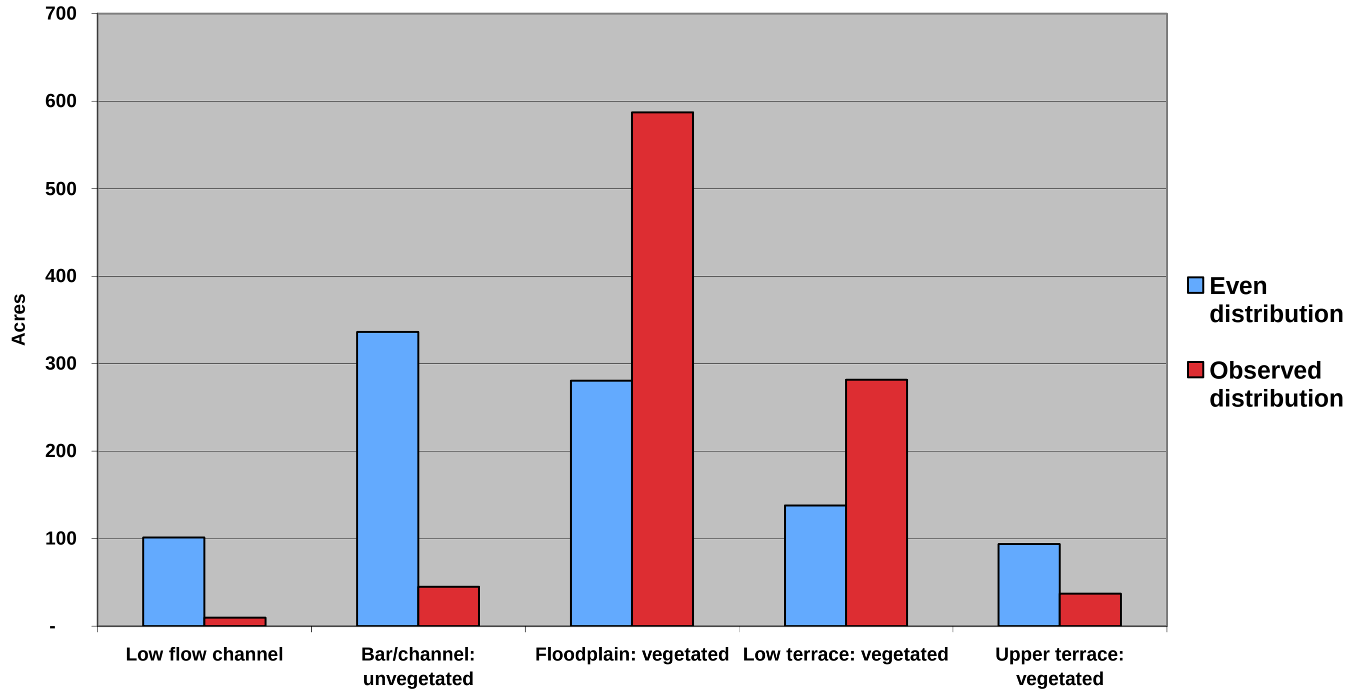


Figure 5-2.9. Observed and expected even distribution of *Arundo* acreage on the Santa Clara watershed by geomorphic class.
Santa Clara has much more low flow channel and bar/channel than the other systems.

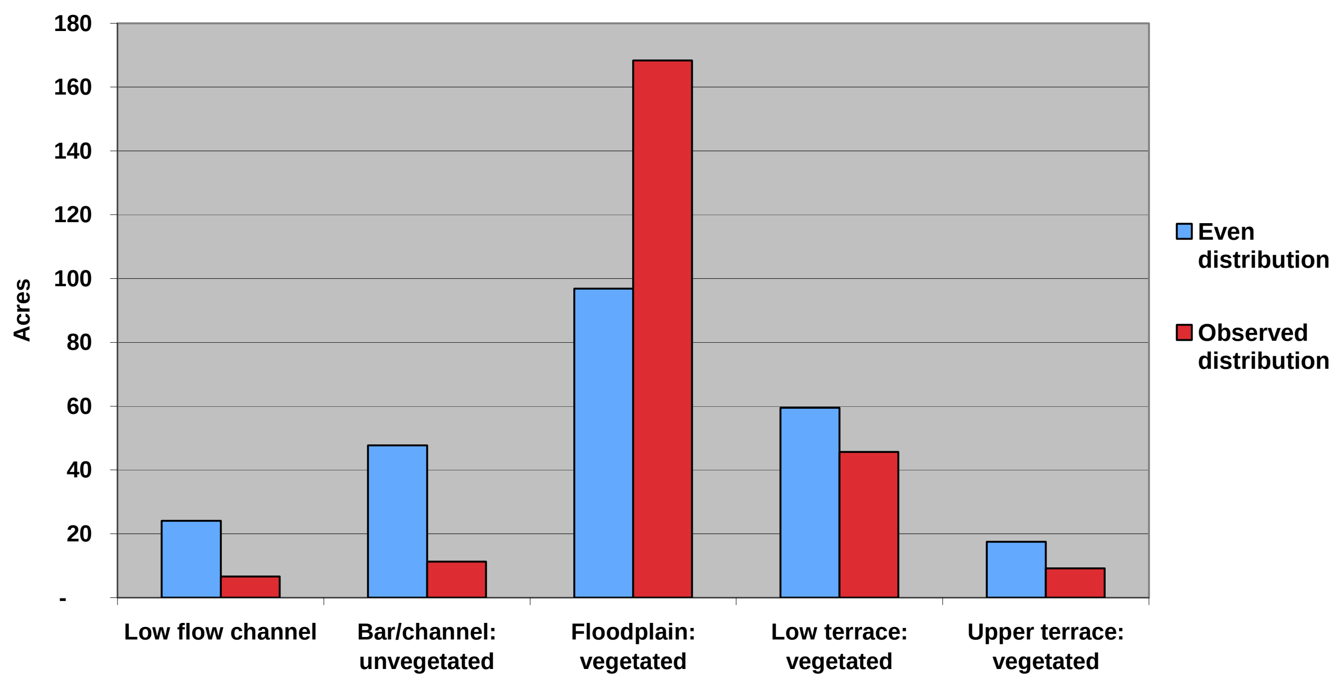


Figure 5-2.10. Observed and expected even distribution of *Arundo* acreage on the Ventura watershed by geomorphic class.

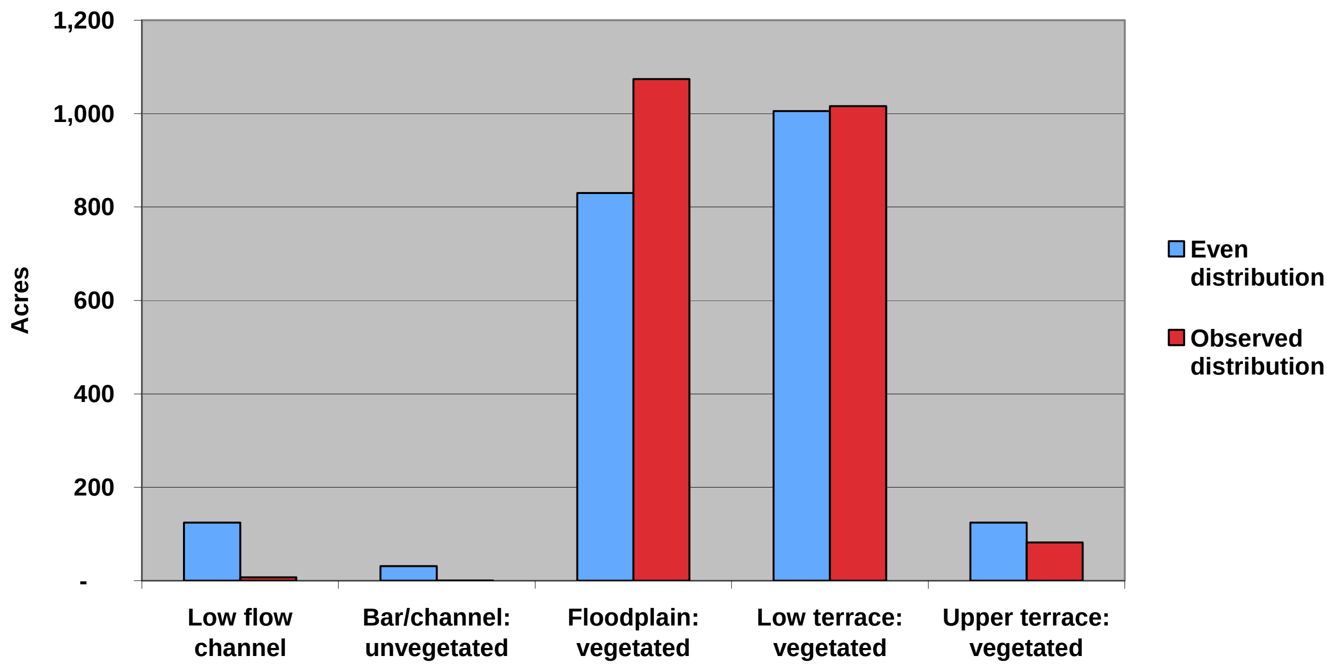


Figure 5-2.11. Observed and expected even distribution of *Arundo* acreage on the Salinas watershed by geomorphic class.

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.

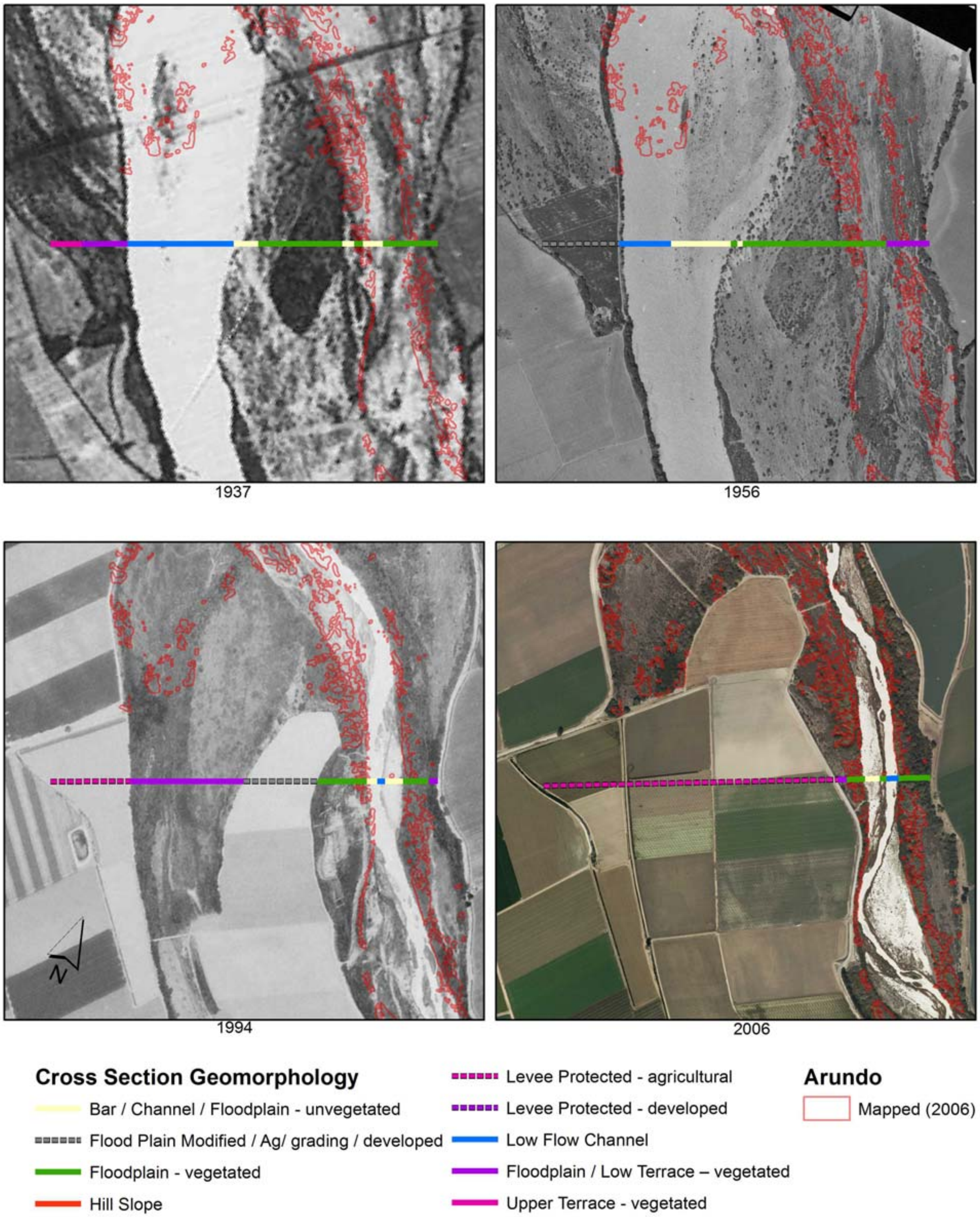


Figure 5-2.12. Cross-section geomorphology using historic aerial imagery on the Salinas watershed from 1937 to 2006.

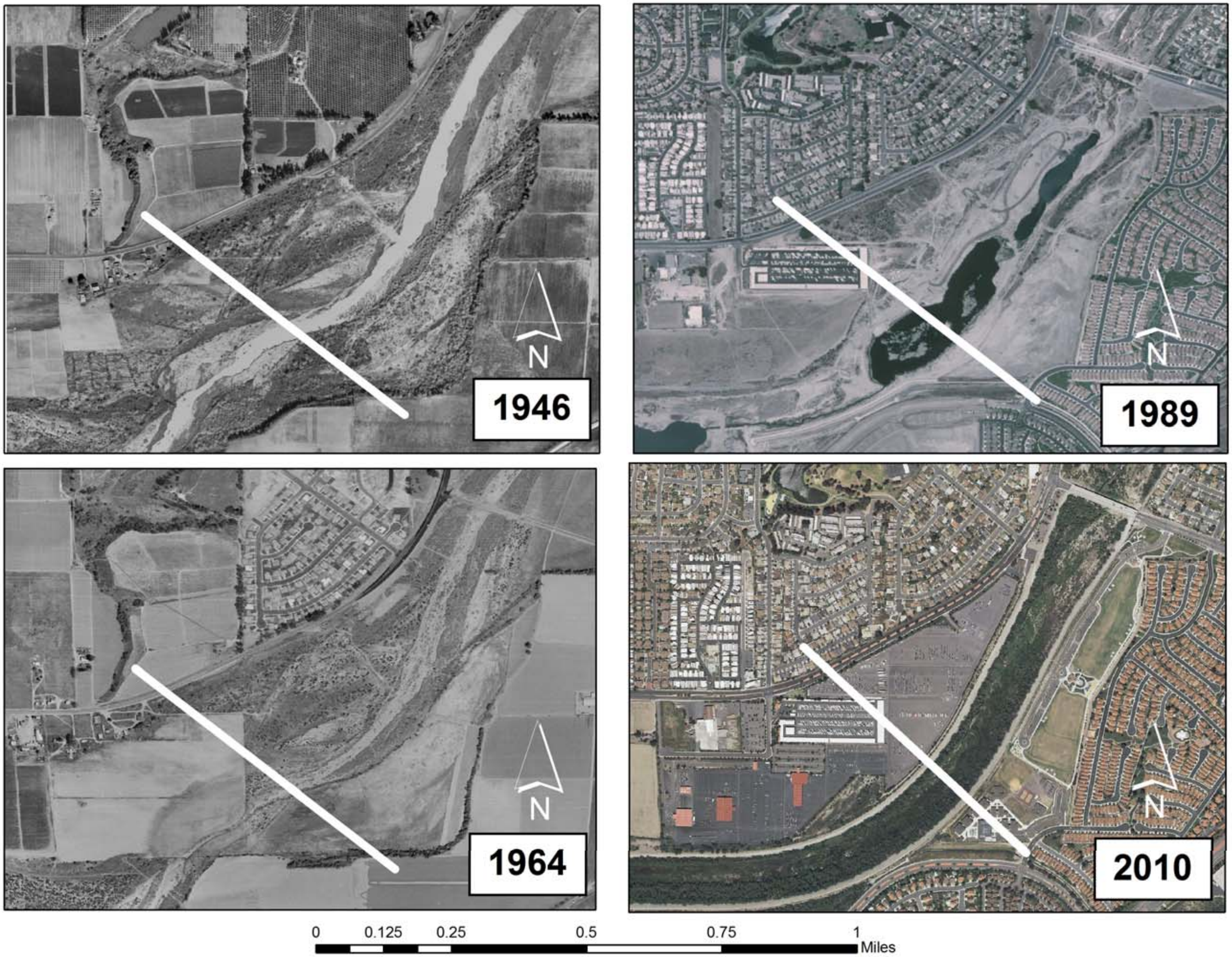


Figure 5-2.13. Historic photo analysis of geomorphic and hydrologic cross-sections on the San Luis Rey River from 1946 to 2010.

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

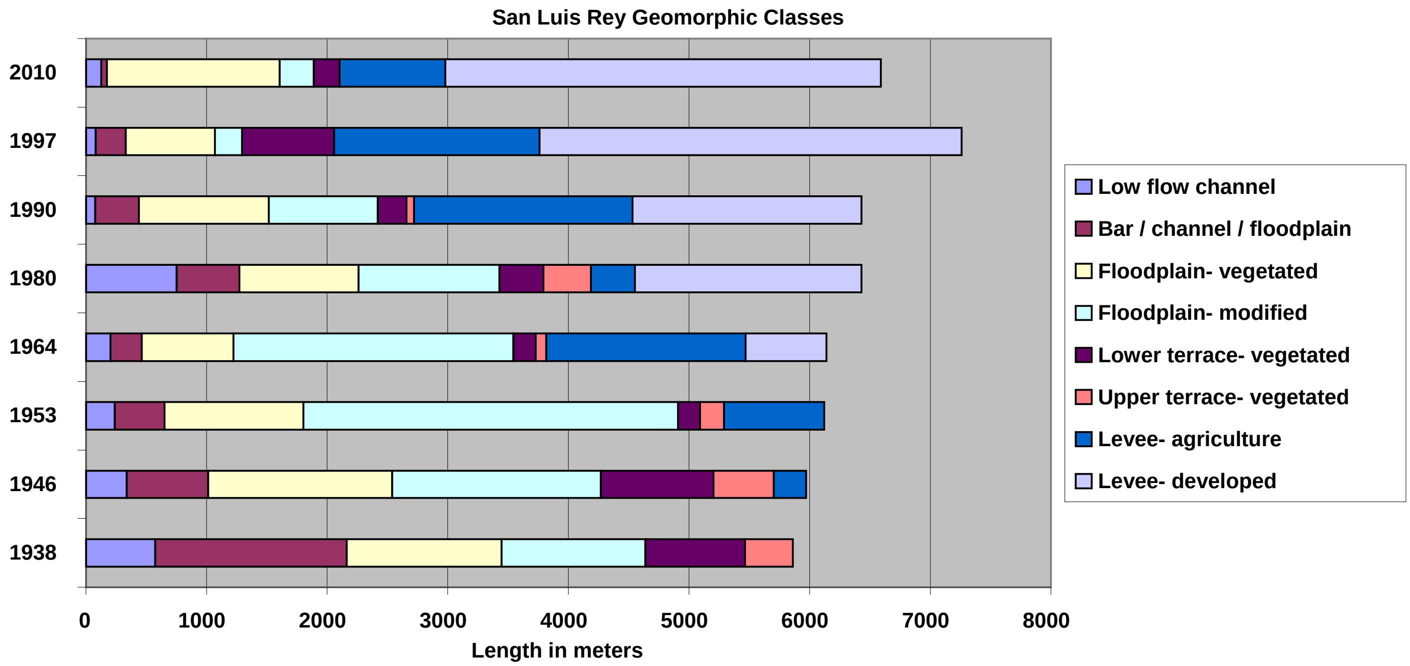


Figure 5-2.14. San Luis Rey geomorphic forms from 1938 to 2010.

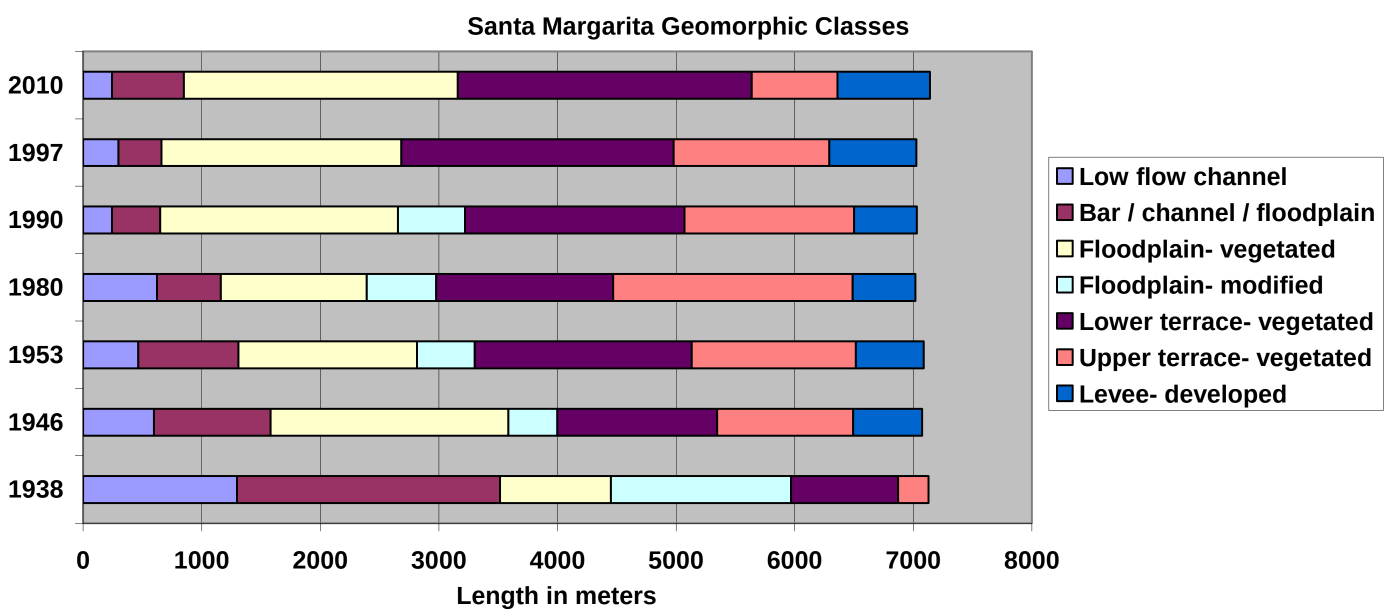


Figure 5-2.15. Santa Margarita geomorphic forms from 1938 to 2010.

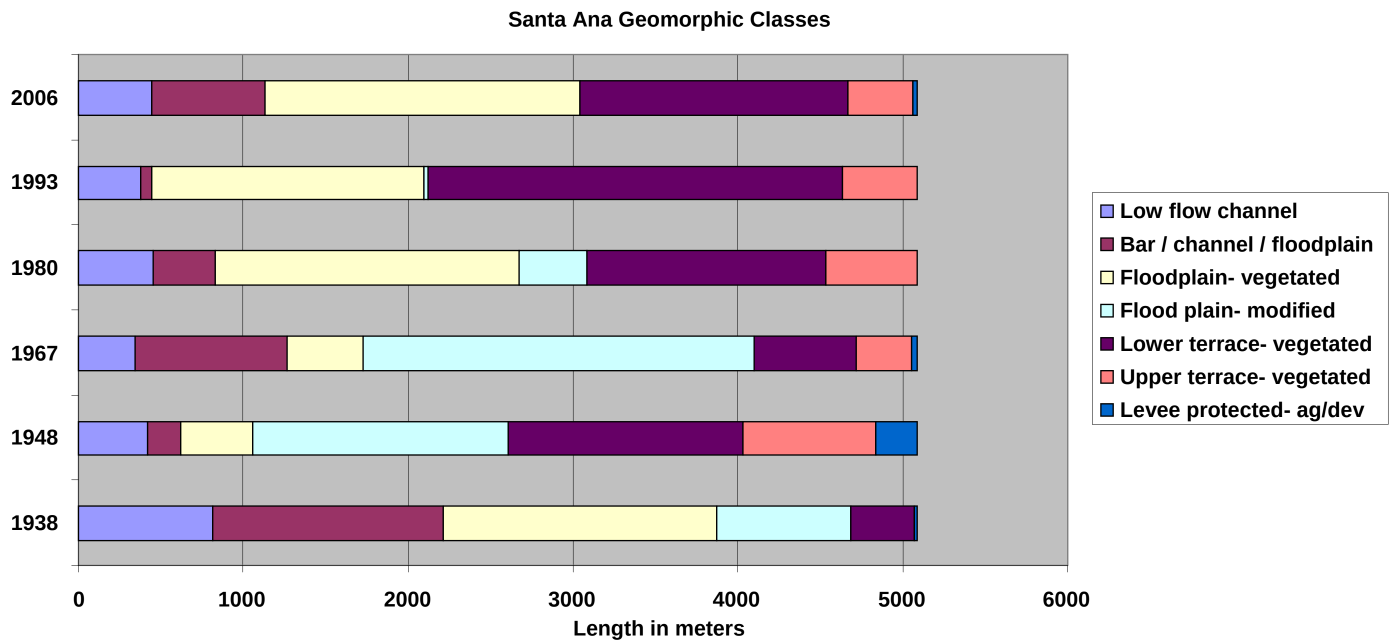


Figure 5-2.16. Santa Ana geomorphic forms from 1938 to 2006.

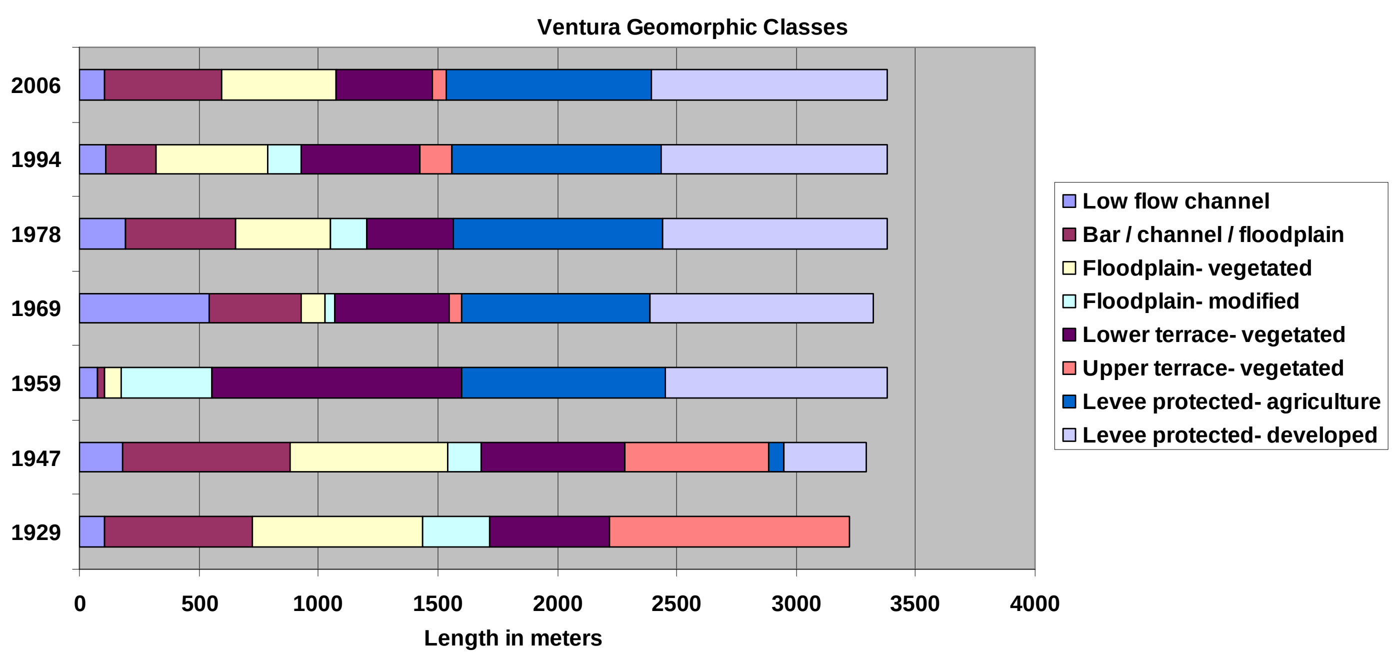


Figure 5-2.17. Ventura geomorphic forms from 1929 to 2006.

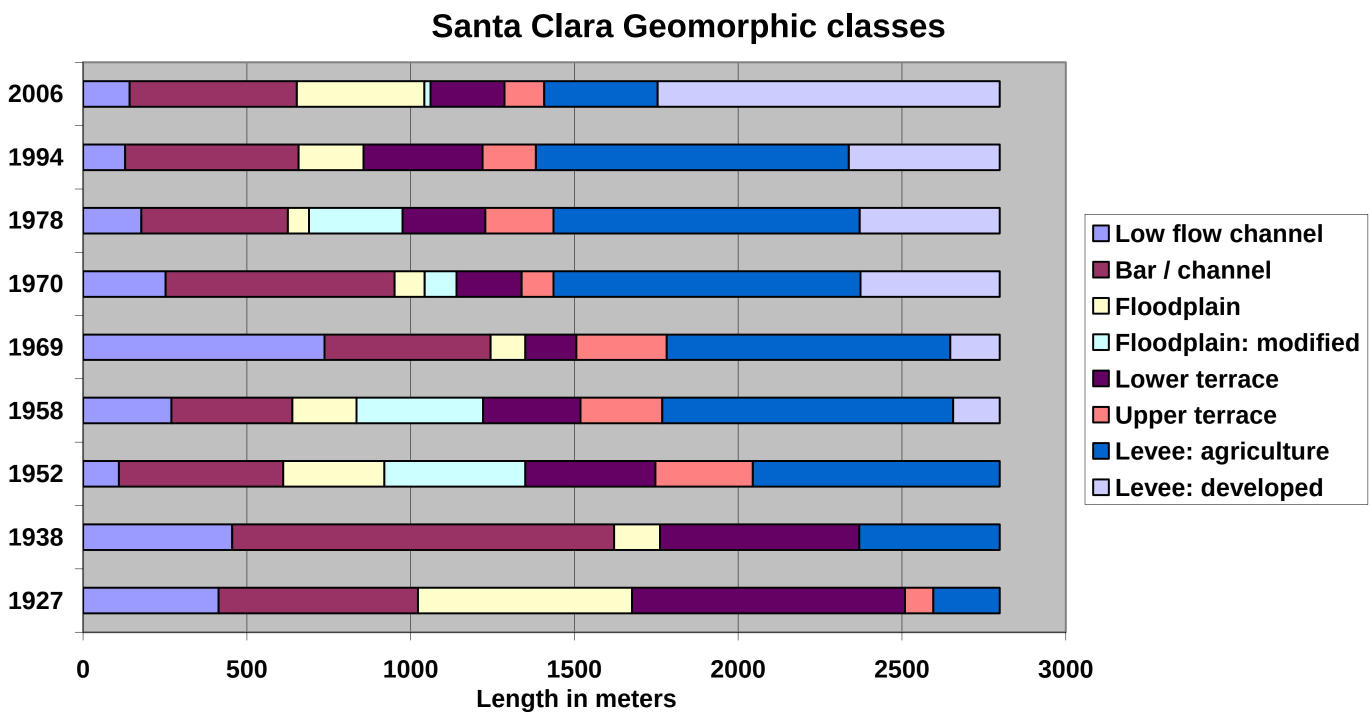


Figure 5-2.18. Santa Clara geomorphic forms from 1927 to 2006.

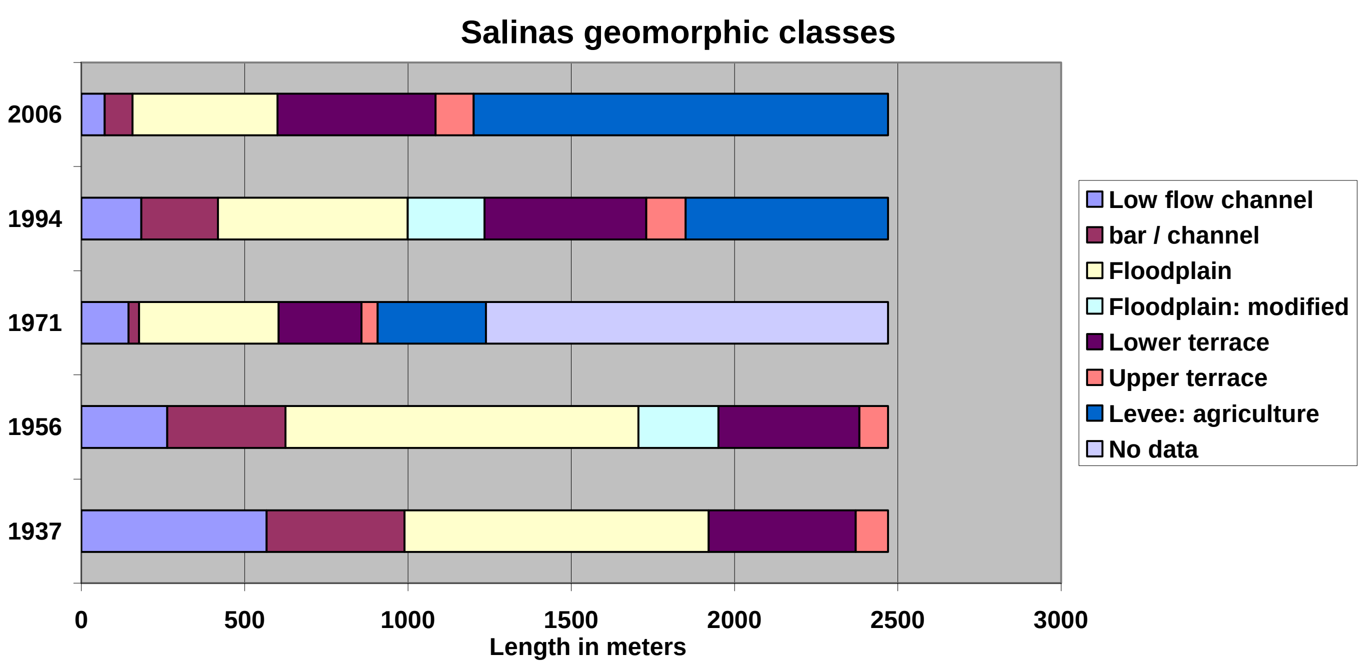


Figure 5-2.19. Salinas geomorphic forms from 1937 to 2006.

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).

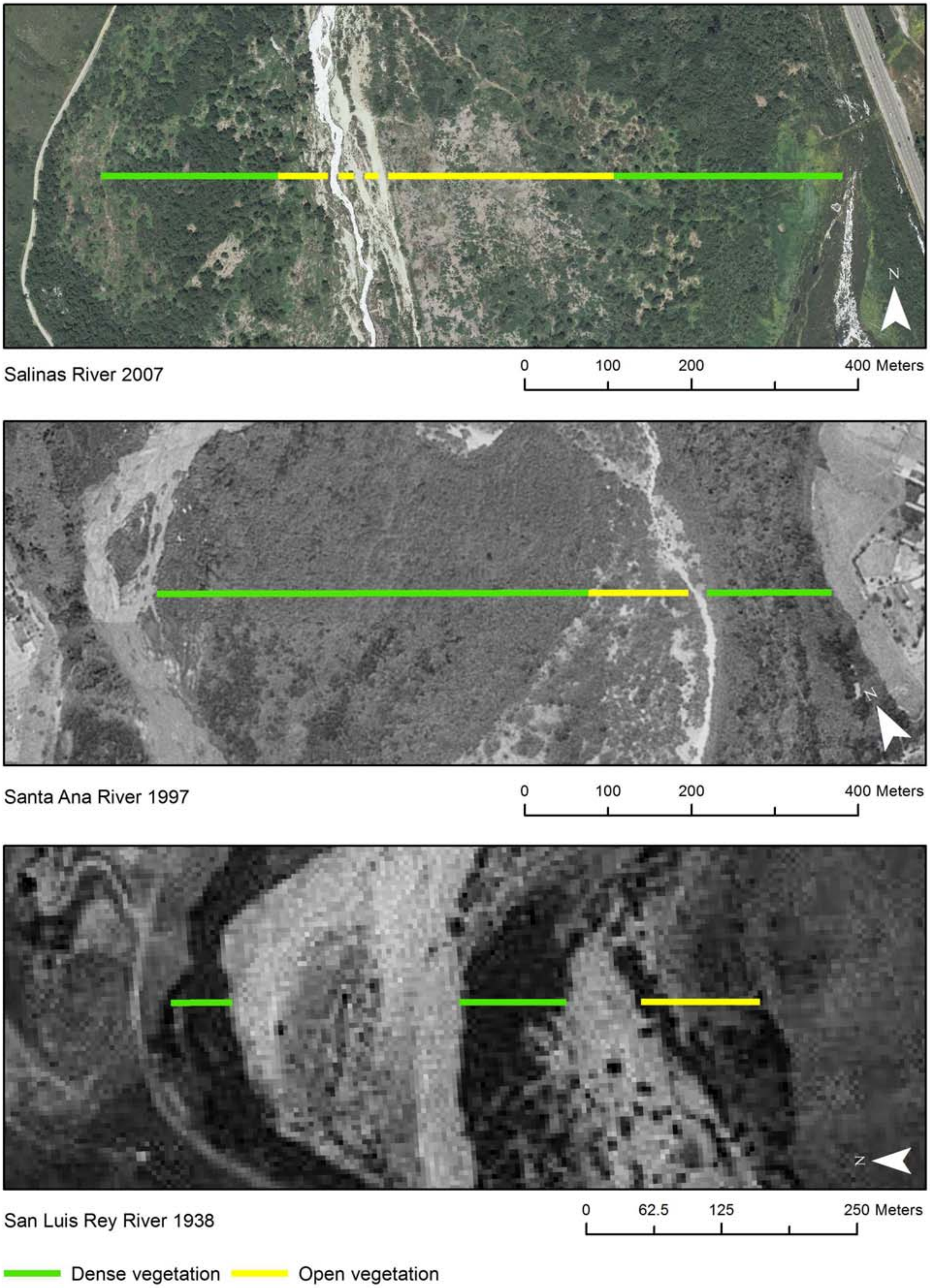


Figure 5-2.20. Aerial imagery showing floodplain and terrace areas with dense and open vegetation classes marked.

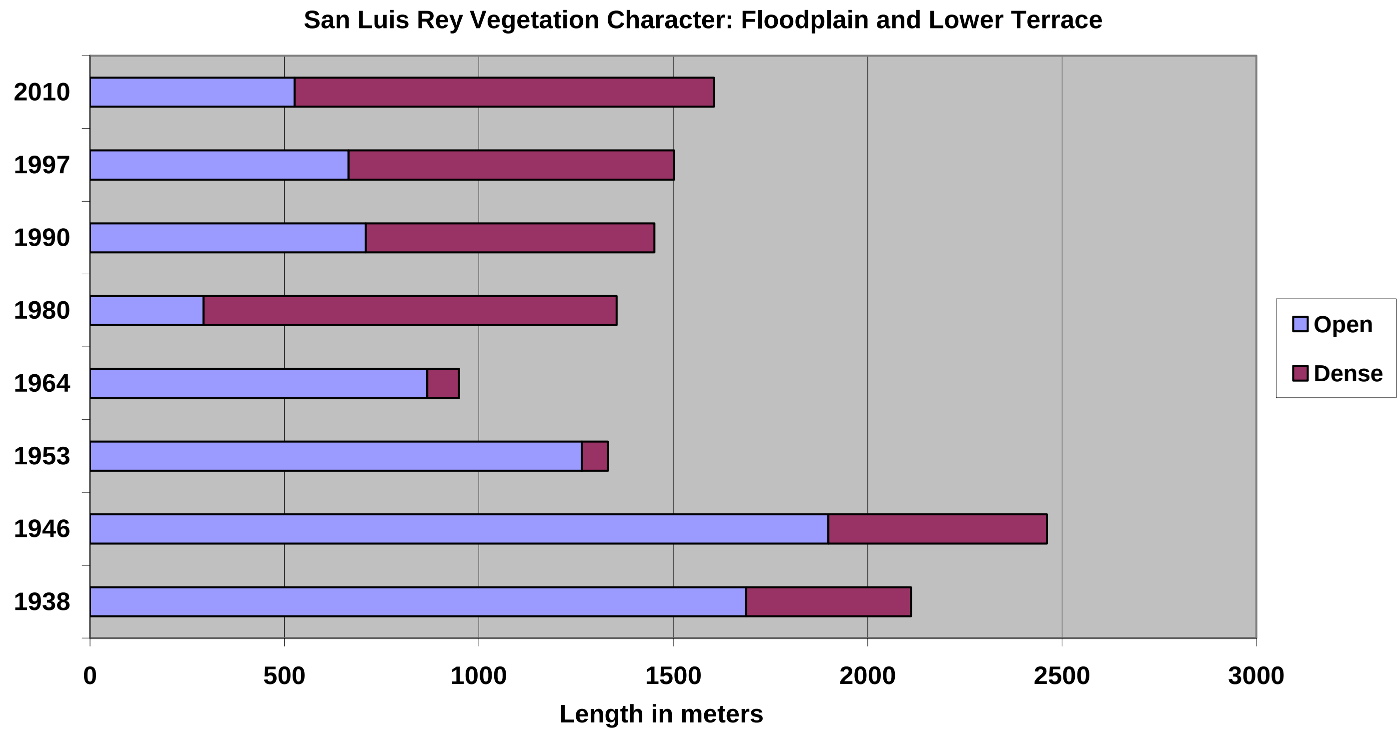


Figure 5-2.21. San Luis Rey open and dense vegetation classification on floodplain and lower terrace areas from 1938 to 2010.

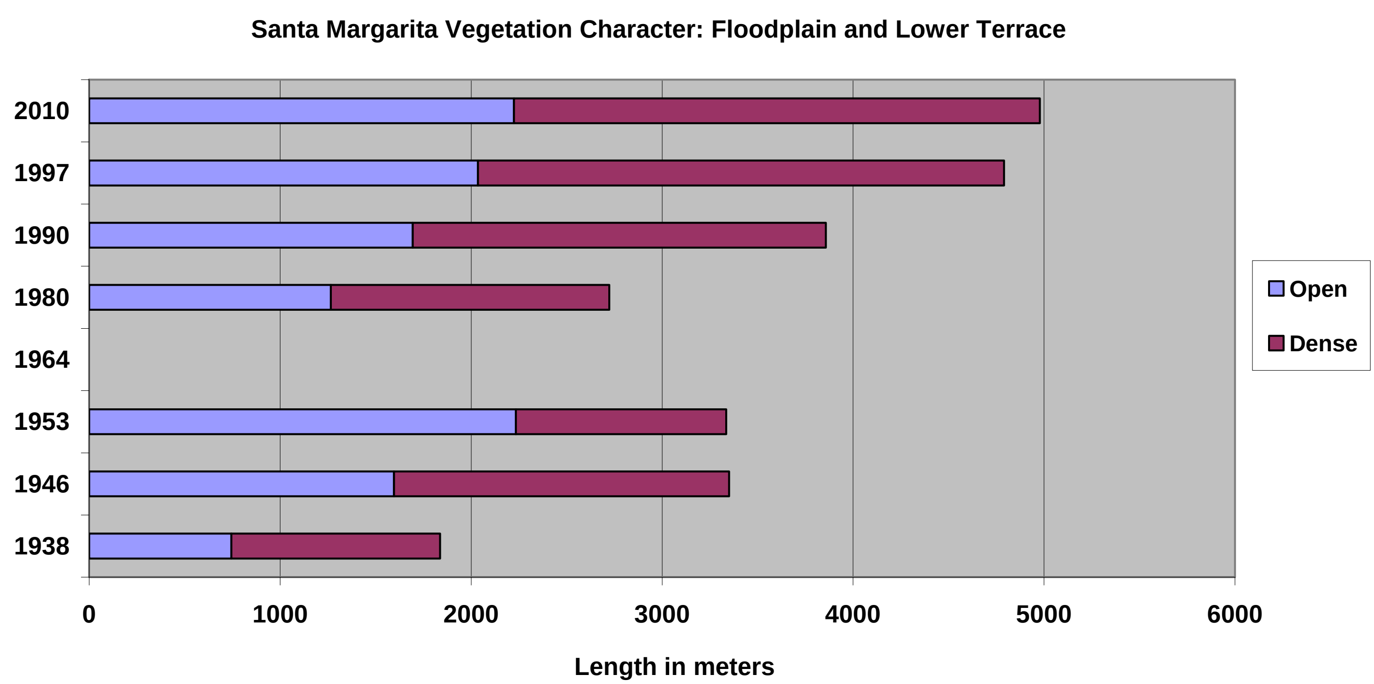


Figure 5-2.22. Santa Margarita open and dense vegetation classification on floodplain and lower terrace areas from 1938 to 2010.

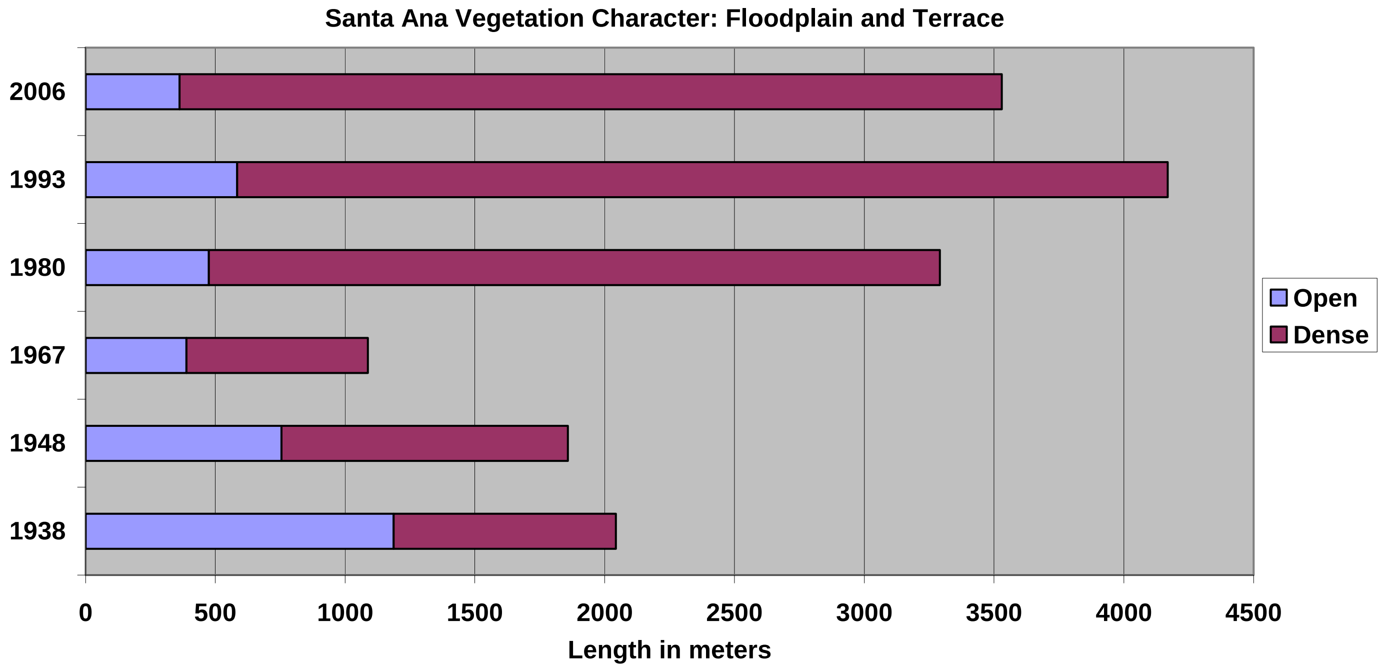


Figure 5-2.23. Santa Ana open and dense vegetation classification on floodplain and lower terrace areas from 1938 to 2006.

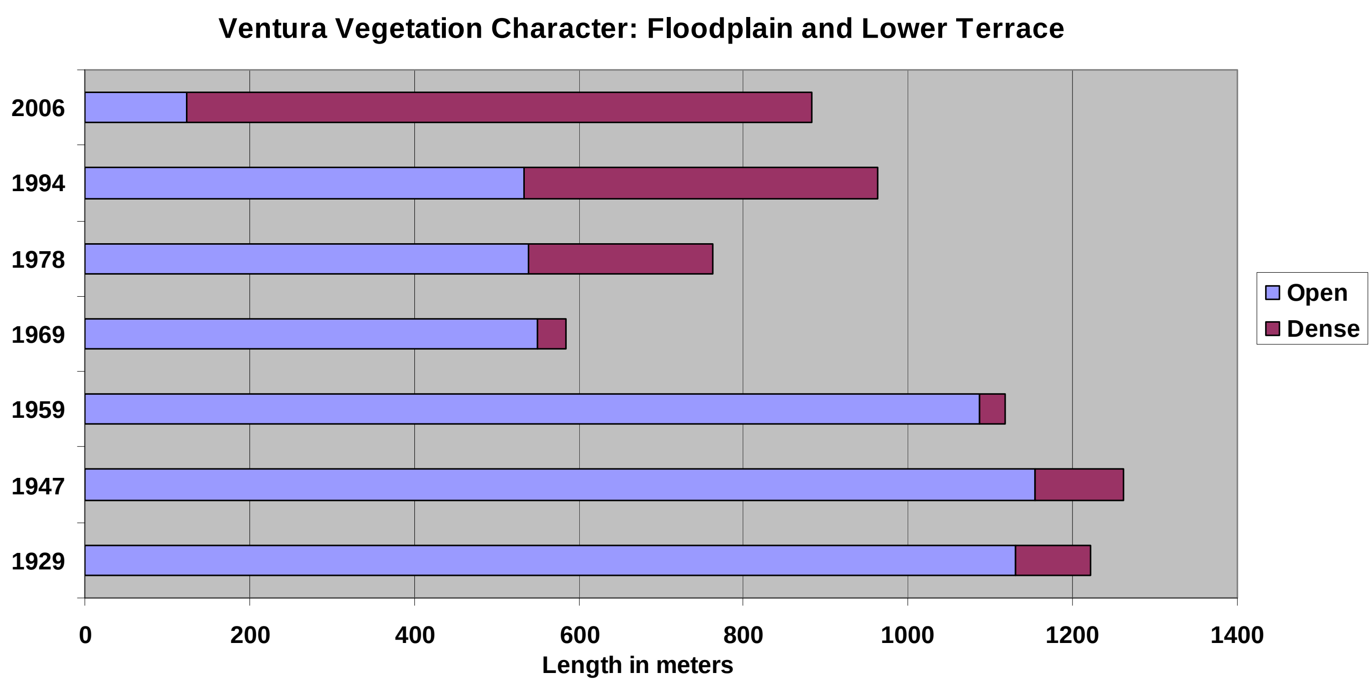


Figure 5-2.24. Ventura open and dense vegetation classification on floodplain and lower terrace areas from 1929 to 2006.

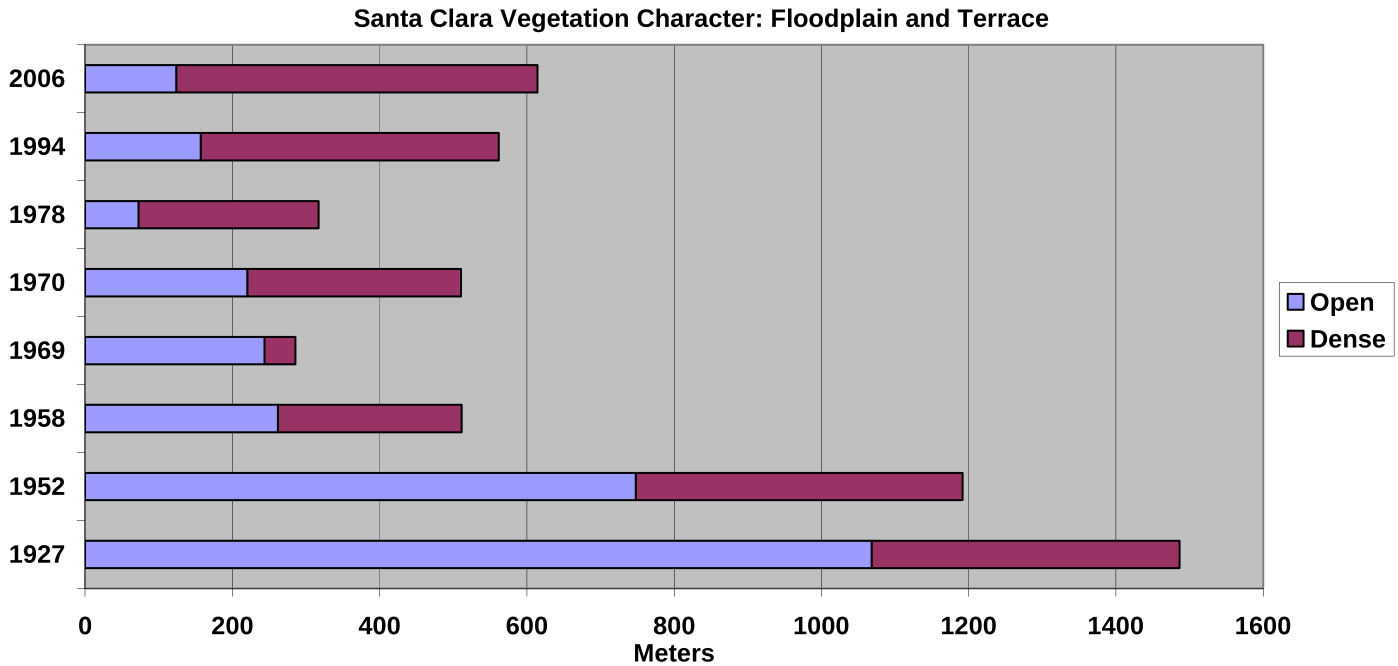


Figure 5-2.25. Santa Clara open and dense vegetation classification on floodplain and lower terrace areas from 1927 to 2006.

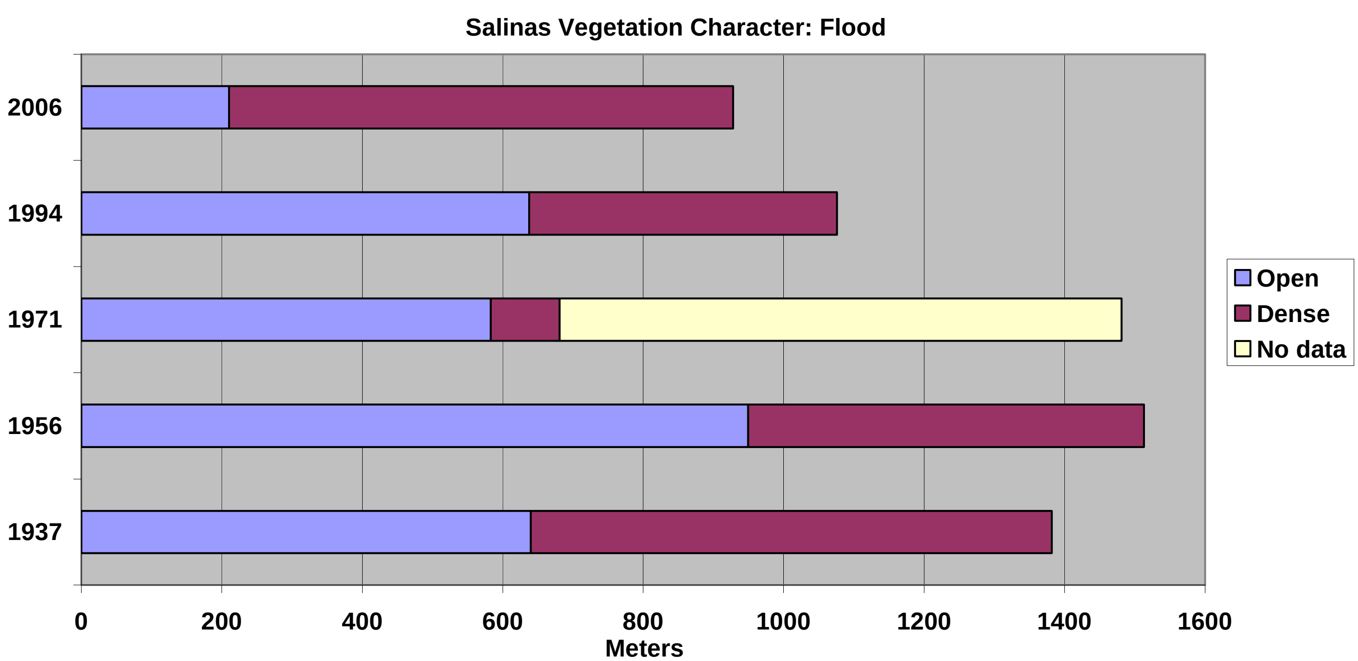


Figure 5-2.26. Salinas open and dense vegetation classification on floodplain and lower terrace areas from 1937 to 2006.

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%

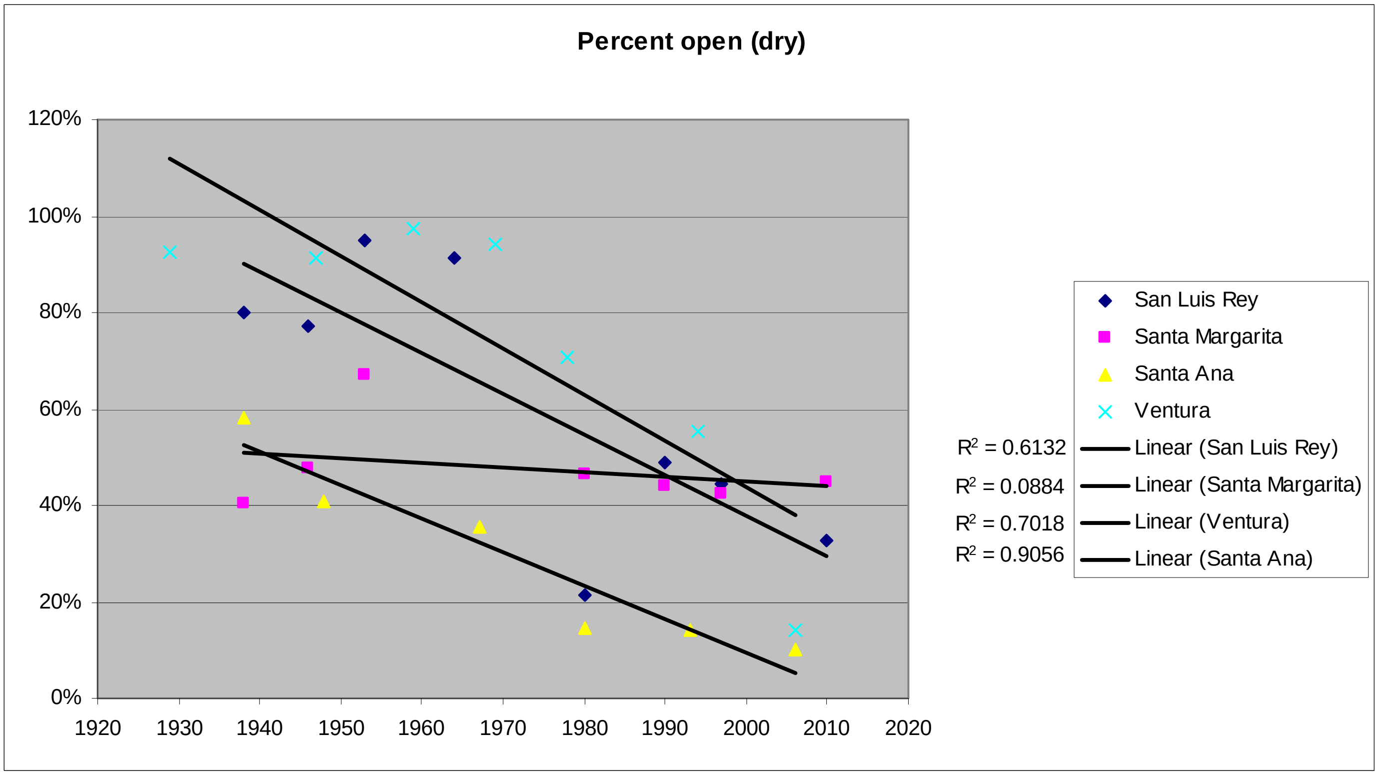


Figure 5-2.27. Trend graph of percent of the open vegetation category from 1927 to 2010 for four watersheds with the AOI.

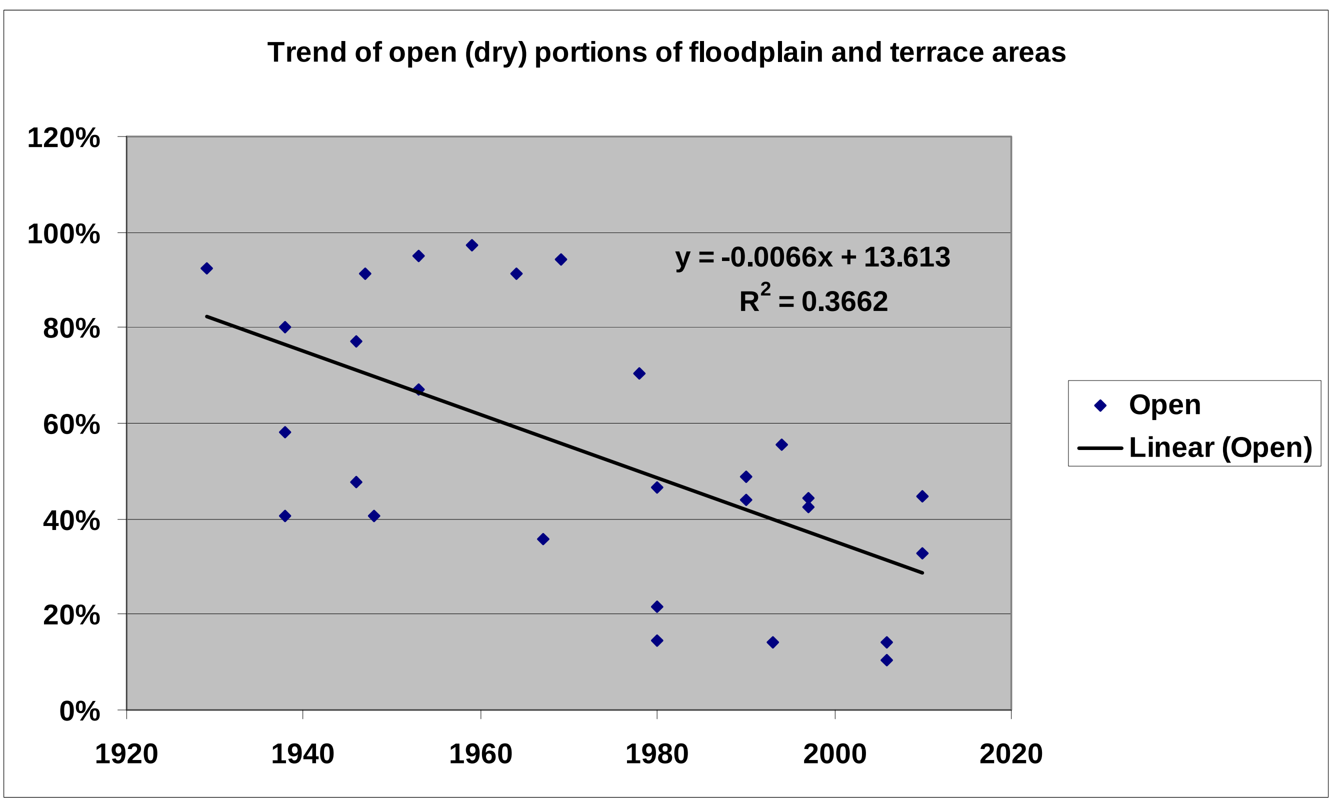


Figure 5-2.28. Trend graph of percent of the open vegetation category from 1927 to 2010 for all watersheds with the AOI.

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).

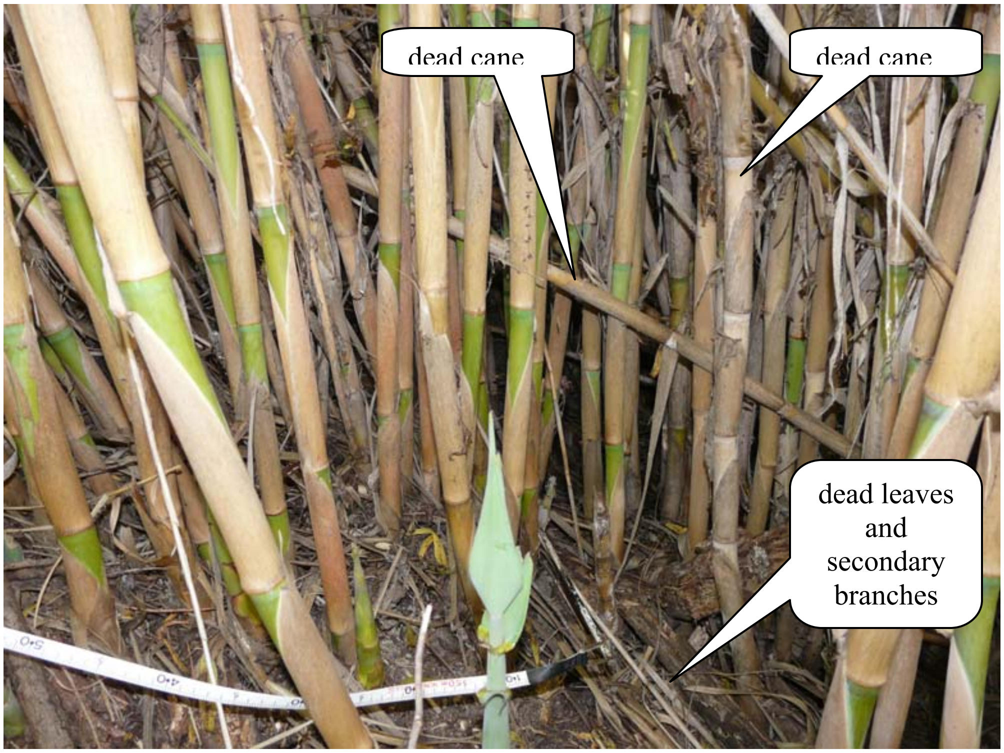


Figure 6-1. Large amount of dead/dry *Arundo* fuel.
While only a small percent of the overall stand biomass is dead and dry, it is enough to start and maintain fires.

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.

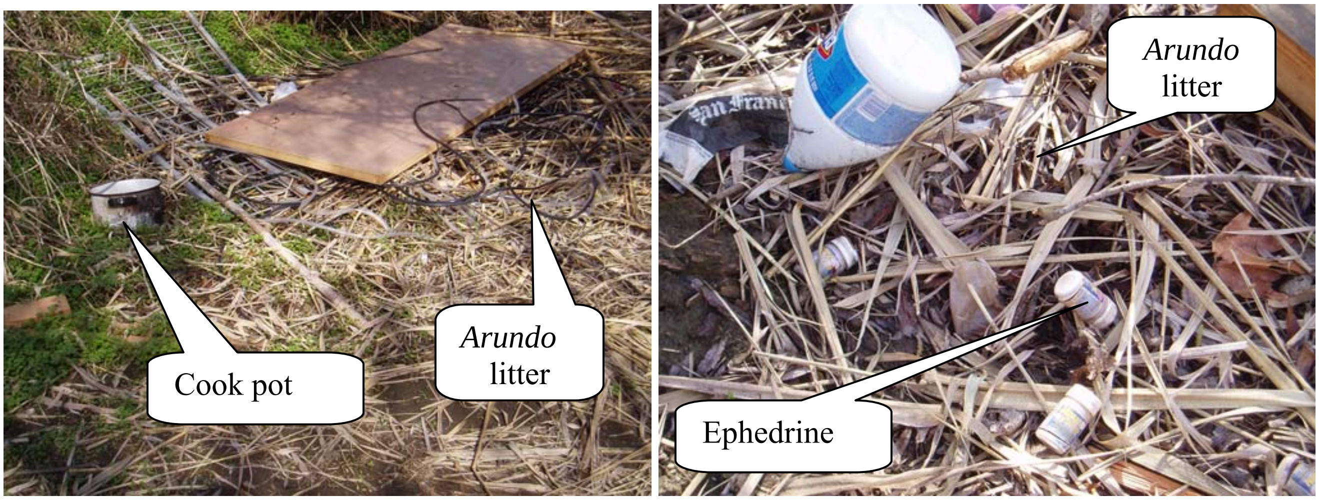


Figure 6-9. Small methamphetamine lab on the San Luis Rey River within *Arundo* stands.

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).

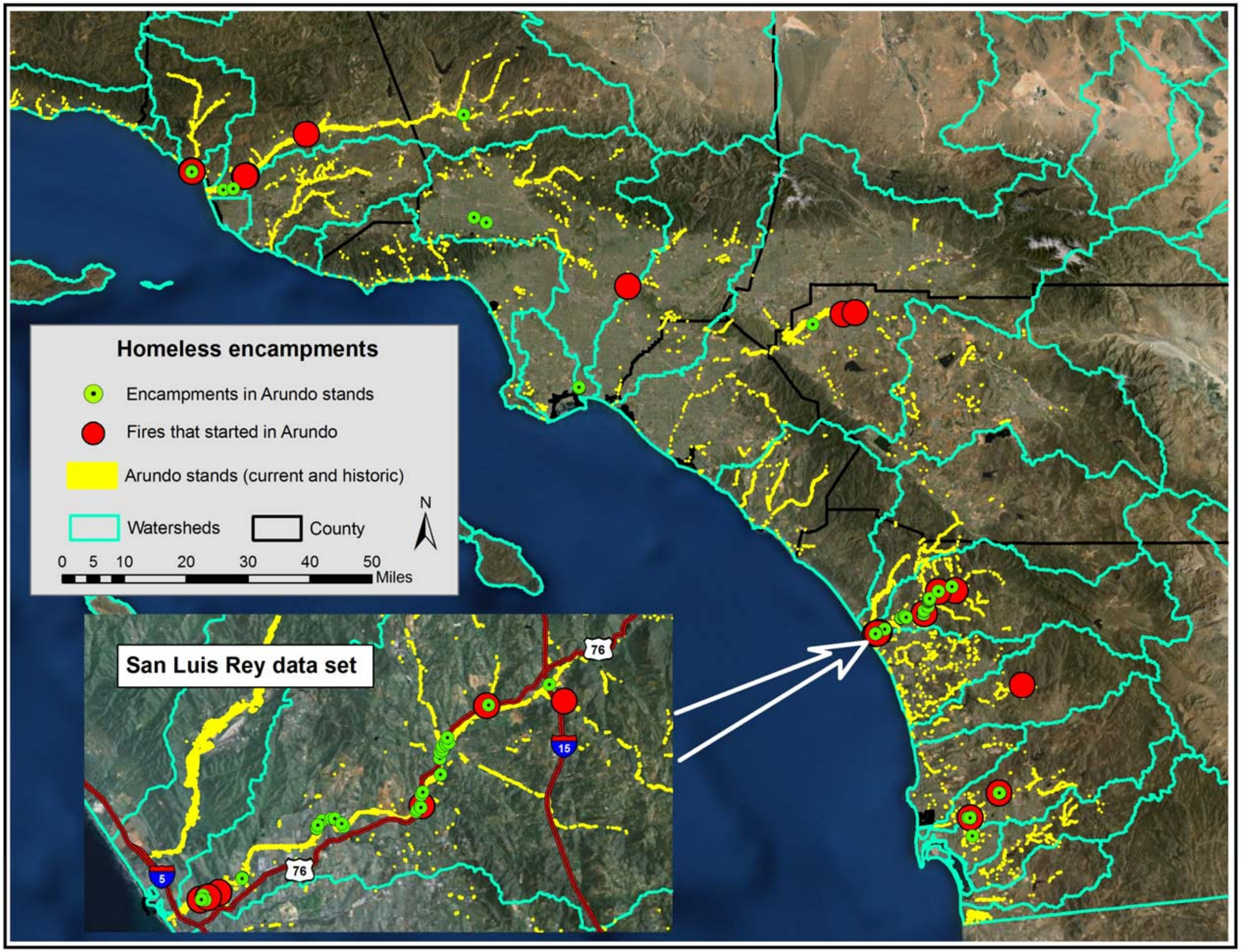


Figure 6-11. Location of *Arundo* fires for some southern California watersheds.

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**

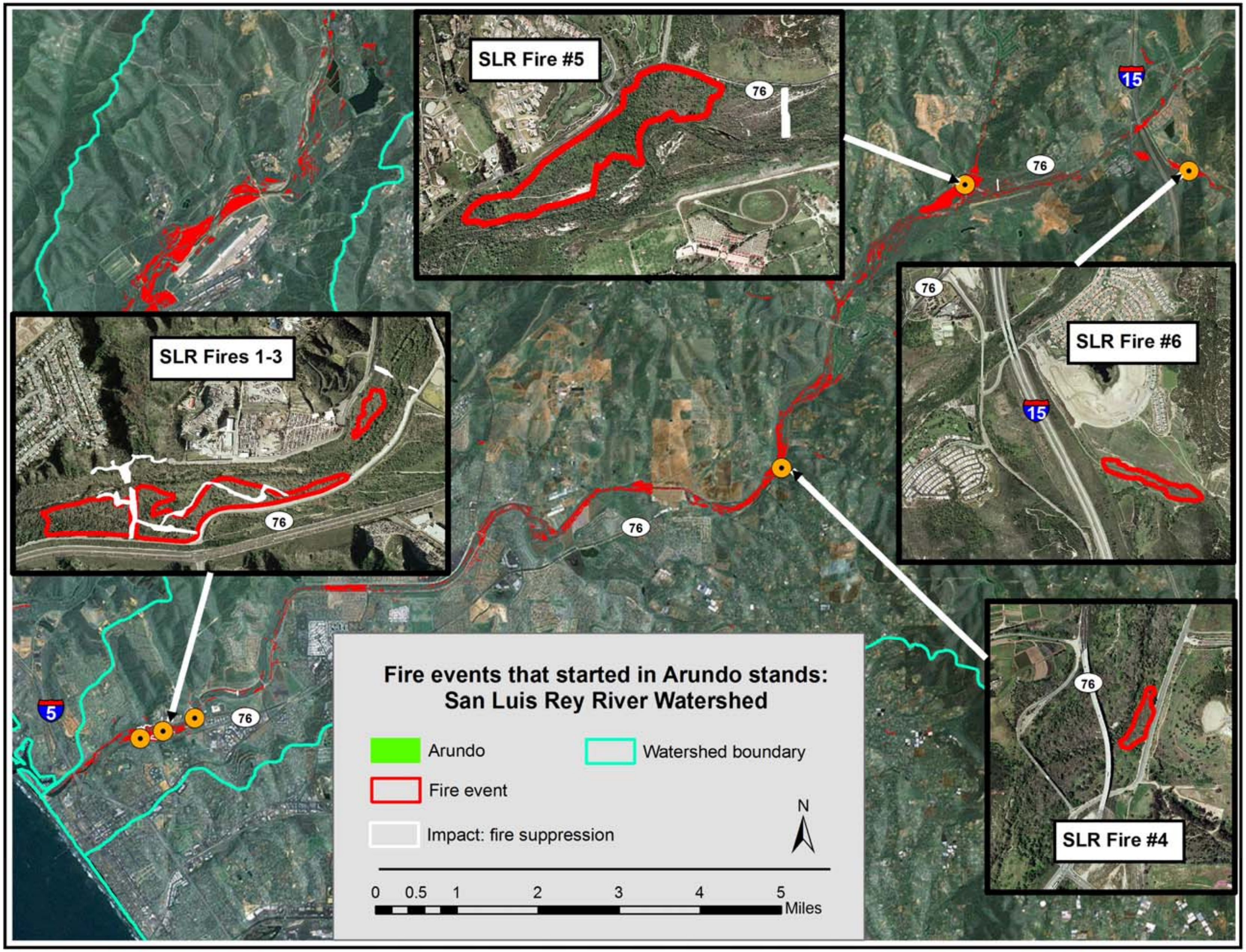


Figure 6-12. Fire events that started in *Arundo* stands on the San Luis Rey River from 2000 to 2007.

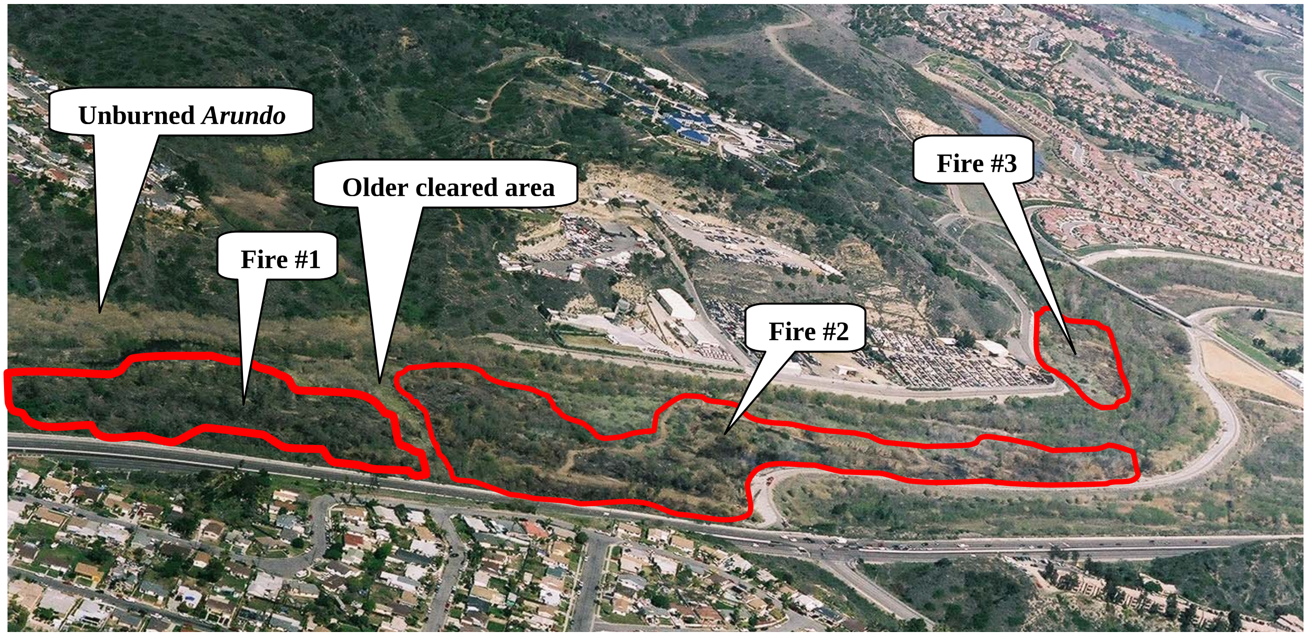


Figure 6-13. Footprint of fires # SLR 1-3 on the San Luis Rey River.

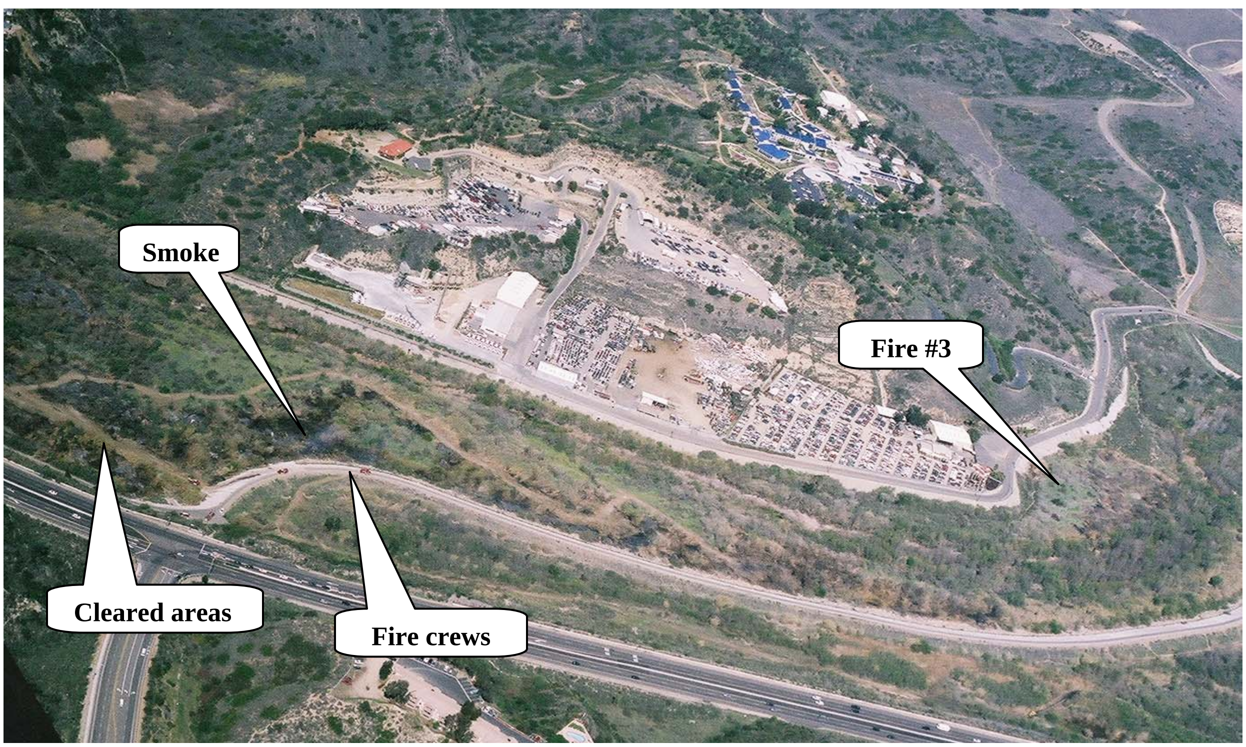


Figure 6-14. Location of fires # SLR 1-3 and fire containment cleared areas on the San Luis Rey River.

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%**

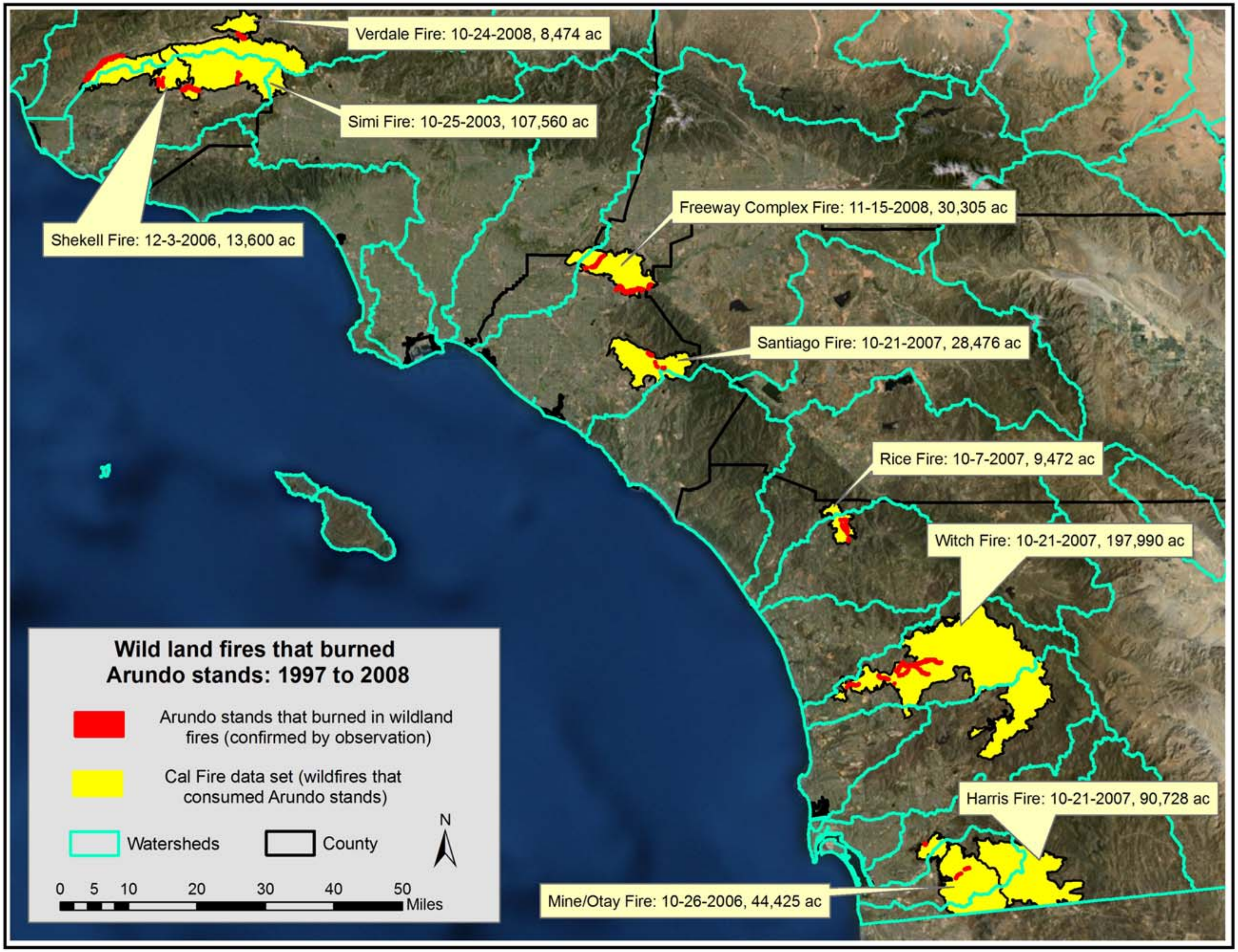


Figure 6-18. Location of wildland fires that burned *Arundo* stands within the project area from 1997 to 2008.

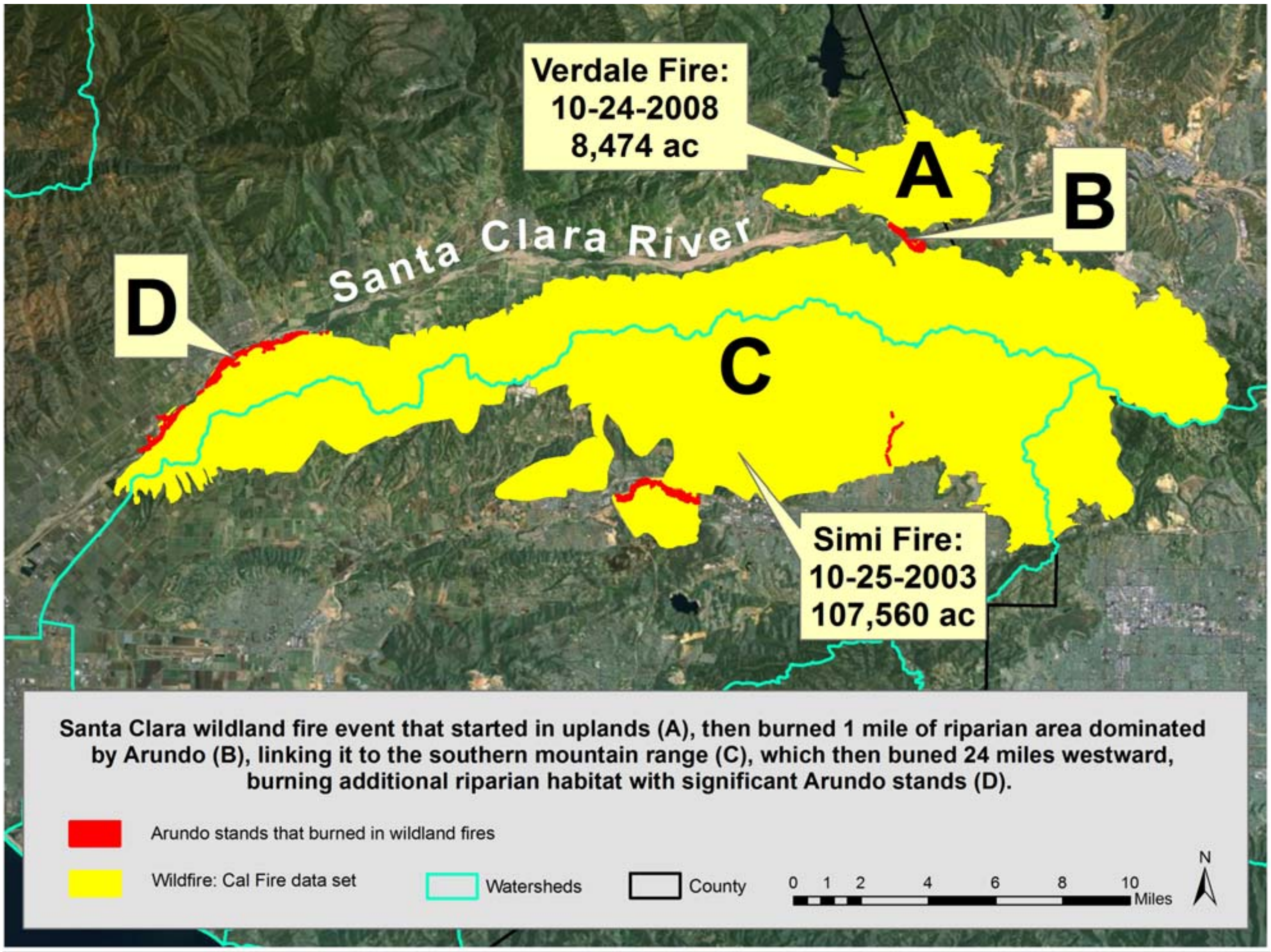


Figure 6-19. Wildfire on the Santa Clara with points A, B, C and D marked.

<u>Conclusions:</u>

- 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.

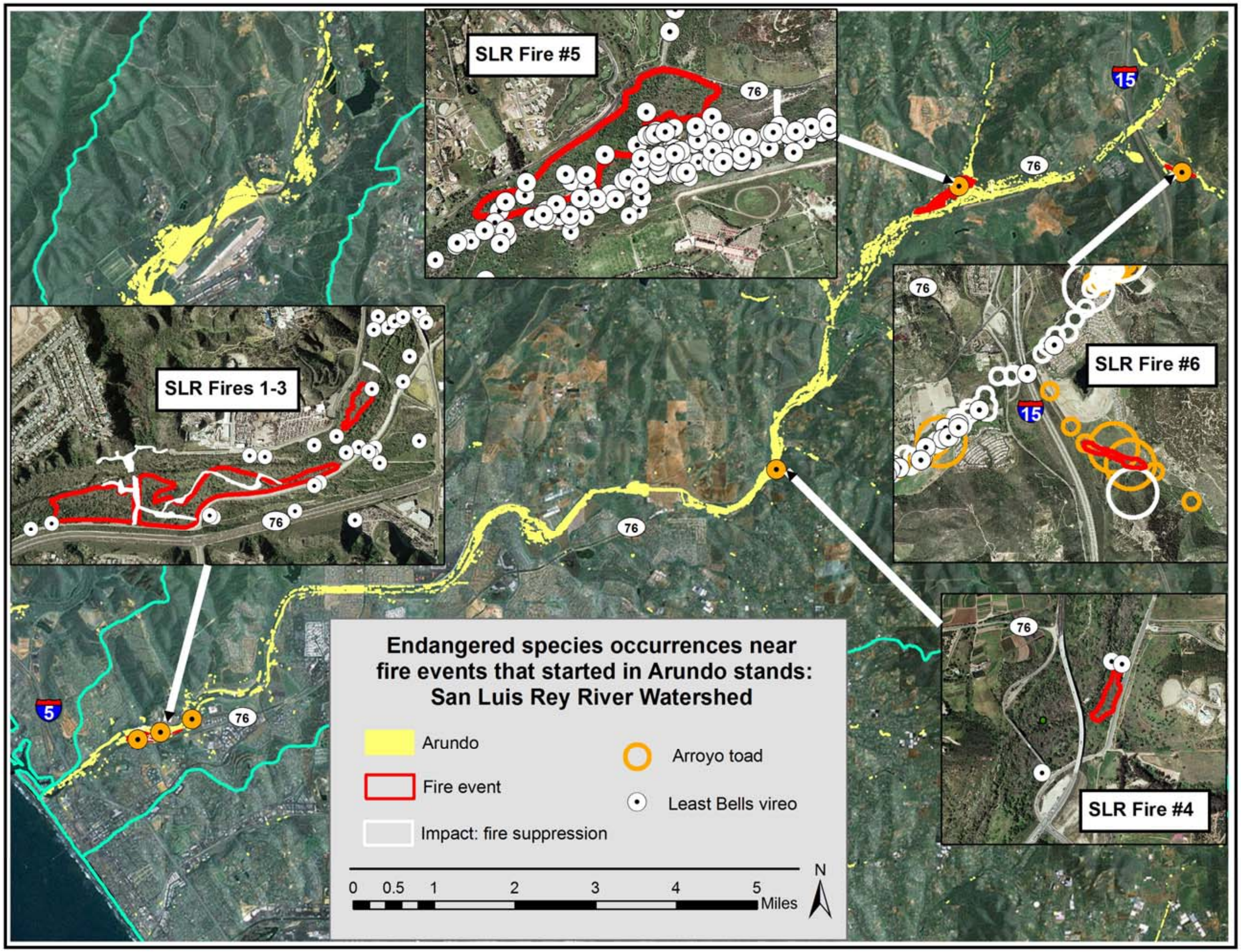


Figure 6-21. Fire events that started in *Arundo* stands on the San Luis Rey River showing sensitive species locations.

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.*

<u>Diet:</u>
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.*

<u>Movement:</u>
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.*

<u>Status/Distribution or Historic and Current Range:</u>
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).

<u>Decline and Threats:</u>
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: <u>High impact, score of 7.</u>

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

<u>General Ecological Needs/Habitat Affinities:</u>
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.

<u>Breeding/Life History:</u>
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.*

<u>Diet:</u>
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.*

<u>Movement:</u>
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.*

<u>Status/Distribution or Historic and Current Range:</u>
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.*

<u>Decline and Threats:</u>
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.*

<u>Movement:</u>
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.*

<u>Status/Distribution or Historic and Current Range:</u>
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.*

<u>Decline and Threats:</u>
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: <u>Moderate/High, score of 6.</u>

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.*

<u>Status/Distribution or Historic and Current Range:</u>
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.*

<u>Decline and Threats:</u>
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.

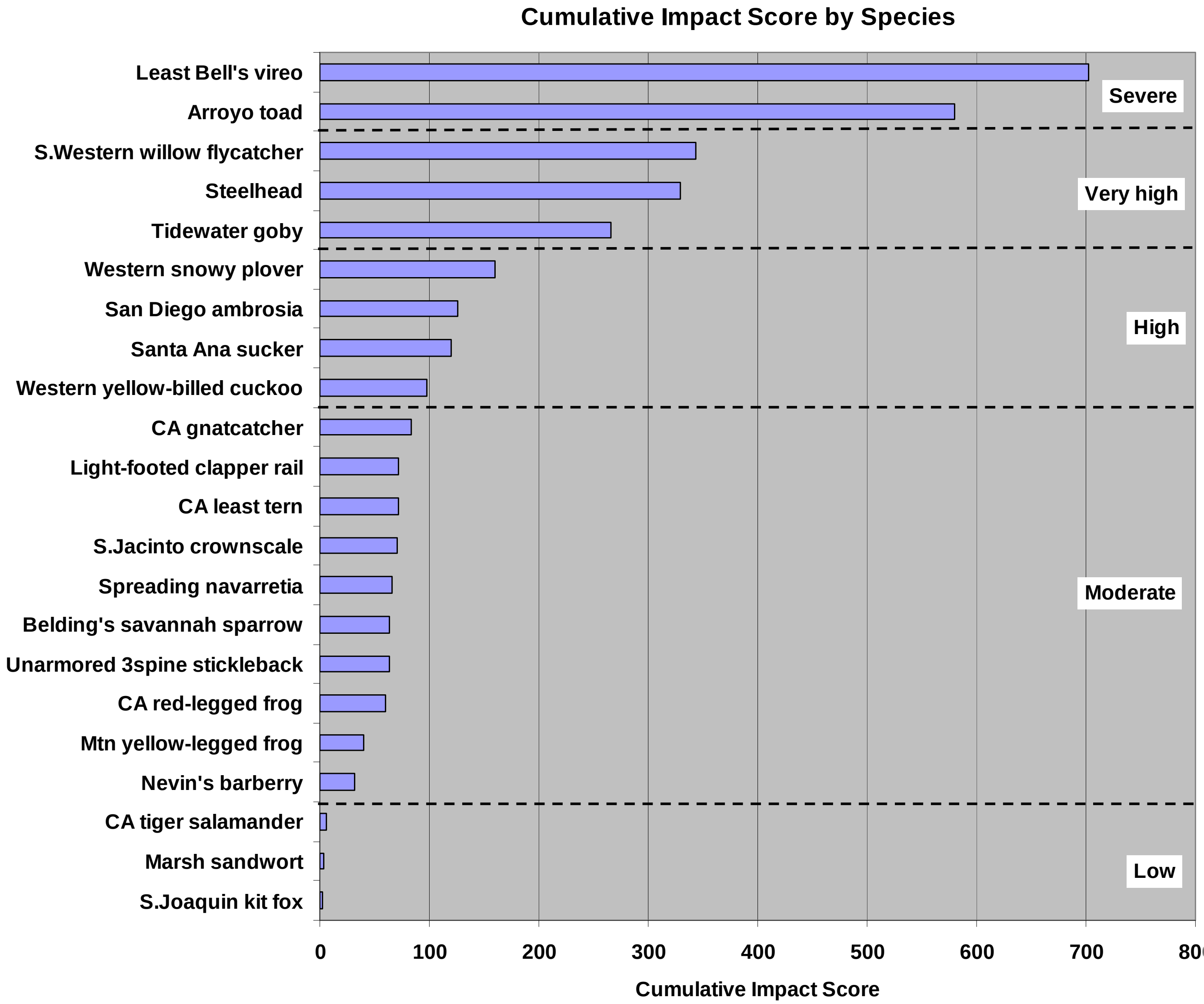


Figure 7-1. Cumulative *Arundo* impact score by species for all watersheds.

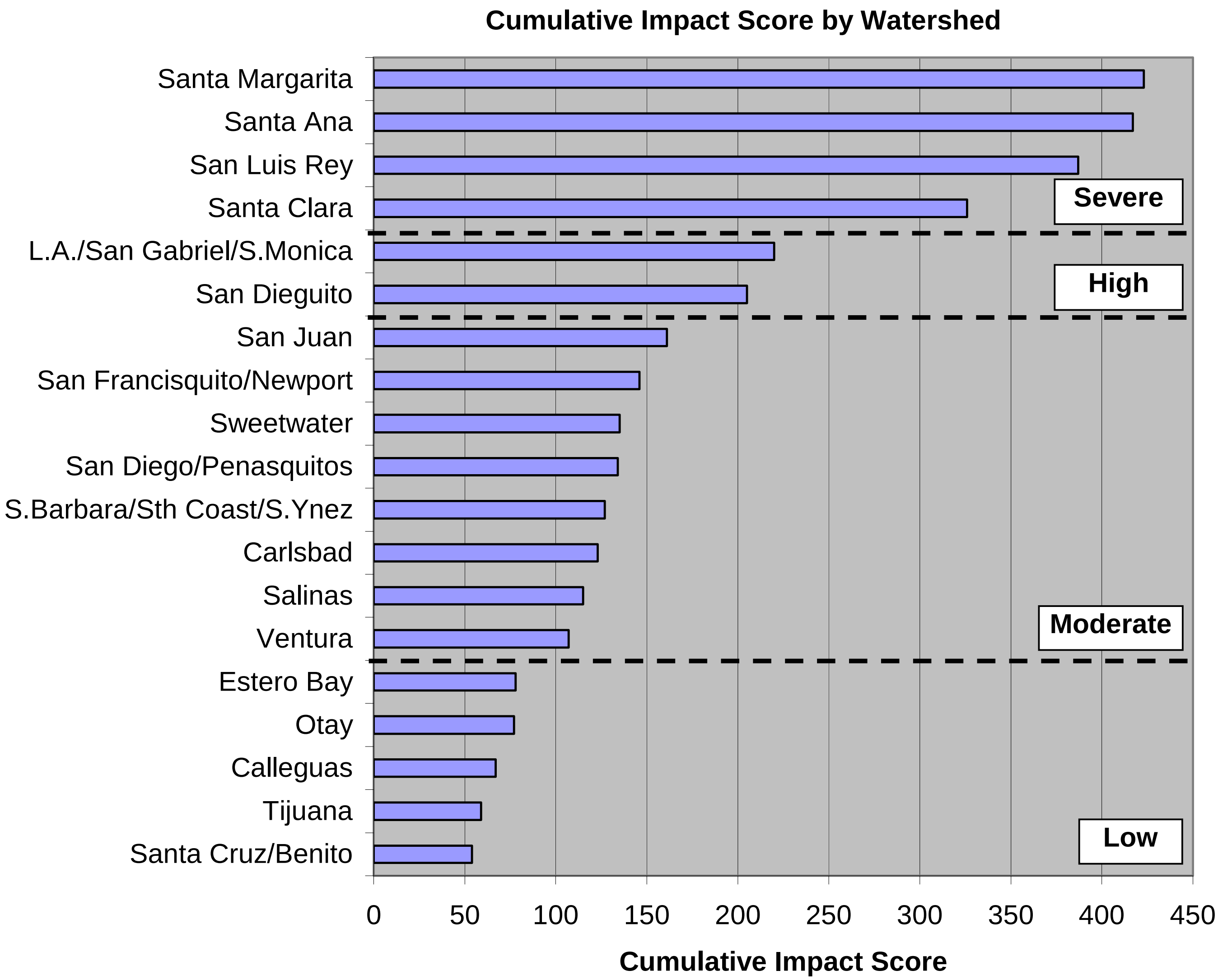


Figure 7-2. Cumulative *Arundo* impact scores by watershed for all federally listed species combined.

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]