2009 UPDATE

Groundwater Management Plan

Orange County Water District

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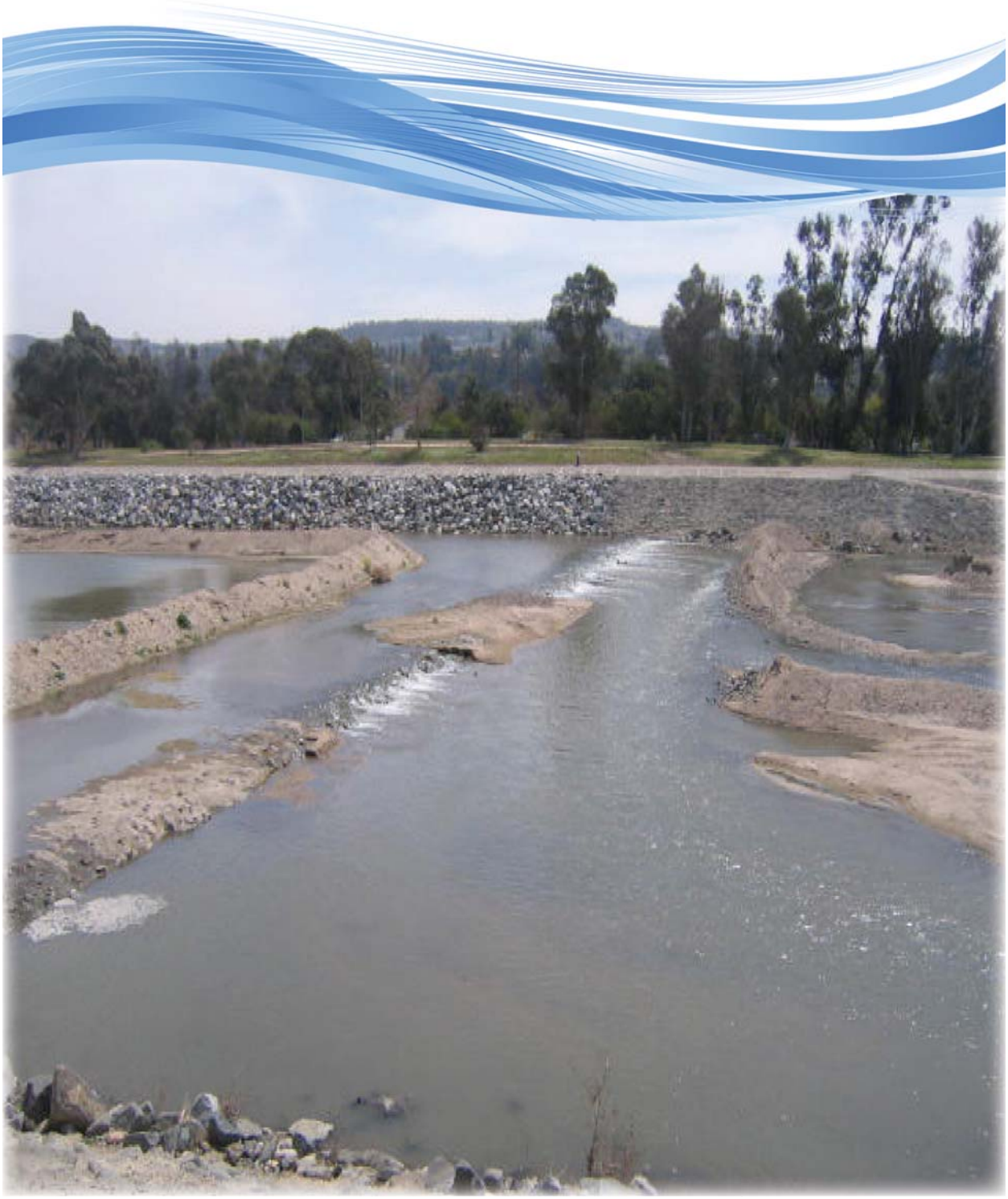

ORANGE COUNTY WATER DISTRICT

GOUNDWATER MANAGEMENT PLAN
2009 UPDATE

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July 9, 2009

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EXECUTIVE SUMMARY

The Orange County Water District (OCWD) is a special district formed in 1933 by an act of the California Legislature. The District manages the groundwater basin that underlies north and central Orange County. Water produced from the basin is the primary water supply for approximately 2.5 million residents living within the District boundaries.

ES-1 Introduction

The mission of the OCWD is to provide local water retailers with a reliable, adequate, high quality water supply at the lowest reasonable cost in an environmentally responsible manner. The District implements a comprehensive program to manage the groundwater basin to assure a safe and sustainable supply. The *Groundwater Management Plan 2009 Update* documents the objectives, operations, and programs aimed at accomplishing the District's mission.

The Orange County groundwater basin meets approximately 60 to 70 percent of the water supply demand within the boundaries of the District as shown in Figures ES-1 and ES-2. Nineteen major producers, including cities, water districts, and private water companies, pump water from the basin and retail it to the public. There are also approximately 200 small wells that pump water from the basin, primarily for irrigation purposes.

OCWD History

Since its founding, the District has grown in size from 162,676 to 229,000 acres. Along with this growth in area has come a rapid growth in population. Facing the challenge of increasing demand for water has fostered a history of innovation and creativity that has enabled OCWD to increase available groundwater supplies while protecting the long-term sustainability of the basin. Groundwater pumping from the basin has grown from approximately 150,000 acre-feet per year (afy) in the mid-1950s to over 300,000 afy, as shown in Figure ES-3.

History of Active Groundwater Recharge

To accommodate increasing demand for water supplies, OCWD started actively recharging the groundwater basin over fifty years ago. In 1949, the District began purchasing imported Colorado River water from the Metropolitan Water District of Southern California (Metropolitan), which was delivered to Orange County via the Santa Ana River upstream of Prado Dam. In 1953, OCWD began making improvements in the Santa Ana River bed and constructing off-channel recharge basins to increase recharge capacity. The District currently operates 1,067 acres of recharge facilities adjacent to the Santa Ana River and its main Orange County tributary, Santiago Creek.

Control of Seawater Intrusion and Construction of the Groundwater Replenishment System

One of the District's primary efforts has been the control of seawater intrusion into the groundwater basin, especially in two areas: the Alamitos Gap and the Talbert Gap. OCWD began addressing the Alamitos Gap intrusion by entering a partnership in 1965 with the Los Angeles County Flood Control District to operate injection wells in the Alamitos Gap. Operation of the injection wells forms a hydraulic barrier to seawater intrusion.

FIGURE ES- 1
ORANGE COUNTY WATER DISTRICT BOUNDARY

To address seawater intrusion in the Talbert Gap, OCWD constructed Water Factory 21, a plant that treated secondary-treated water from the Orange County Sanitation District (OCSD) to produce purified water for injection. Water Factory 21 operated for approximately 30 years until it was taken off line in 2004. It was replaced by an advanced water treatment system, the Groundwater Replenishment (GWR) System. The GWR System, the largest water purification project of its kind, began operating in 2008 to provide water for the Talbert Injection Barrier as well as to supply water to recharge basins in the City of Anaheim.

FIGURE ES- 2
ORANGE COUNTY GROUNDWATER BASIN

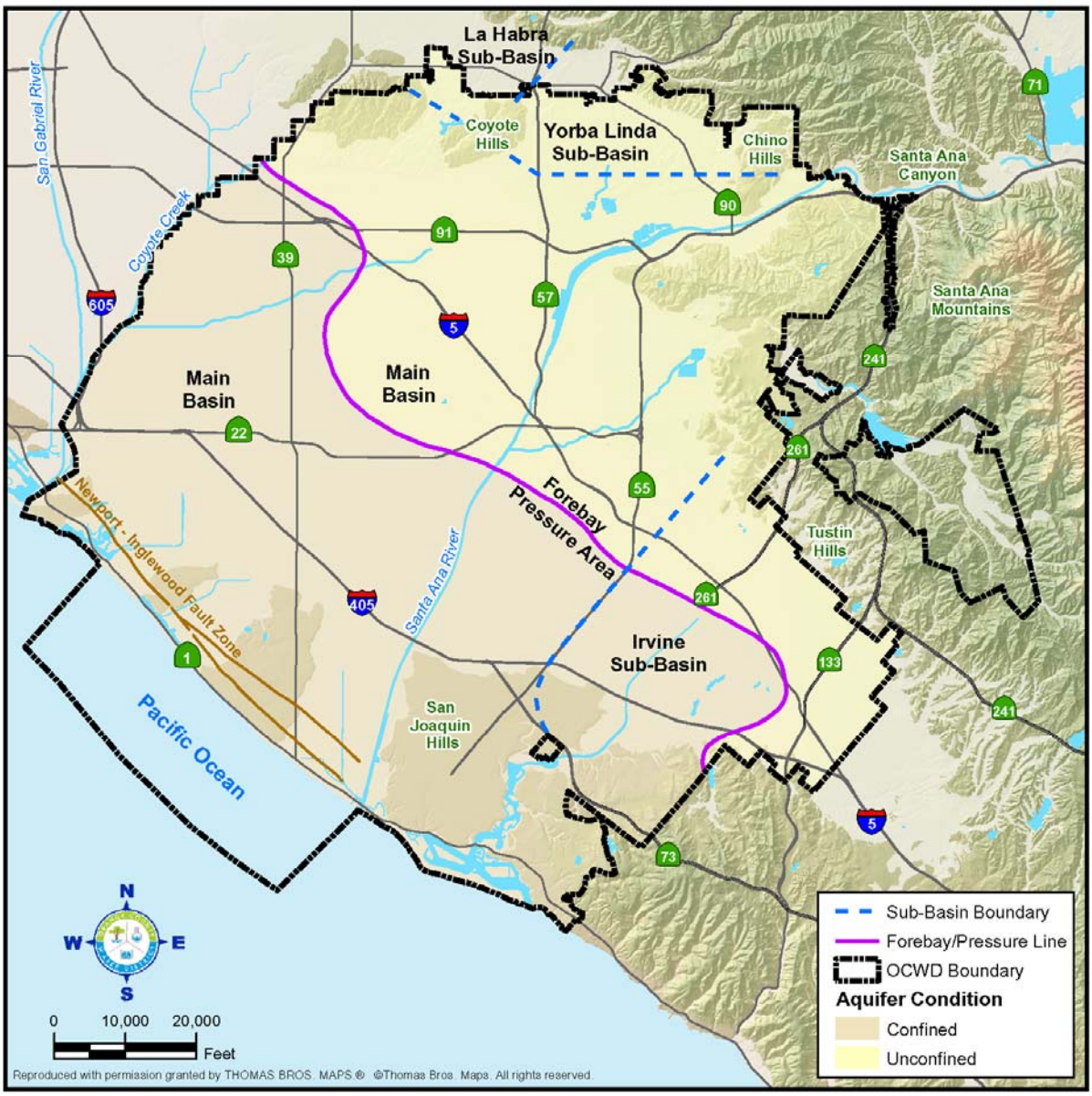
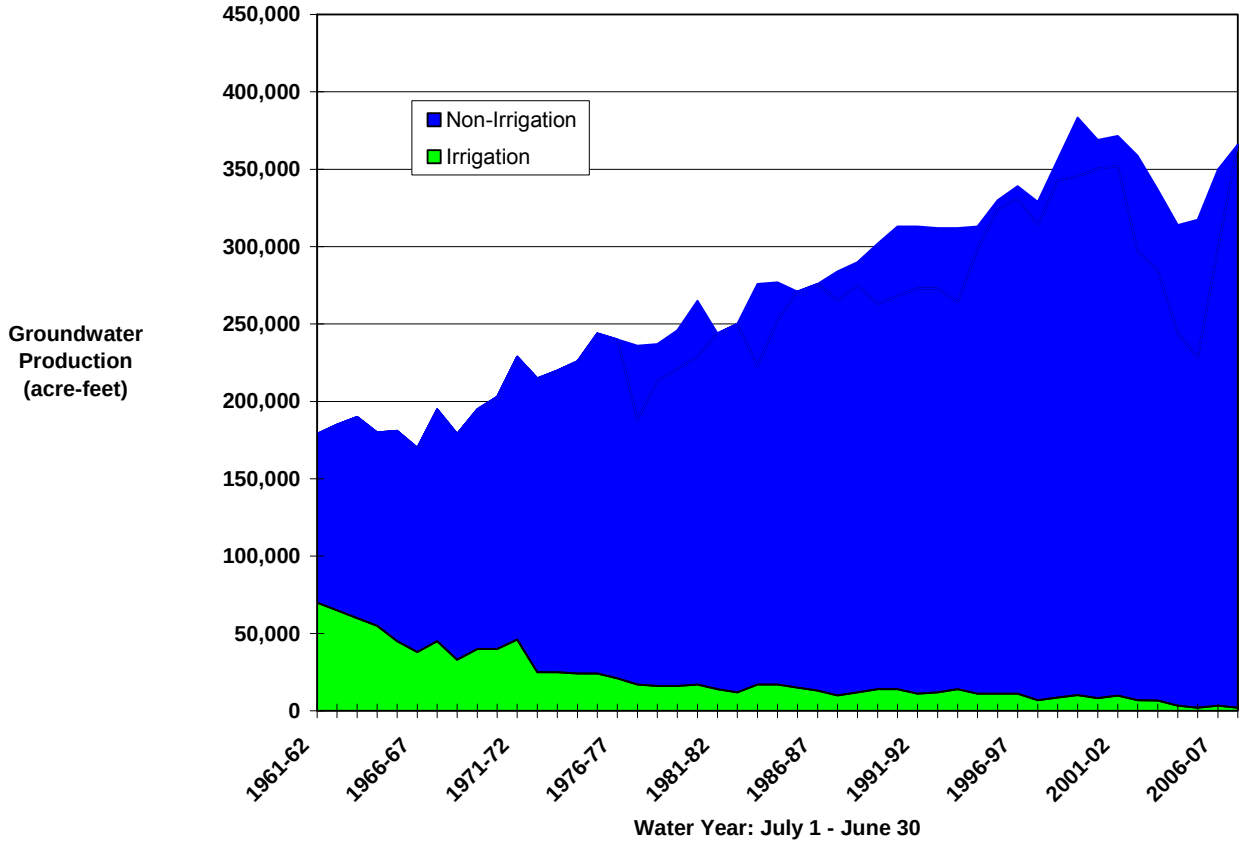


FIGURE ES- 3
GROUNDWATER PRODUCTION



Preparation of the Groundwater Management Plan

The District's previous update to the *Groundwater Management Plan* was prepared in 2004. The five Key Performance Indicators established in the 2004 plan were accomplished, as shown in Table ES-1. In addition, over eighteen major projects completed between 2004 and 2008 have improved District operations, increased groundwater recharge capacity, and improved water quality.

The *Groundwater Management Plan 2009 Update* provides information on District operations, lists projects completed since publication of the 2004 report, and discusses plans for future projects and operations. The updated plan was prepared and adopted in accordance with procedures stipulated by A.B. 3030 and Section 10750 et seq. of the California Water Code.

Goals and Objectives

The District's goals are to (1) protect and enhance groundwater quality, (2) to protect and increase the sustainable yield of the basin in a cost-effective manner and (3) to increase the efficiency of OCWD's operations. Section 1.8 contains a complete list of management objectives aimed at accomplishing these goals.

TABLE ES- 1
KEY PERFORMANCE INDICATORS

2004 Groundwater Management Plan Key Performance Indicators	2008 Status
Cease landward migration of 250 mg/L chloride contour by 2006	GWR System began operation in 2008.
	Reliable, local water supplies available for barrier injection increased from 5 mgd to 30 mgd.
	Reversal of landward migration at Talbert Barrier observed in 2008.
Increase Prado water conservation pool elevation by four feet by 2005	Memorandum of Agreement with the Army Corps of Engineers was executed in 2006 allowing a four-foot increase in the maximum winter pool elevation.
Increase recharge capacity by 10,000 afy	Increase in recharge capacity of greater than 10,000 afy occurred with (1) the La Jolla Recharge Basin coming on line in 2008 and (2) operation of Basin Cleaning Vehicles.
All water recharged into the basin through District facilities meets or is better than Department of Public Health MCLs and Notification Levels.	No exceedances of MCLs or Notification Levels in recharge water as documented in *Santa Ana River Water Quality Monitoring Reports* (OCWD 2005, 2006, 2007, and 2008) and GWR System permit reports.
Reduce basin overdraft by 20,000 afy	Basin's accumulated overdraft was reduced by 202,000 af between June 2004 and June 2007. (OCWD *Engineer's Report*, 2008)

ES-2 Basin Hydrogeology

The Orange County groundwater basin covers an area of approximately 350 square miles underlying the north half of Orange County beneath broad lowlands known as the Tustin and Downey plains. The aquifers comprising the basin extend over 2,000 feet deep and form a complex series of interconnected sand and gravel deposits. In the inland area, generally northeast of Interstate 5, the clay and silt deposits become thinner and more discontinuous, allowing larger quantities of groundwater to flow between shallow and deeper aquifers.

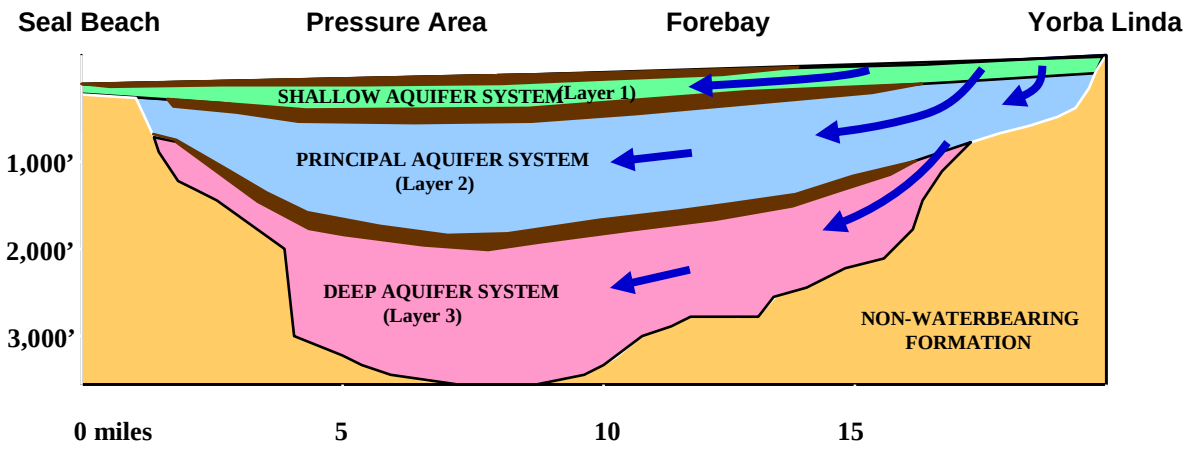
Forebay and Pressure Areas

The basin is divided into two primary hydrologic divisions; the Forebay and Pressure areas (see Figure ES-2). The boundary between the two areas generally delineates the areas where surface water or shallow groundwater can or cannot move downward to the first producible aquifer in significant quantities from a water supply perspective. Most of the groundwater recharge occurs in the Forebay.

OCWD conducts an extensive groundwater monitoring network to collect data to depths of up to 2,000 feet in the basin. Data from these monitoring wells were used to delineate

the depth of the "principal" aquifer system, within which most of the groundwater production occurs. Figure ES-4 schematically depicts the basin's three aquifer systems, with groundwater flowing from Yorba Linda to the coast.

FIGURE ES- 4
GROUNDWATER BASIN CROSS-SECTION



Shallower aquifers exist above the principal aquifer system. Production from this system, principally for industrial and agricultural uses, is typically about five percent of total basin production. Deeper aquifers exist below the principal aquifer system, but these zones have been found to contain colored water or are too deep to economically construct production wells; few wells penetrate this system.

A vast amount of water is stored within the basin, although only a fraction of this amount can be removed without causing physical damage such as seawater intrusion or the potential for land subsidence.

Water Budget

OCWD developed a hydrologic budget in order to construct a Basin Model and to evaluate basin production capacity and recharge requirements. The hydrologic budget quantifies the amount of basin recharge, groundwater production, and subsurface flows along the coast and across the Orange/Los Angeles County line.

Calculation of Groundwater Elevation, Storage, and Accumulated Overdraft

Annual changes in the amount of groundwater stored in the basin are estimated using groundwater elevation measurements and aquifer storage coefficients for the three primary aquifer systems in the basin. This three-layer method involves measuring the water levels throughout the basin at the end of each water year at nearly every production and monitoring well in the basin. Water level measurements are contoured and digitized into the Geographic Information System. Storage change volumes for each of the three aquifer levels are determined and then totaled to provide a net annual storage change for the basin.

The District estimates that the basin can be operated on a short-term basis with a maximum accumulated overdraft (storage reduction from full condition) of approximately 500,000 acre-feet (af) without causing irreversible seawater intrusion and land subsidence. In 2007, OCWD developed a new methodology to calculate accumulated overdraft and storage change. The need for this change was driven by the record-setting wet year of 2004-05, which resulted in the basin approaching a near-full condition. Analysis showed that the traditional method of cumulatively adding the annual storage change each year contained considerable uncertainty. The updated approach is based on a determination of the amount of groundwater in storage in each of the three major aquifer systems.

Elevation Trends and Groundwater Model

Groundwater level profiles generally following the Santa Ana River in Orange County are prepared to evaluate changes in the basin due to groundwater pumping and OCWD recharge operations. Groundwater levels are managed within a safe basin operating range to protect the long-term sustainability of the basin and to protect against land subsidence.

The District has developed a comprehensive computer-based groundwater flow model. Development of the model substantially improved the overall understanding of processes and conditions in the basin. The model also allows analysis of how the basin reacts to various theoretical pumping and recharge conditions. The model's ability to simulate known and projected future conditions will evolve and improve as new data become available and updated simulations are completed.

ES-3 Groundwater Monitoring

For its size, the Orange County groundwater basin is one of the world's most extensively monitored. The comprehensive monitoring program tracks dynamic basin conditions including groundwater production, storage, elevations, and water quality.

OCWD's monitoring program has helped improve groundwater management throughout the basin by:

- Establishing on an annual basis the appropriate level of groundwater production.
- Determining the extent of seawater intrusion and subsequently building improvements to seawater barriers to prevent and reverse such intrusion.
- Discovering areas of groundwater contamination to protect public health and beneficial use of groundwater, and to begin remediation efforts at an early stage.
- Assuring that the groundwater basin is managed in accordance with relevant laws and regulations.

Collection and Management of Monitoring Data

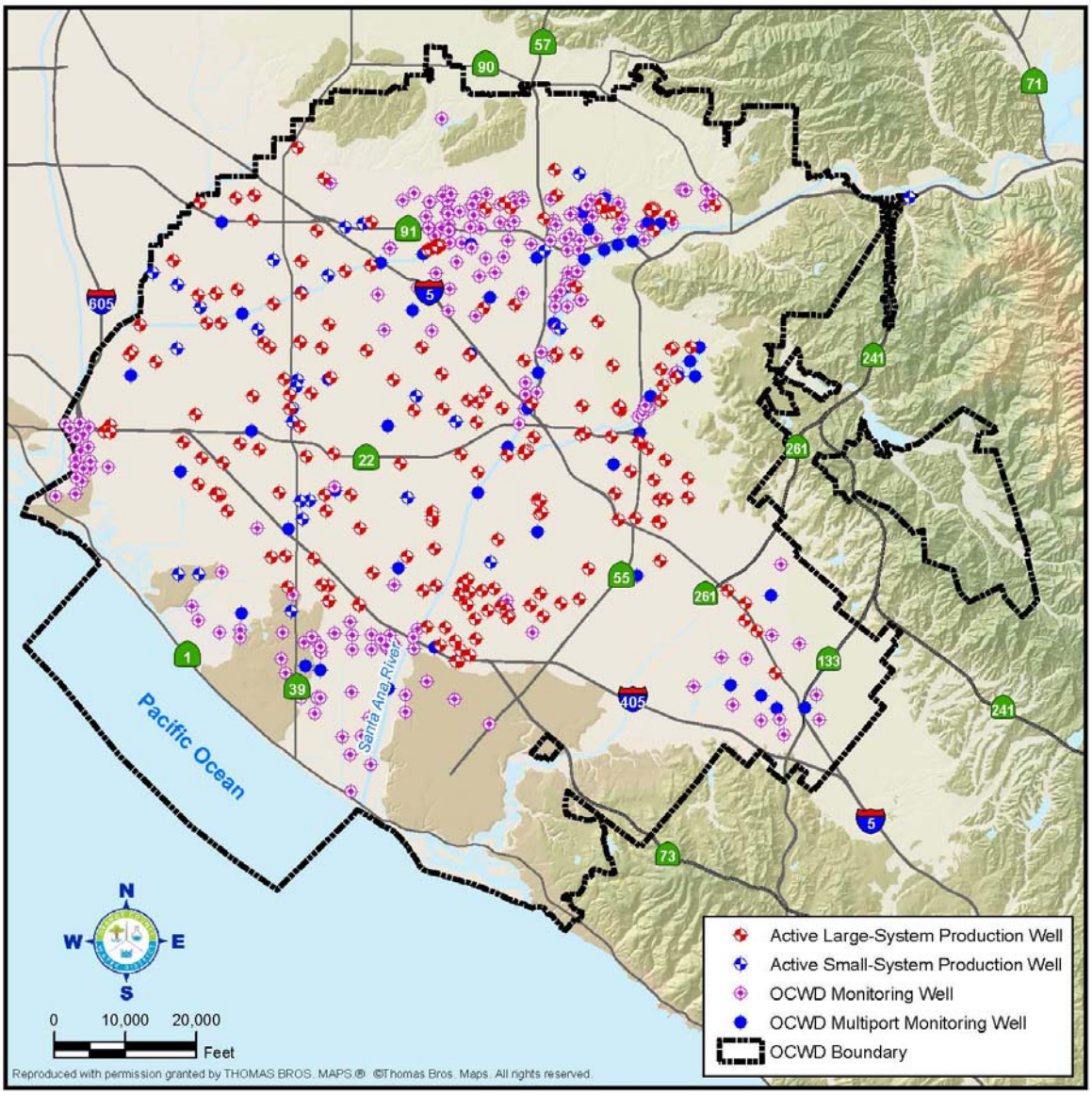
Large-capacity well owners report monthly groundwater production for each of their wells. OCWD operates its own groundwater monitoring network with a diverse cross-section of well types and broad range of well depths and screened intervals. The type

and number of wells in the basin wide monitoring program are shown in Table ES-2; the distribution of wells is shown in Figure ES-5.

TABLE ES- 2
DISTRIBUTION OF WELLS IN BASIN WIDE MONITORING PROGRAM

Well Type	No. of Wells	No. of Individual Sample Points
Drinking Water Wells	228	228
Industrial And Irrigation wells	123	123
OCWD Monitoring Wells (excluding seawater monitoring)	254	728
OCWD Seawater Intrusion Monitoring Wells	93	244
Total	**698**	**1323**

FIGURE ES- 5
PRODUCTION AND MONITORING WELL NETWORK



In 2008, nearly 14,000 groundwater samples were collected and analyzed in order to comply with state and federal regulations and to enable OCWD to monitor the water quality of the basin. The number of water quality samples continues to increase in response to new regulatory requirements and to gain a better understanding of the basin. OCWD's laboratory is state-certified to perform bacteriological, inorganic, and organic analyses. State-certified contractor laboratories analyze radiological samples.

OCWD's water quality monitoring program includes:

- Testing groundwater samples for more than 100 regulated and unregulated chemicals at a specified monitoring frequency established by the U.S. Environmental Protection Agency (EPA) and the California Department of Public Health (CDPH) regulations.
- Monitoring and preventing the encroachment of seawater into fresh groundwater zones along coastal Orange County.
- Assessing Santa Ana River water quality. Since the quality of the surface water that is used to recharge the groundwater basin affects groundwater quality, a routine monitoring program is maintained to continually assess ambient river water quality. Water samples are collected each month from the river. The District also monitors the quality of imported replenishment water and tests selected monitoring wells to assess the water quality in areas where GWR System water is being injected and recharged.

Data Management and Publication

Data collected in OCWD's monitoring program are stored in the District's electronic database, the Water Resources Management System (WRMS). WRMS contains comprehensive well information, as well as information on subsurface geology, groundwater modeling, and water quality. Data are used in calibrating the basin model, evaluating the causes of seasonal groundwater fluctuations, and estimating changes in basin storage throughout the year.

Regular District publications include the annual release of the Engineer's Report on Groundwater Conditions, Water Supply and Basin Utilization; the Santa Ana River Water Quality Monitoring Report; and the Groundwater Replenishment System Operations Annual Report.

ES-4 Recharge Water Supply Management

OCWD operates recharge facilities to maximize groundwater recharge. Recharging water into the basin through natural and artificial means is essential to support pumping from the basin. The basin's primary source of water for groundwater recharge is flow from the Santa Ana River. OCWD diverts river flows into recharge basins located in and adjacent to the Santa Ana River and its main Orange County tributary, Santiago Creek. Other sources of recharge water include natural infiltration, recycled water, and imported water.

History of Recharge Operations

Active recharge of groundwater began in 1949, in response to increasing drawdown of the basin and, consequently, the serious threat of seawater intrusion. In 1953, OCWD began to make improvements in the Santa Ana River bed and areas adjacent to the river to increase recharge capacity. Today the District owns and operates a network of recharge facilities that cover 1,067 acres, as shown in Figure ES-6. The District has an ongoing program to assess enhancements in the existing recharge facilities, evaluate new recharge methods, and analyze potential new recharge facilities.

OCWD Recharge Facilities

Surface water from the Santa Ana River flows into Orange County through the Prado Dam. The District is able to recharge essentially all non-storm flow in the Santa Ana River that enters Orange County through Prado Dam. The dam was built and is operated by the Army Corps of Engineers (ACOE) for flood control purposes. Agreements between the ACOE and OCWD enable the dam to be operated for water conservation purposes, such that the District is able to capture a portion of the storm flows for groundwater recharge.

Water released at Prado Dam naturally flows downstream into Orange County and percolates through the river's 300-400 foot-wide unlined channel bottom. Active management of recharge begins at the intersection of the river and Imperial Highway in the City of Anaheim. It is in the six-mile reach of the river below Imperial Highway and areas adjacent to the river where many of the recharge basins are located. The recharge facilities are grouped into four major components: the Main River System, the Off-River System, the Deep Basin System, and the Burris Basin/Santiago System.

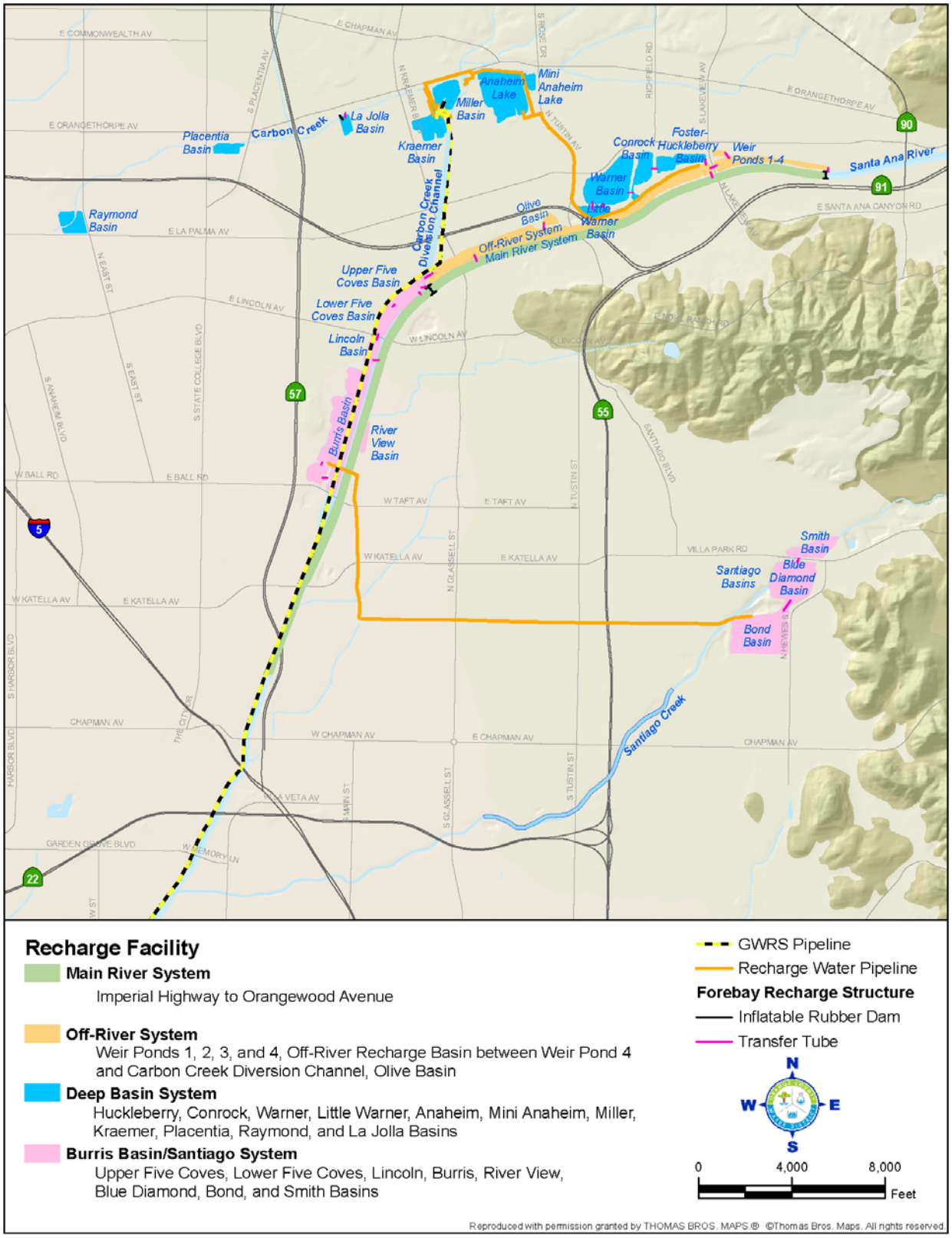
The Main River System consists of approximately 290 acres of the Santa Ana River Channel. One of the District's main control facilities, the Imperial Inflatable Dam and Bypass structure diverts Santa Ana River water flows from the Main River System into the Off-River System. The Off-River System is a shallow, sandy bottom, 100- to 200-foot wide channel that runs parallel to the Main River System; a levee separates these two systems.

Water can be diverted from the Off-River System into the Deep Basin System. These recharge basins range in depth from ten to sixty feet. Flows are regulated between these basins to maximize recharge.

Water in the Santa Ana River can also be diverted at the Five Coves Inflatable Dam into the Burris Basin/Santiago System. This system includes 373 acres of shallow and deep recharge basins. The Santiago Pipeline allows water to be diverted from Burris Basin into the Santiago Basins.

The Santiago Basins recharge water diverted from Burris Basin as well as flows from Santiago Creek. The creek is a tributary of the Santa Ana River that extends from the Santa Ana Mountains through the City of Orange to its confluence with the Santa Ana River in the City of Santa Ana.

FIGURE ES- 6
OCWD RECHARGE FACILITIES IN ANAHEIM AND ORANGE



Sources of Recharge Water Supplies

In addition to Santa Ana River and Santiago Creek, other sources of recharge water include natural recharge, imported water, and water purified by OCWD's GWR System. The GWR System (Figure ES-7) is a cooperative project with the OCSD that began operating in 2008. Secondary-treated wastewater from OCSD undergoes treatment consisting of microfiltration, reverse osmosis, and advanced oxidation with ultraviolet light and hydrogen peroxide. The water purified through the GWR System is injected into the groundwater basin near the coast to maintain a barrier preventing seawater intrusion and provides an additional supply of water for recharge operations.

FIGURE ES-7
GROUNDWATER REPLENISHMENT SYSTEM

ES-5 Groundwater Quality Management

OCWD conducts an extensive program aimed at protecting the quality of the water in the basin. These efforts include groundwater monitoring, participating in and supporting regulatory programs, remediation projects, working with groundwater producers, and providing technical assistance.

Groundwater Protection Policy

The District adopted a Groundwater Protection Policy in May 1987, in recognition of the serious threat posed by groundwater contamination. This policy is described in Section 5 of the Plan.

Salinity and Nitrate Management

Managing salinity, the amount of dissolved minerals in water, and nitrates are significant water quality challenges in southern California. Elevated levels of nitrates pose a risk to human health. High concentrations of salts can contaminate groundwater supplies, constrain implementation of water recycling projects, and cause other negative economic impacts such as the need for increased water treatment by residential, industrial and commercial users.

Sources of salinity in water used to recharge the groundwater basin include Santa Ana River water, imported water, shallow groundwater within Orange County, seawater migrating into the basin, precipitation, and legacy contamination from historical agricultural operations. Water treatment plants, also referred to as desalters, have been built in Riverside and San Bernardino Counties to reduce salinity levels in water supplies. Within Orange County, desalters in Tustin and Irvine are reducing salinity levels in the groundwater basin. The GWR System provides a dependable supply of low salinity water that is expected to reduce the basin salt imbalance by approximately 47,000 tons/year.

Nitrates are one of the most common and widespread contaminants in groundwater supplies. Elevated levels of nitrates in soil and water supplies originate from fertilizer use, animal feedlots and wastewater disposal systems. OCWD conducts an extensive program to protect the basin from nitrate contamination, including operating 450 acres of wetlands in the Prado Basin (Figure ES-8) to naturally remove nitrate before the water enters the District's recharge facilities.

FIGURE ES-8
PRADO WETLANDS

Ninety-eight percent of the drinking water wells pumping from the Orange County groundwater basin meet the nitrate drinking water standard. The two percent that do not meet the nitrate standard are treated to reduce nitrate levels prior to being served to customers.

The Irvine and Tustin desalters are in operation to remove salts and nitrate from groundwater. The Irvine Desalter also addresses contamination from organic compounds.

Synthetic Organic Contaminants

Ninety-five percent of the basin's groundwater that is used for drinking water is pumped from the main aquifer. Water from this aquifer continues to be of high quality. OCWD routinely monitors potential contamination and is working to remediate some localized contamination in the shallow aquifer.

One contaminant of concern is methyl tertiary butyl ether (MTBE), a chemical previously added to gasoline. The District analyzes groundwater for MTBE and other fuel-related contaminants. The District is implementing remediation efforts to address contamination from volatile organic compounds (VOCs). Two particular projects are the North Basin Groundwater Protection Project and the South Basin Groundwater Protection Project. The North Basin Groundwater Protection Project is being constructed in Anaheim and Fullerton to remove and contain groundwater contaminated with VOCs. The South Basin Groundwater Protection Project is being designed to address VOC and perchlorate contamination in the area of southeast Santa Ana/South Tustin and the western portion of Irvine.

ES-6 Integrated Management of Production and Recharge

OCWD is internationally known for its unique, proactive, supply-side management approach. This is a major factor that has enabled the District to develop one of the most advanced and progressive groundwater management systems in the world. Growth in demand for water supplies has challenged the District to augment recharge water supplies, effectively manage demands on the basin, and balance the amount of total recharge and total pumping to protect the basin.

Cooperative Efforts to Protect Water Supplies and Water Quality

OCWD participates in cooperative efforts with local, state, and federal regulatory agencies and stakeholders within the District boundaries and in the Santa Ana River Watershed. For example, the ACOE works cooperatively with OCWD to store water behind Prado Dam and to release flows at rates that allow for the maximum capture of water for recharge operations. Other cooperative efforts include natural resource conservation efforts in the Prado Basin and participating in working groups and task forces with stakeholders throughout the watershed.

Water Supplies

OCWD provides access to basin supplies at a uniform cost to all entities without regard to the length of time they have been producing from the basin. The District's programs include operating the groundwater recharge basins, increasing supplies of recycled

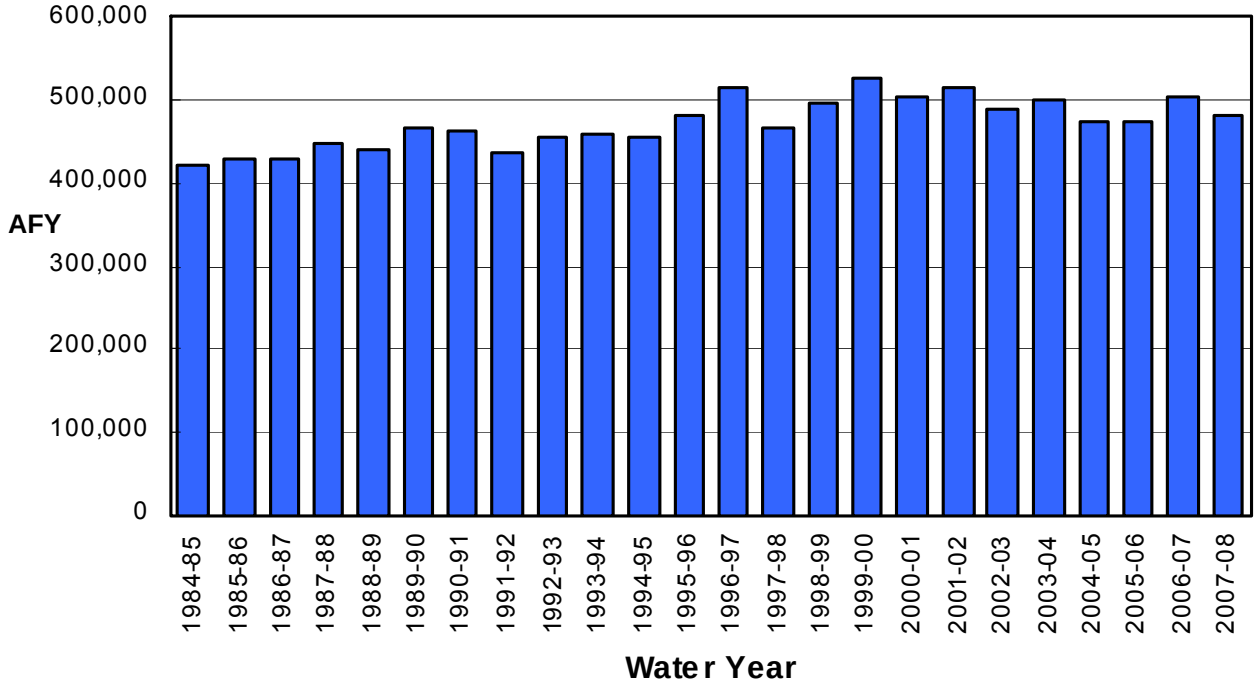
water available for groundwater recharge, producing recycled water for irrigation and other non-potable uses, participating in water conservation efforts, and working with the Municipal Water District of Orange County (MWDOC) in developing and conducting other supply augmentation projects and strategies.

Water Demand

Numerous factors influence water demands such as population growth, economic conditions, conservation programs, and hydrologic conditions. Estimates of future demands are therefore subject to some uncertainty and are updated on a regular basis.

Total water demand within the District's boundary for water year 2007-08 (July 1-June 30) was 480,000 af. Total demand is met with a combination of groundwater, imported potable water, local surface water, and recycled water used for irrigation and industrial purposes. Figure ES-9 shows historical total District water demands from 1984 to the present. Estimating water demands is necessary for the planning of future water supply project and programs.

FIGURE ES-9
HISTORICAL TOTAL DISTRICT WATER DEMANDS



Basin Operating Range

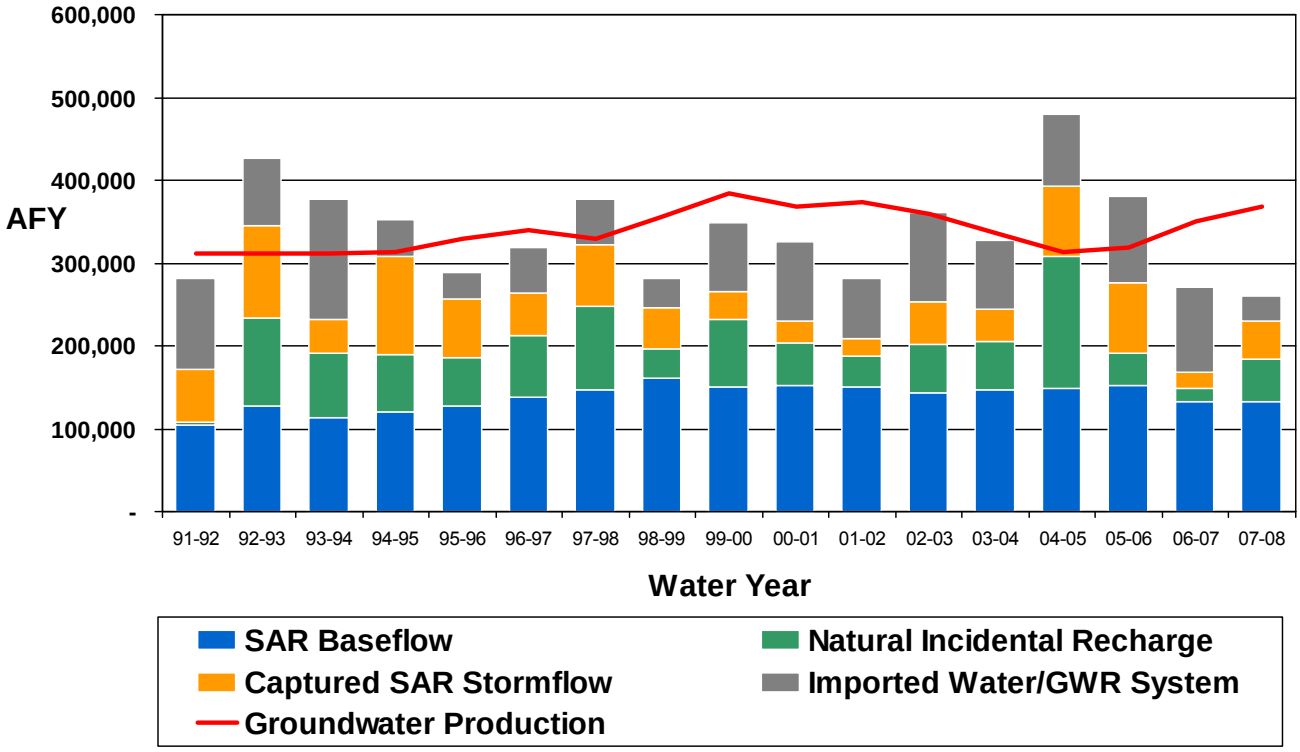
Total pumping from the basin is managed through a process that uses financial incentives to encourage groundwater producers to pump an aggregate amount of water that is sustainable without harming the basin. The process that determines a sustainable level of pumping considers the basin's safe operating range and the amount of recharge water available to the District. The basin operating range refers to the upper and lower levels of groundwater storage in the basin that can be reached without

causing negative impacts. Each year the District estimates the level of storage for the following year.

Integrated Management of Recharge and Production

Over the long term, the basin must be maintained in an approximate balance to ensure the long term viability of the water supply. In one particular year, water withdrawals may exceed water recharged as long as over the course of a number of years this is balanced by years where water recharged exceeds withdrawals. Levels of basin production and water recharged since water year 1991-92 are shown in Figure ES-10. The primary mechanism used by OCWD to manage pumping is the Basin Production Percentage (BPP). The BPP is the percentage of each Producer's total water supply that comes from groundwater pumped from the basin. The BPP is set uniformly for all Producers. Groundwater production at or below the BPP is assessed the Replenishment Assessment. Pumping above the BPP is also assessed a Basin Equity Assessment, which is calculated so that the cost of groundwater production is higher than purchasing imported potable water. This serves to discourage production above the BPP.

FIGURE ES-10
BASIN PRODUCTION AND RECHARGE SOURCES



Drought Management

During a drought, flexibility to maintain pumping from the basin becomes increasingly important. To the extent that the basin has water in storage that can be pumped out during a drought, the basin provides a valuable water supply asset during drought conditions. For the basin to serve as a safe, reliable supply, sufficient groundwater must be stored before a drought occurs and the basin needs to be refilled after a period of storage reduction occurs.

ES-7 Financial Management

The District has an excellent revenue base and a strong "AA+" financial rating. The District also has the ability to issue additional long-term debt, if necessary, to develop projects to increase the basin's yield and protect water quality. The annual operating budget for fiscal year 2008-09 was approximately $116.3 million.

OCWD maintains reserve funds to ensure financial integrity and to purchase supplemental water when it becomes available for groundwater recharge. The District's primary sources of revenue include the Replenishment Assessment, Basin Equity Assessment, property taxes, and other miscellaneous revenues such as rental fees on District property.

The District's programs to protect and increase the basin's sustainable yield in a cost-effective manner continue to evolve due to changes in the availability of recharge water supplies. Below average rainfall over the past four years in the Santa Ana River Watershed as well as other factors has reduced the availability of Santa Ana River water. The availability of imported water supplies for groundwater recharge has also changed significantly in the last few years. The occurrence of wet and dry periods, the future availability and cost of imported water supplies for recharge, and changing water management practices of agencies in the watershed will continue to affect the District's management of the basin.

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1 INTRODUCTION

The Orange County Water District (OCWD) manages the Orange County Groundwater Basin (the basin) in coastal Southern California This section provides background information on the District and sets the framework for the Groundwater Management Plan 2009 Update (Plan). The subsections below:

- **Discuss the District's formation, mission, and operating authorities.**
- **Trace changing conditions in the basin that are important to development of the Plan.**
- **Describe the public participation component of the Plan.**
- **Discuss the Plan's compliance with the California Water Code.**
- **Present basin management objectives that guide the District's management of the basin.**
- **Explain the District's public education programs.**

1.1 History of OCWD

The OCWD was formed by a special act of the California Legislature in 1933 to manage the groundwater basin that underlies north and central Orange County. District boundaries are shown in Figure 1-1. OCWD is not a water retailer and does not serve water to the public; rather, the District manages the groundwater basin.

Figure 1-1
Orange County Water District Boundary

Nineteen major producers, including cities, water districts, and private water companies, pump water from the basin and retail it to the public. There are also approximately 200 small wells that pump water from the basin, primarily for irrigation purposes. OCWD protects and manages the quantity and quality of the groundwater resource that meets approximately 60 to 70 percent of the water supply demand for a population of over 2.5 million.

Since its founding, the District has grown in area from 162,676 to 229,000 acres and has experienced an increase in population from approximately

120,000 to 2.5 million people. Facing the challenge of increasing demand for water has fostered a history of innovation and creativity that has enabled OCWD to increase available groundwater supplies while protecting the long-term sustainability of the basin.

The District's powers, as defined in its enabling legislation by the State of California (Water Code App §40-1, *et seq*., or the 'OCWD Act'), include the following:

> *Within or outside the District to construct, purchase, lease or otherwise acquire, and to operate and maintain necessary waterworks… to replenish the undergroundwater basin within the district, or to augment and protect the quality of the common water supplies of the district, … (portions of Section 2.5 of OCWD Act)*
>
> *For the common benefit of the district and for the purpose of managing the groundwater basin and managing, replenishing, regulating, and protecting the groundwater supplies within the district to exercise the following powers:*
>
> > *Provide for the conjunctive use of groundwater and surface water resources within the district area.*
> >
> > *Store water in undergroundwater basins or reservoirs within or outside of the district. Regulate and control the storage of water and the use of groundwater basin storage space in the groundwater basin.*
> >
> > *Purchase and import water into the district.*
> >
> > *Transport, reclaim, purify, treat, inject, extract, or otherwise manage and control water for the beneficial use of persons or property within the district and to improve and protect the quality of the groundwater supplies within the district. (Portions of Section 2.6 of OCWD Act)*
>
> *To provide for the protection and enhancement of the environment within and outside the district in connection with the water activities of the district. (Section 2.7 of OCWD Act)*

These powers illustrate the range of activities the District is involved with in managing the groundwater basin.

The Orange County Groundwater Basin was used by early settlers to supplement Santa Ana River surface water. Adequate, dependable water supplies were always a challenge for the residents of this semi-arid land. By 1900, conflicts over water supplies were escalating. The county's economic growth into an agricultural center was only one source of the problem. The other source was upstream: Santa Ana River flows were decreasing due to increased water use in the basins upstream of Orange County. San

Bernardino, Riverside, and Orange Counties were dependent on the same water source – the Santa Ana River in the Santa Ana River Watershed (shown in Figure 1-2).

FIGURE 1-2
SANTA ANA RIVER WATERSHED

In the early 1900s, reduced river flows and lowering of the Orange County groundwater table heightened conflicts between water users. Lower basin users initiated legal and other efforts to secure rights to water supplies. In 1932, The Irvine Company filed suit against upper basin users to protect its rights to river flows. Around the same time, the Orange County Farm Bureau formed the Santa Ana Basin Water Rights Protective Association to consider options to secure adequate supplies. This group developed a series of proposals, one of which led to legislation that created the OCWD.

The Orange County Water District Act was passed by the state legislature on June 4, 1933. The new District promptly joined The Irvine Company's lawsuit and was party to the 1942 settlement of that suit. The agreement limited the amount of river water that could be used for recharge in the upper basin to ensure that Orange County would have a share of Santa Ana River water.

Creation of the District and settlement of the lawsuit did not immediately solve the water supply problems in Orange County. Throughout the 1930s to early 1950s, groundwater pumping continued to exceed the rate of water recharged into the basin, a condition referred to as "overdraft." OCWD began looking for additional water supplies.

Efforts to bring more water into southern California were already underway. The Metropolitan Water District of Southern California (Metropolitan), created in 1927, built an aqueduct to transport and sell Colorado River water. Between 1949 and 1953, OCWD purchased 28,000 acre feet per year (afy) of Metropolitan water for groundwater recharge. However, these additional supplies were not enough to satisfy growing demand; by 1954, groundwater levels fell an average of fifteen feet below sea level. Now, the principal limitation faced by OCWD was the lack of an adequate, dependable funding base for purchasing the large amounts of recharge water needed to refill the overdrafted basin.

OCWD's only funding source at that time was local *ad valorem* taxes. Using property taxes to buy imported water was becoming controversial. Property owners in most of the District belonged to Metropolitan so their property taxes were funding imported water purchases. But water users pumping from the basin who were not Metropolitan members were benefiting from the imported supply without paying for it. In addition, some tax-paying property owners were not using the water that they were being charged for.

A twelve-person Orange County Water Basin Conservation Committee (the Committee of Twelve) was formed in 1952 to develop a solution to the funding problem. This process is described by author William Blomquist in his book "Dividing the Waters" (Blomquist, 1992).

> *"The area's water management problems were discussed at a joint meeting in 1952 of the Water Problems Committee of the Orange County Farm Bureau, the Water Committee of the Associated Chambers of Commerce, and the Board of Directors of the Orange County Water District. The twelve-man Orange County Water Basin Conservation Committee (the Committee of 12) was formed to study the issues further and develop recommendations. The Committee of 12 maintained the area's basic commitment to increasing supply rather than restricting*

demand. They considered and rejected centralized control over water consumption and distribution by an agency empowered to enforce conservation, or adjudication and limitation of water rights using the court-reference procedure. They supported instead a proposal to fund replenishment by taxing pumping. This approach held the promise of raising the necessary funds, relating producers' taxation to their benefits received, and relieving non-producers from paying for replenishment except to the extent that they purchased water from producers. Furthermore, at least theoretically, a tax on pumping would build in conservation incentives without mandating conservation.

OCWD was not authorized to tax pumping, so the Orange County Water District Act would have to be amended. The Committee of 12 assembled a package of amendments that amounted to a substantial redesign of the district. To be fair, a pump tax would have to be implemented basin-wide, so the Committee proposed enlarging the district's territory to include Anaheim, Fullerton, and Santa Ana, plus areas owned by the Anaheim Union Water Company and the Santa Ana Valley Irrigation Company near the canyon. A pump tax would make it necessary to measure and record water production from the thousands of wells within the district, so an amendment was proposed requiring every producer therein to register wells with OCWD and to record and submit production data to the District twice per year. The Committee also proposed that an annual District Engineer's Report on basin conditions and groundwater production be submitted to the District and water users, to allow them to monitor the effects of the replenishment program and to provide a shared picture on a regular basis of basin conditions, including the extent of seawater intrusion and the level of the water table."

Passage of these proposed amendments in 1954 was one of the most significant modifications to the original District Act. These major revisions gave OCWD the authority to assess a charge to pump groundwater, known as a Replenishment Assessment (RA). The OCWD Board of Directors voted to institute the first RA on June 9, 1954. The District now had adequate funds to purchase the amount of imported water needed for groundwater recharge, to monitor water quality and basin conditions, maintain and improve spreading facilities and pay for administrative costs.

One pressing problem arising from overdrafting the basin was seawater intrusion. In 1956, the groundwater level dropped to its lowest historical point, as much as 40 feet below sea level, and seawater intruded 3 ½ miles inland. Although imported water was helping refill the basin, the challenge of seawater intrusion remained. This was a problem primarily in two areas: the Alamitos Gap at the mouth of the San Gabriel River at the Orange County/Los Angeles County border and the Talbert Gap in Fountain Valley. In 1965, the District began a joint program that continues to the present with the Los Angeles County Flood Control District to inject fresh water in the Alamitos Gap to prevent saltwater intrusion.

The Talbert Gap was a greater challenge as it needed nearly six times the amount of water. After much research and planning, the District built Water Factory 21 (WF-21), a

water treatment plant that treated secondary-treated water from the Orange County Sanitation District (OCSD) to produce purified water for injection into the Talbert Gap. For over 20 years, a blend of WF-21 water and imported water was used to successfully manage seawater intrusion at the Talbert Gap.

WF-21, with a capacity that varied through time from four to fifteen million gallons per day (mgd), operated until 2004 when it was shut down to allow for construction of the Groundwater Replenishment (GWR) System. In operation since 2008, the GWR System is capable of producing up to 72 mgd of water for use in Talbert Barrier operations and for groundwater recharge.

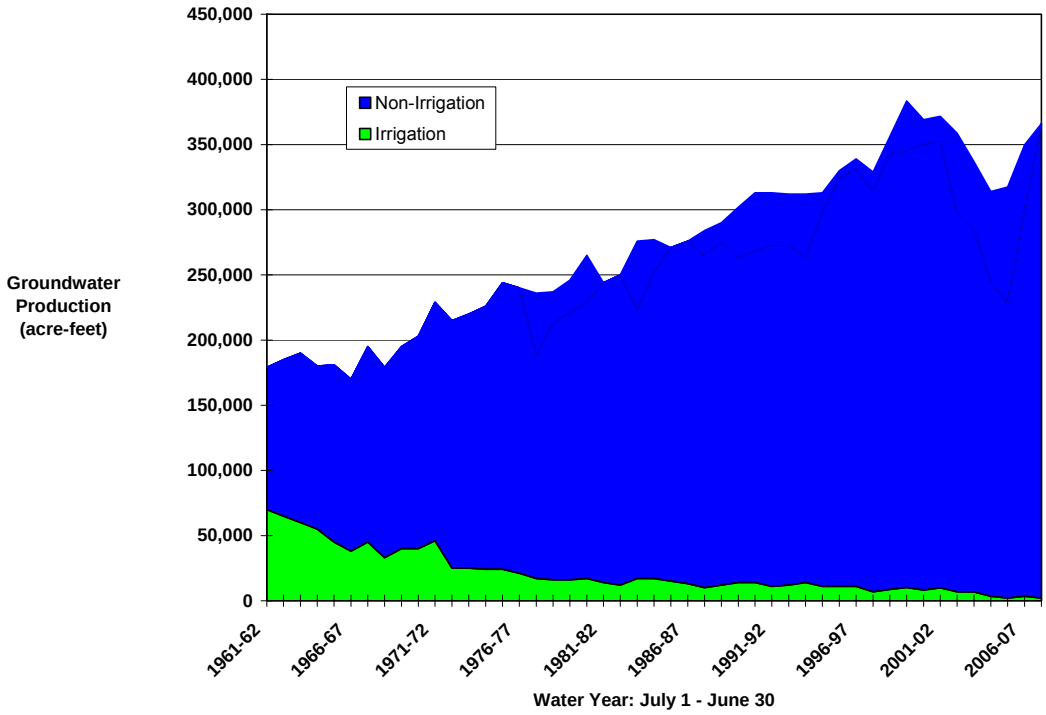
OCWD's recharge operations have played a central role in expanding water supplies. Efforts to increase the capture of Santa Ana River baseflows and stormflows and to recharge imported water date back to 1949. Currently, OCWD operates approximately 1,067 acres of riverbed and off-stream infiltration basins in the cities of Anaheim and Orange. Figure 1-3 is a view of the Santa Ana River looking upstream. Freeway 22 crosses the river in the foreground, Freeway 5 in the middle of the photograph, and Freeway 57 in the background.

FIGURE 1-3
SANTA ANA RIVER LOOKING UPSTREAM IN ANAHEIM AND ORANGE

OCWD has achieved world-renowned status for its innovative approach to groundwater recharge, water quality protection, and groundwater resource management. The District has employed groundwater management techniques to increase the annual yield from the basin as shown in Figure 1-4. Annual production increased from approximately 150,000 afy in the mid-1950s to approximately 350,000 afy in water year 2007-08.

OCWD has managed the basin in order to provide a reliable supply of relatively low-cost water and to accommodate rapid population growth while at the same time avoiding the costly and time-consuming adjudication of water rights experienced in nearly every other major groundwater basin in Southern California.

FIGURE 1-4
GROUNDWATER PRODUCTION 1961-2008



Note: Non-irrigation includes In-lieu recharge. (See explanation of In-lieu recharge water in Section 4.2.4.3)

1.2 Groundwater Producers

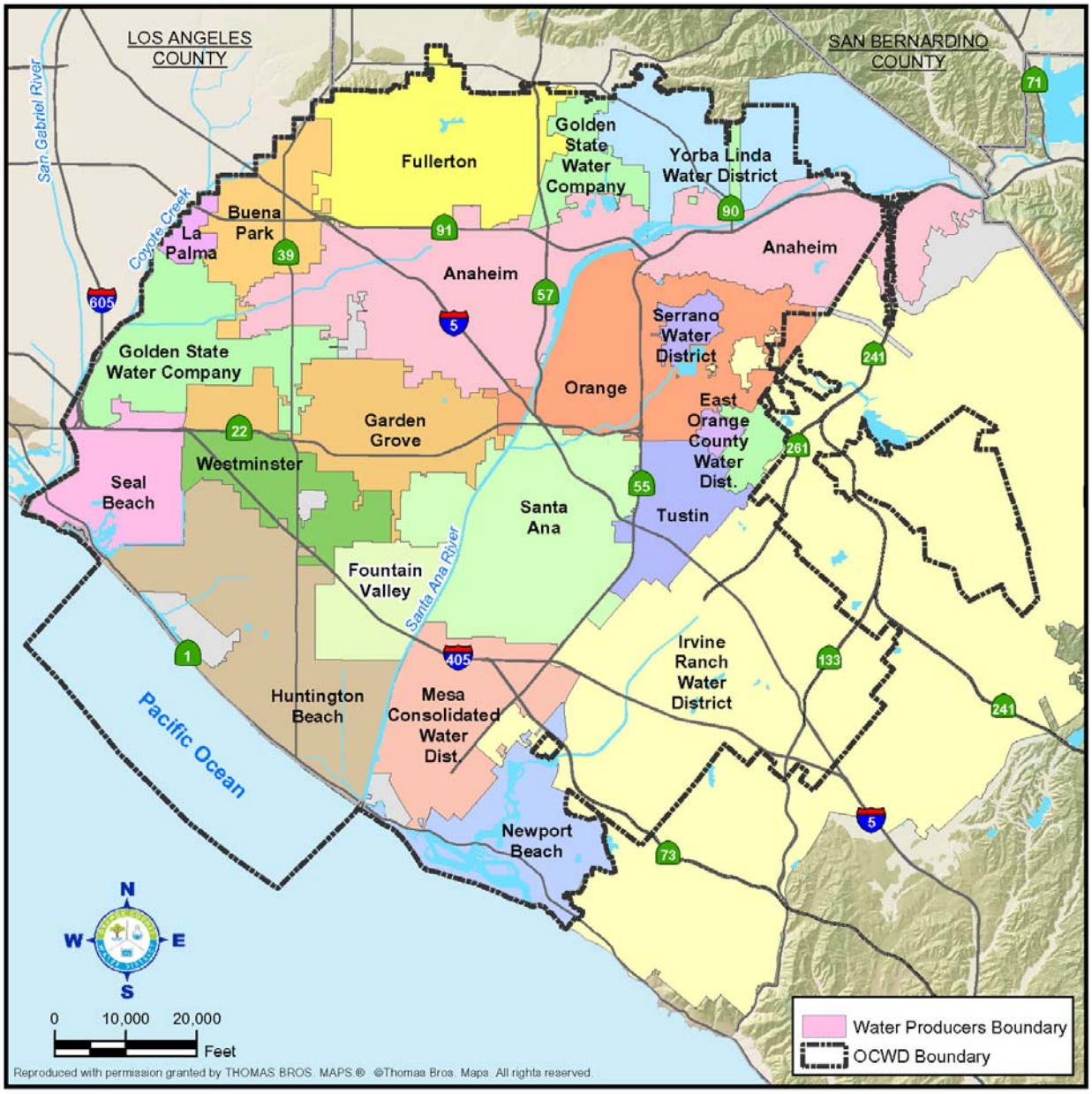
The local agencies that produce the majority of the groundwater from the basin are shown in Figure 1-5. As part of its plan to involve other affected agencies and work cooperatively where service areas or boundaries overlie the basin, the District meets monthly with nineteen local, major water producers to discuss and evaluate important basin management issues. This group is referred to as the groundwater producers (Producers). Generally each year a chairman is elected to represent the group. This monthly meeting provides a forum for the Producers to provide their input to the District on important issues such as:

- Setting the Basin Production Percentage (BPP) each year;
- Reviewing the merits of proposed capital improvement projects;
- Purchasing imported replenishment water to recharge the groundwater basin;
- Reviewing water quality data and regulations;

- Maintaining and monitoring basin water quality; and
- Budgeting and considering other important policy decisions.

The District as the groundwater basin manager and the Producers as the local retailers cooperate to serve the 2.5 million residents within the OCWD service territory. The Producers and OCWD served as the Advisory Committee for the preparation of this *Groundwater Management Plan*.

FIGURE 1-5
RETAIL WATER AGENCIES WITHIN OCWD



1.3 Public Education Programs

Proactive community outreach and public education are central to the operation of the OCWD. Each year, staff members give more than 120 presentations to community leaders and citizens, conduct more than 70 tours of OCWD facilities, and take an active part in community events. In addition to presentations and tours, OCWD administers multiple education programs as described below.

Since its inception in 1996, the Children's Water Education Festival has been the largest of its kind in the nation, hosting more than 6,000 children each year. This two-day outdoor event teaches children about water resources, recycling, pollution prevention, wetland preservation, and other environmental topics through interactive and hands-on activities.

In 2007, the O.C. Water Hero program was initiated to make water conservation fun while helping children and parents develop effective water-use efficiency habits that will last a lifetime. The program challenges both children and their parents to commit to saving 20 gallons of water a day.

O.C. Water 101 is a free water education class that is offered to the public. This one-day session focuses on the global water crisis, how water affects health, California's unique water situation, future challenges for water supplies in Orange County, and how water agencies are helping to conserve available water resources. Discussions include high-tech solutions to help alleviate water shortages today and in the future, as well as providing individuals with the resources and information necessary to save water.

The Hotel/Motel Water Conservation Program began in 1999 to assist hotels and motels in Orange County. At no cost, hotels and motels can order laminated towel rack hangers, bed cards, or combination cards that ask guests to consider reusing their towels and bed linens during their stay. The cards, which gently encourage guests to be environmentally aware, help hotels and motels save money and water.

In 2008, the District, in conjunction with the Municipal Water District of Orange County (MWDOC) and the Orange County Business Council, hosted the O.C. Water Summit, which brought over 400 key policy makers, community leaders and business professionals together to discuss the state's water challenges and possible regional solutions.

The District was recognized as a Groundwater Guardian member in 1996, thereafter forming the OCWD Groundwater Guardian Team. This program is designed to empower local citizens and communities to take voluntary steps toward protecting groundwater resources. The OCWD Groundwater Guardian Team attends and supports community events that are related to this cause.

Through its programs and outreach efforts OCWD informs and educates the public about Orange County's water supply, as well as overall water issues. OCWD strives to draw the communities' attention to the state's water needs and teaches them effective ways to minimize water consumption. The community is encouraged to make life-long commitments to conserving water and respecting it as a precious resource.

1.4 Preparation of the Orange County Water District Groundwater Management Plan

OCWD prepared the first *Groundwater Management Plan* in 1989 and updated the plan in 1990, 1994, and 2004.

The 2009 update of the Plan includes new information about projects completed by the District in the past five years and the updated approach to calculating basin storage changes. The Plan identifies OCWD's goals and basin management objectives in protecting and managing the Orange County groundwater basin. The Plan also describes factors for the District's Board to consider in making decisions regarding how much pumping the basin can sustain.

Specific projects that may be developed as a result of recommendations in the Plan would be separately reviewed and approved by the District's Board of Directors and processed for environmental review prior to project implementation. The Plan does not commit the District to a particular program or level of basin production, but describes the factors to consider and key issues as the Board makes basin management decisions on a regular basis each year. Potential projects that are conceptually described in the Plan are described in greater detail in the District's *Long-Term Facilities Plan* (OCWD, 2009).

1.5 OCWD Accomplishments, 2004-2008

In the *OCWD 2004 Groundwater Management Plan*, the District established quantifiable objectives, identified as Key Performance Indicators. Those Key Performance Indicators are listed in Table 1-1 along with a summary of actions taken and projects completed to accomplish them.

TABLE 1-1
KEY PERFORMANCE INDICATORS

2004 Groundwater Management Plan Key Performance Indicators	2008 Status
Cease landward migration of 250 mg/L chloride contour by 2006	GWR System began operation in 2008.
	Reliable, local water supplies available for barrier injection increased from 5 mgd to 30 mgd.
	Reversal of landward migration at Talbert Barrier observed in 2008.
Increase Prado water conservation pool elevation by four feet by 2005	Memorandum of Agreement with the Army Corps of Engineers was executed in 2006 allowing a 5,000 af increase in the maximum winter pool elevation.
Increase recharge capacity by 10,000 afy	Increase in recharge capacity of greater than 10,000 afy occurred with (1) the La Jolla Recharge Basin coming on line in 2008 and (2) operation of Basin Cleaning Vehicles.

2004 Groundwater Management Plan Key Performance Indicators	2008 Status
All water recharged into the basin through District facilities meets or is better than Department of Public Health MCLs and Notification Levels	No exceedances of MCLs or Notification Levels in recharge water as documented in *Santa Ana River Water Quality Monitoring Reports* (OCWD 2005, 2006, 2007, 2008) and GWR System permit reports.
Reduce basin overdraft by 20,000 afy	Basin's accumulated overdraft was reduced by 202,000 af between June 2004 and June 2007. (OCWD Engineer's Report, 2008)

Major accomplishments since adoption of the 2004 Plan include:

- Phase 1 of the GWR System began operating in 2008 with a capacity of purifying 72 afy of water for the Talbert Barrier and groundwater recharge.
- The Irvine Desalter Project, a cooperative project between OCWD and Irvine Ranch Water District (IRWD), began operating in 2007 to remediate groundwater contamination and provide 8,000 afy of additional water supplies.
- The *Report on Evaluation of Orange County Groundwater Basin Storage and Operational Strategy*, published in February 2007, established a new methodology for calculating accumulated overdraft and establishing new full-basin benchmarks (see Appendix D).
- Development of a groundwater model.
- Beginning the construction of the North Basin Groundwater Protection Project.
- Securing the rights to divert and use up to 362,000 afy of Santa Ana River water through a decision of the State Water Resources Control Board in December 2008.

A comprehensive list of projects completed between 2004 and 2009 and the location in the Plan of the project description is shown in Table 1-2.

Table 1-2
Summary of Completed Projects 2004-2009

Project	Description	Location in GWMP	Construction Completed	Operation Began
Groundwater Replenishment System	Purifies up to 72,000 afy of secondary-treated water from OCSD to create a new water supply for seawater intrusion barrier and groundwater recharge	Section 4.2.3.1	2007	2008
Prado Basin Water Conservation Project	Increases winter-time storage level at Prado Dam by 5,000 af	Section 4.1.1	N/A	2006
Talbert Barrier Expansion	Expanded Talbert Seawater Intrusion Barrier by constructing 8 new injection wells (4 with 1 casing each and 4 with 3 casings each)	Section 6.3.3	2007	2008
Irvine Desalter Project	Constructed extraction and treatment system to pump and treat up to 8,000 afy contaminated groundwater	Section 5.8.4	2007	2007
La Jolla Recharge Basin	New 6-acre recharge basin increases recharge capacity up to 9,000 afy	Section 4.4.1	2008	2008
Olive Basin Intake Structure Improvements	Construction of new intake structure and transfer pipe decreases sediment fouling of recharge basin	Section 4.4.1	2006	2007
Basin Cleaning Vehicles	Construction of four basin cleaning vehicles removes sediment from recharge basins	Section 4.1	2004	2004
Santiago Creek Recharge Enhancement	Grading of Santiago Creek bed improves recharge rate by an estimated 3,600 afy	Section 4.4.1	2008	2008
Conjunctive Use “8 Well Project”	Construction of 8 new extraction wells as part of Conjunctive Use Project with MWD to allow storage and withdrawal of imported water in the groundwater basin for use in drought years	Section 6.3.3	2007	N/A

Project	Description	Location in GWMP	Construction Completed	Operation Began
Mini-Anaheim Recharge Basin Modifications	Modifications to increase recharge basin performance	Section 4.4.1	2005	2005
Kraemer-Miller Pipeline Improvements	New pipelines to provide enhanced supply of recharge water to recharge basins	Section 4.4.1	2007	2007
Santiago Creek Monitoring Wells	Three new monitoring wells constructed to assess hydrogeologic conditions along Santiago Creek	Section 4.2.2	2009	2009
Monitoring Wells for GWR System	Construction of three new monitoring wells for GWR System compliance monitoring	Section 3.7.3	2004	2005
Monitoring Wells for North Basin Groundwater Protection Project	Construction of new monitoring wells to assess occurrence of groundwater contamination	Section 5.8.1	2008	2008
Extraction Wells for North Basin Groundwater Protection Project	Four new extraction wells constructed to remove contaminated groundwater	Section 5.8.1	2009	Estimated in 2010
Lincoln & Burris Exploratory Wells	Construction of ten monitoring wells to characterize the ability of sediments adjacent to the basin to percolate water	Section 4.4.1	2006	2007
Prado Wetlands Reconstruction	Flood damage repairs restore wetlands function	Section 5.3.3	2008	2008
Warner Basin Dam	Construction of a dam to replace need for building temporary earthen berms for each basin cleaning.	Section 4.4.1	2007	2007

1.6 Public Outreach

The California Water Code describes the process for development and adoption of a groundwater management plan that includes a public participation component. To adopt this plan, publicly-noticed meetings held as part of the District's regularly-scheduled board meetings and information were posted on the OCWD website. Appendix A contains copies of the public notices.

In addition to the publicly-noticed public participation opportunities and postings on the web site, the District held workshops with the Producers. The Producers include cities, special districts, and investor-owned utilities that produce more than 90 percent of the water pumped from the basin. The content of the Plan was developed with input and review from the Producers through holding workshops and providing the Producers with draft versions of the Plan prior to its finalization. This group and OCWD served as the advisory committee of stakeholders guiding the development and implementation of the plan and providing a forum for resolving controversial issues.

As part of its overall outreach program, the District informs and engages the public in groundwater discussions through an active speaker's bureau, media releases, and the water education class "Orange County Water 101".

1.7 Compliance with California Water Code

Criteria regarding adoption of a groundwater management plan are included in Section 10750 et seq. of the California Water Code, also referred to as A.B. 3030. A complete list of required and recommended components of groundwater management plans and the location of those components in the Plan can be found in Appendix B. This plan is developed to meet the requirements of the California Water Code.

1.8 Groundwater Management Goals and Basin Management Objectives

OCWD's goals in managing the Orange County groundwater basin are as follows:

- To protect and enhance the groundwater quality of the Orange County groundwater basin,
- To protect and increase the sustainable yield of the basin in a cost-effective manner, and
- To increase the efficiency of OCWD's operations.

Basin management objectives that accomplish all three of the above mentioned goals include:

- Updating the *Groundwater Management Plan* periodically,
- Updating the *Long-Term Facilities Plan* periodically, and
- Continuing annual publication of the *Santa Ana River Water Quality Report*; the *Engineer's Report on the Groundwater Conditions, Water Supply and Basin*

Utilization; the *Santa Ana River Watermaster Report*; and the *Groundwater Replenishment System Operations Annual Report*.

More specific basin management objectives set to accomplish one of the above mentioned goals are summarized below and described in detail in this report.

1.8.1 PROTECT AND ENHANCE GROUNDWATER QUALITY

Basin management objectives established by OCWD to protect and enhance groundwater quality include:

- Conducting groundwater quality monitoring programs throughout the basin.
- Monitoring and managing recharge water supplies so that water recharged through District facilities meets or is better than primary drinking water levels and notification levels.
- Monitoring the quality of Santa Ana River water on a routine basis at Imperial Highway and in the upper watershed.
- Implementing the District's Groundwater Quality Protection Policy.
- Constructing and managing water quality treatment projects.
- Operating seawater intrusion barriers to prevent landward migration of seawater into the groundwater basin.
- Supporting natural resource programs in the Santa Ana River Watershed to improve water quality.
- Participating in cooperative efforts with regulators and stakeholders within the Santa Ana River Watershed.

1.8.2 PROTECT AND INCREASE THE BASIN'S SUSTAINABLE YIELD IN A COST EFFECTIVE MANNER

Basin management objectives established by OCWD to protect and increase the basin's sustainable yield include:

- Monitoring groundwater levels, recharge rates, and production rates.
- Operating the groundwater basin in accordance with the *Groundwater Basin Storage and Operational Strategy*.
- Managing recharge operations to maximize recharge of the groundwater basin.
- Researching and implementing new strategies and programs to increase recharge capacity.
- Promoting incidental recharge to the extent feasible without negatively impacting groundwater quality.

- Planning for and conducting programs that maximize the capacity of the basin to respond to and recover from droughts.
- Supporting natural resource programs in the Santa Ana River watershed.

1.8.3 Increase Operational Efficiency

Basin management objectives established by OCWD to increase operational efficiency include:

- Managing the District's finances to provide long-term fiscal stability and to maintain financial resources to implement District programs.
- Operating District programs in a cost-effective and efficient manner.
- Managing natural resource programs in the Santa Ana River watershed in an efficient manner.
- Implementing efficient environmental management programs to reduce greenhouse gas emissions, such as use of solar power where feasible.

District programs that are conducted to meet the state goals and basin management objectives and to contribute to a more reliable supply for long-term beneficial uses of groundwater are described in the following sections, a summary of which can be found in Appendix C.

2 BASIN HYDROGEOLOGY

The groundwater basin covers approximately 350 square miles in north-central Orange County and is composed of layers of sediment with variable thickness and hydraulic properties. Because of the basin's size and complexity, understanding basin hydrogeology is critical to successful water management. This section:

- **Describes the hydrogeologic characteristics of the basin, including aquifer systems, basin boundaries, and physiographic features.**
- **Describes the major components of inflows and outflows that compromise the basin water budget.**
- **Presents groundwater storage and elevation trends and issues related to land subsidence.**
- **Explains the updated methodology for calculating accumulated overdraft and groundwater storage change implemented in 2007.**
- **Traces the history, development, and operation of the District's Basin Model.**

2.1 DESCRIPTION OF BASIN HYDROGEOLOGY

The Orange County Groundwater Basin is located in the area designated by the California Department of Water Resources (DWR) as Basin 8-1, the "Coastal Plain of Orange County Groundwater Basin" in Bulletin 118 (DWR, 2003).

Figure 2-1 displays the OCWD boundaries in relation to the boundaries of Basin 8-1. The groundwater basin underlies the north half of Orange County beneath broad lowlands known as the Tustin and Downey plains. The basin covers an area of approximately 350 square miles, bordered by the Coyote and Chino Hills to the north, the Santa Ana Mountains to the northeast, and the Pacific Ocean to the southwest. The basin boundary extends to the Orange County-Los Angeles line to the northwest, where groundwater flow is unrestricted across the county line into the Central Basin of Los Angeles County (see Figure 2-2). The Newport-Inglewood fault zone forms the southwestern boundary of all but the shallow aquifer in the basin.

Basin aquifers are over 2,000 feet deep and form a complex series of interconnected sand and gravel deposits (DWR, 1967). In coastal and central portions of the basin, these deposits are extensively separated by lower-permeability clay and silt deposits, known as aquitards. In the inland area, generally northeast of Interstate 5, the clay and silt deposits become thinner and more discontinuous, allowing larger quantities of groundwater to flow more easily between shallow and deeper aquifers. Figure 2-3 presents a geologic cross section through the basin along the Santa Ana River.

Shallower aquifers exist above the principal aquifer system, the most prolific being known as the Talbert aquifer. Production from this shallow aquifer system is typically about five percent of total basin production. The majority of water from the shallow

aquifer is pumped by small systems for industrial and agricultural use although the cities of Garden Grove, Anaheim, and Tustin have a few large system wells that pump from the shallow aquifer for municipal use.

Deeper aquifers exist below the principal aquifer system. Few wells penetrate into this region because of the high cost of drilling deep wells and because the aquifers contain colored water in some areas. The treatment and use of colored water is discussed in detail in Section 5.4.

FIGURE 2-1
DWR Bulletin 118 Groundwater Basins

2.1.1 FOREBAY AND PRESSURE AREAS

The Department of Water Resources, formerly the Division of Water Resources (DWR, 1934), divided the basin into two primary hydrologic divisions, the Forebay and Pressure areas, as shown in Figure 2-2. The Forebay/Pressure area boundary generally delineates the areas where surface water or shallow groundwater can or cannot move downward to the first producible aquifer in quantities significant from a water-supply perspective. From a water-quality perspective, the amount of vertical flow to deeper aquifers from surface water or shallow groundwater may be significant in terms of impacts of past agricultural or industrial land uses (e.g., fertilizer application and leaky underground storage tanks).

FIGURE 2-2
ORANGE COUNTY GROUNDWATER BASIN

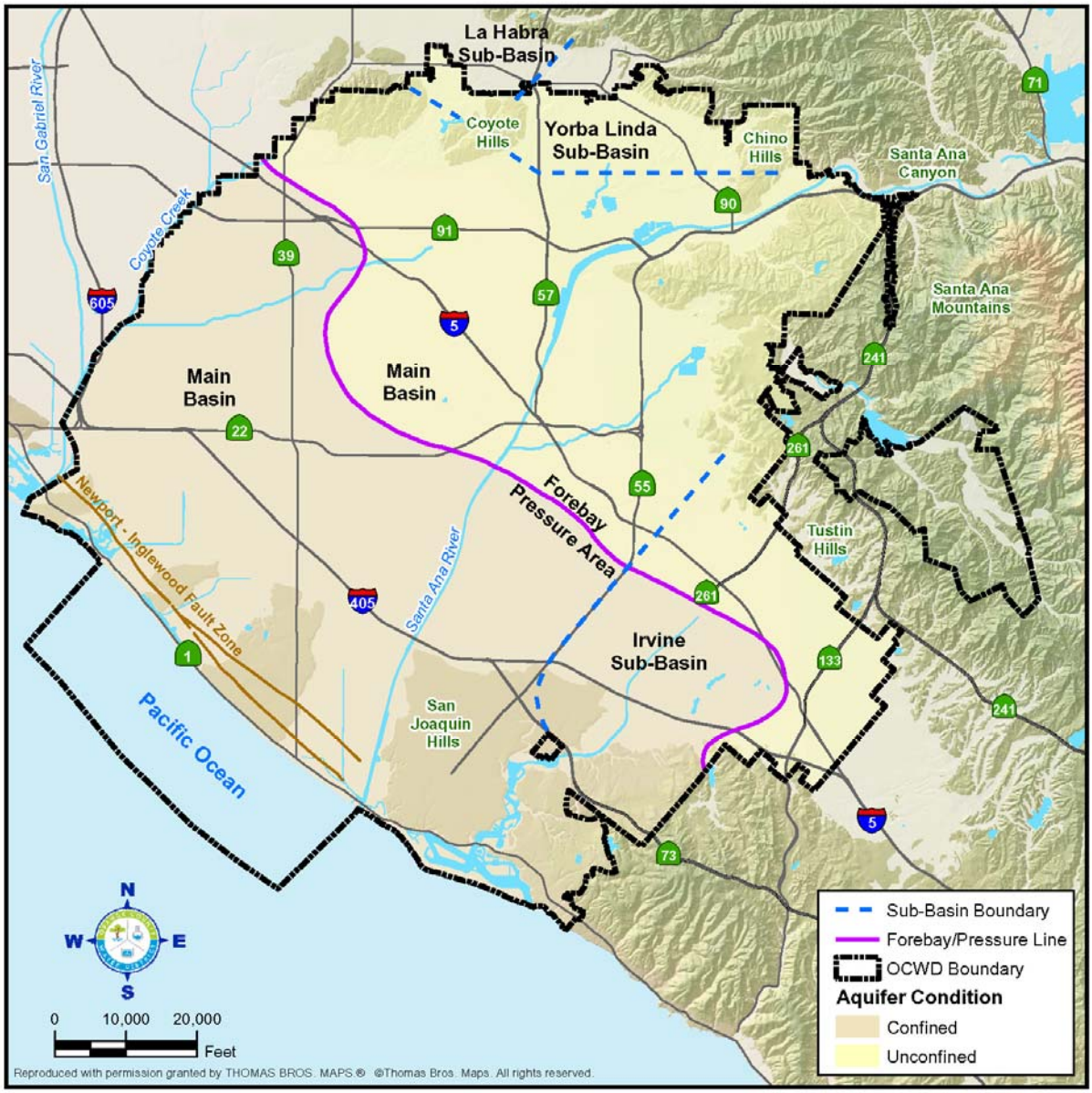
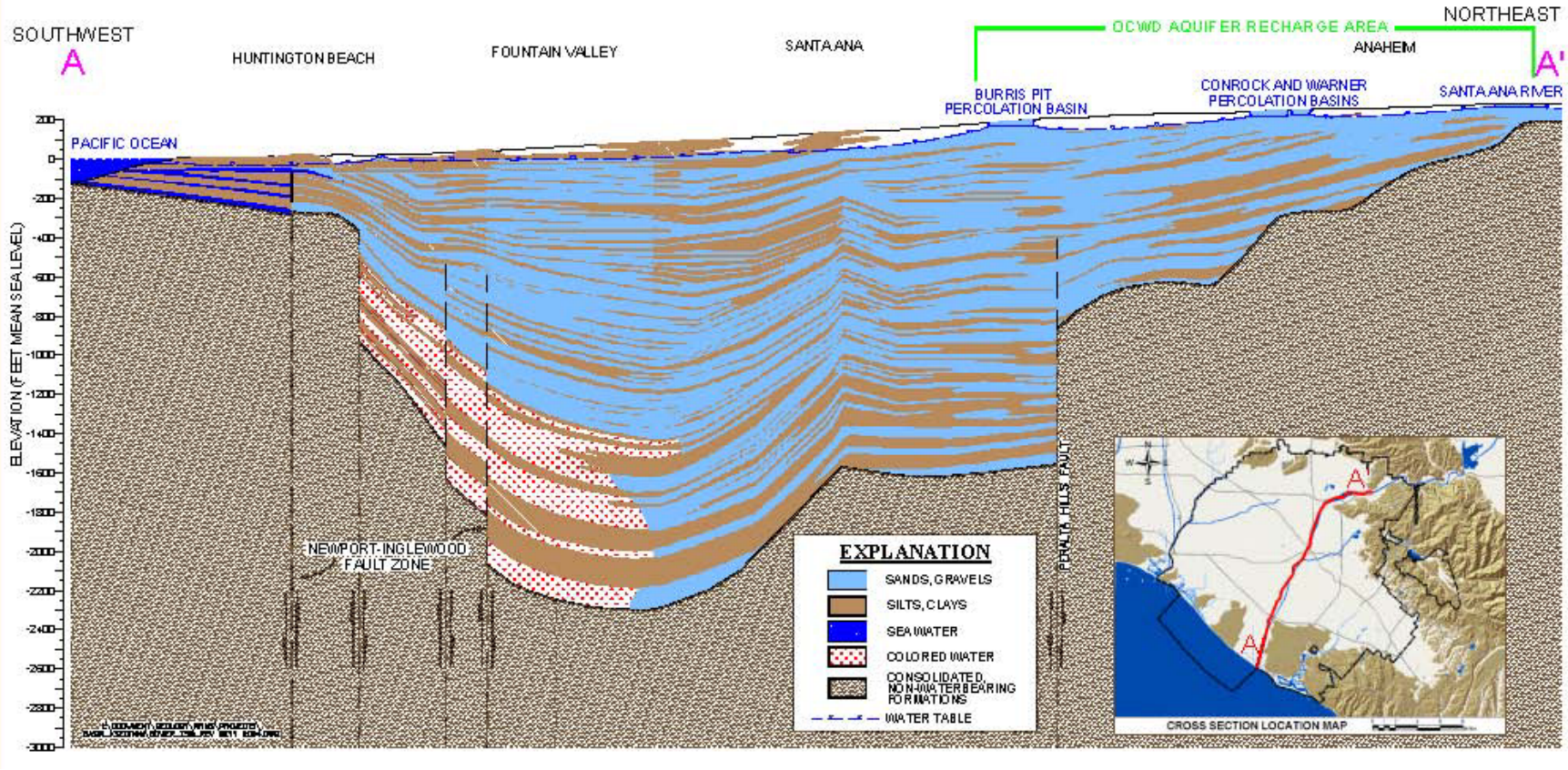


FIGURE 2-3
GEOLOGIC CROSS-SECTION THROUGH ORANGE COUNTY GROUNDWATER BASIN



The Forebay refers to the area of intake or recharge where most of the groundwater recharge occurs. Highly-permeable sands and gravels with few and discontinuous clay and silt deposits allow direct percolation of Santa Ana River and other surface water. The Forebay area encompasses most of the cities of Anaheim, Fullerton, and Villa Park and portions of the cities of Orange and Yorba Linda.

The Pressure Area, in a general sense, is defined as the area of the basin where large quantities of surface water and near-surface groundwater is impeded from percolating into the major producible aquifers by clay and silt layers at shallow depths (upper 50 feet). The principal and deeper aquifers in this area are under "confined" conditions (under hydrostatic pressure); the water levels of wells penetrating these aquifers exhibit large seasonal variations. Most of the central and coastal portions of the basin fall within the Pressure Area.

2.1.2 GROUNDWATER SUBBASINS, MESAS AND GAPS

The Irvine subbasin, bounded by the Santa Ana Mountains and the San Joaquin Hills, forms the southern-most portion of the basin. The Costa Mesa Freeway (State Route 55) and Newport Boulevard form the subbasin's approximate western boundary with the main basin. Here the aquifers are thinner and contain more clay and silt deposits than aquifers in the main portion of the basin. The Irvine Ranch Water District (IRWD) is the primary groundwater producer.

The aquifer base in the Irvine subbasin ranges from approximately 1,000 feet deep beneath the former Marine Corps Air Station (MCAS) Tustin to less than 200 feet deep at the eastern boundary of the former MCAS El Toro. East of former MCAS El Toro, the aquifer further thins and transitions into lower-permeability sandstones and other semi-consolidated sediments, which have minor water storage and transmission capacity. Groundwater historically flowed out of the Irvine subbasin westerly into the main basin since the amount of natural recharge in the area, predominantly from the Santa Ana Mountains, was typically greater than the amount of pumping (Singer, 1973; Banks, 1984). With the operation of the Irvine Desalter Project commencing in 2007, groundwater production in the Irvine subbasin may exceed the natural replenishment from the adjacent hills and mountains, in which case groundwater would be drawn into the Irvine subbasin from the Main Basin.

The Yorba Linda subbasin is located north of the Anaheim Forebay recharge area, within the cities of Yorba Linda and Placentia. Due to low transmissivity and high total dissolved solids (TDS) concentrations (Mills, 1987) there is little groundwater pumped from this subbasin. Groundwater from the Yorba Linda subbasin flows southward into the Main basin since the limited groundwater production is less than the natural replenishment from the adjacent Chino Hills.

The La Habra Basin is located north of the Main Basin within the cities of La Habra and Brea. It comprises a shallow alluvial depression between the Coyote Hills and the Puente Hills. Similar to the Yorba Linda subbasin, little groundwater production occurs in the La Habra Basin due to low transmissivity and poor water quality (high TDS). Hydrogeologic studies have indicated that 2,200 to 5,500 afy of groundwater flows out of the La Habra Basin in two areas: (1) southerly into the Main Basin along the Brea

Creek drainage between the East and West Coyote Hills and (2) westerly into the Central basin in Los Angeles County (James M. Montgomery, 1977; Ramsey, 1980; OCWD, 1994).

Four relatively flat elevated areas, known as mesas, occur along the coastal boundary of the basin. The mesas were formed by ground surface uplift along the Newport Inglewood Fault Zone. Ancient meandering of the Santa Ana River carved notches through the uplifted area and left behind sand- and gravel-filled deposits beneath the lowland areas between the mesas, known as gaps (Poland et al., 1956). Groundwater in the shallow aquifers within the gaps is susceptible to seawater intrusion. The Talbert and Alamitos seawater intrusion barriers were constructed to address this problem. Locations of mesas and details of seawater barrier operations are discussed in Section 3.6.

2.2 DETERMINATION OF TOTAL BASIN VOLUME

A vast amount of fresh water is stored within the basin, although only a fraction of this water can be removed practically using pumping wells and without causing physical damage such as seawater intrusion or the potential for land subsidence (Alley, 2006). Nonetheless, it is important to note the total volume of groundwater that is within the active flow system, i.e., within the influence of pumping and recharge operations.

OCWD used its geographic information system and the aquifer system boundaries described in detail in Section 2.8 to calculate the total volume of each of the three major aquifer systems as well as the intervening aquitards. The total volume was calculated by multiplying the area and thickness of each hydrogeologic unit. Because groundwater fills the pore spaces that represent typically between 20 and 30 percent of the total volume, the total volume was multiplied by this porosity percentage to arrive at a total groundwater volume. Assuming the basin is completely full, based on District estimates, the total amount of fresh groundwater stored in the basin is approximately 66 million acre-feet (maf), as shown in Table 2-1.

TABLE 2-1
ESTIMATED BASIN GROUNDWATER STORAGE BY HYDROGEOLOGIC UNIT
(Volumes in Acre-feet)

Hydrogeologic Unit	Pressure Area	Forebay	Total
Shallow Aquifer System	3,800,000	1,200,000	5,000,000
Aquitard	900,000	200,000	1,100,000
Principal Aquifer System	24,300,000	8,600,000	32,900,000
Aquitard	1,600,000	300,000	1,900,000
Deep Aquifer System	18,800,000	6,300,000	25,100,000
Total	**49,400,000**	**16,600,000**	**66,000,000**

Notes: 1. Volumes calculated using the 3-layer basin model surfaces with ArcInfo Workstation GRID.
2. A porosity of 0.25 was assumed for aquifer systems.
3. A porosity of 0.30 was assumed for aquitards.

For comparison, DWR (1967) estimated that about 38 maf of fresh water is stored in the groundwater basin when full. DWR used a factor known as the specific yield to calculate this volume. The specific yield (typically between 10 and 20 percent) is the amount of water that can be drained by gravity from a certain volume of aquifer and reflects the soil's ability to retain and hold a significant volume of water due to capillary effects. Thus, DWR's *drainable* groundwater volume, although technically correct, is roughly half of OCWD's estimate of *total* groundwater volume in the basin.

2.3 WATER BUDGET

OCWD staff developed a hydrologic budget (inflows and outflows) for the purpose of constructing the Basin Model and for evaluating basin production capacity and recharge requirements. The key components of the budget include measured and unmeasured (estimated) recharge, groundwater production, and subsurface flows along the coast and across the Orange/Los Angeles County line. Because the basin is not operated on an annual safe-yield basis, the net change in storage in any given year may be positive or negative; however, over the period of several years, the basin must be maintained in an approximate balance.

Table 2-2 presents the components of a balanced basin water budget (no annual change in storage) and does not represent data for any given year. The annual budget presented is based on the following assumptions: (1) average precipitation, (2) accumulated overdraft of 400,000 af, (3) recharge of 235,000 af at the Forebay recharge facilities, and (4) adjusted groundwater production so that total basin inflows and outflows are equal. The 235,000 af of Forebay recharge consists of 148,000 af of Santa Ana River baseflow, 50,000 af of Santa Ana River stormflow, and 37,000 af of GWR System water. The major components of the water budget are described in the following sections.

2.3.1 MEASURED RECHARGE

Measured recharge consists of all water artificially recharged at OCWD's Forebay percolation facilities and water injected at the Talbert Barrier and on the Orange County side of the Alamitos Barrier. Santa Ana River stormflows and baseflows serve as the primary source of recharge in the Forebay.

OCWD's Talbert Barrier is a series of injection wells that span the 2.5-mile wide Talbert Gap, between the Newport and Huntington Beach mesas. A blend of imported and purified water is injected into multiple aquifers that are used for municipal supply. Over 95 percent of the injected water flows inland and becomes part of the basin's replenishment supply.

The Alamitos Barrier is a series of wells injecting a blend of imported and purified water into multiple aquifer zones that span the Alamitos Gap at the Los Angeles/Orange County line. Essentially all of the injected water flows inland, replenishing groundwater basins in the two counties. From inspection of groundwater contour maps, it appears that roughly one-third of the Alamitos Barrier injection water remains within or flows into Orange County.

TABLE 2-2
REPRESENTATIVE ANNUAL BASIN WATER BUDGET

FLOW COMPONENT	Acre-feet
INFLOW	
Measured Recharge	
1. Forebay recharge facilities	235,000
2. Talbert Barrier injection	35,000
3. Alamitos Barrier injection, Orange County portion only	2,500
Subtotal:	**272,500**
Estimated Unmeasured Recharge (average precipitation)	
1. Inflow from La Habra basin	3,000
2. Recharge from foothills into Irvine subbasin	14,000
3. Areal recharge from rainfall/irrigation into Main basin	17,500
4. Recharge from foothills into Yorba Linda subbasin	6,000
5. Subsurface inflow at Imperial Highway beneath Santa Ana River	4,000
6. Santa Ana River recharge, Imperial Highway to Rubber Dam	4,000
7. Subsurface inflow from Santiago Canyon	10,000
8. Recharge along Peralta Hills	4,000
9. Recharge along Tustin Hills	6,000
10. Seawater inflow through coastal gaps	500
Subtotal:	**69,000**
TOTAL INFLOW:	**341,500**
OUTFLOW	
1. Groundwater Production	333,500
2. Subsurface Outflow	8,000
TOTAL OUTFLOW:	**341,500**
CHANGE IN STORAGE:	**0**

2.3.2 UNMEASURED RECHARGE

Unmeasured recharge also referred to as “incidental recharge” accounts for a significant amount of the basin’s producible yield. This includes recharge from precipitation at the basin margin along the Chino, Coyote, and San Joaquin Hills and the Santa Ana Mountains; Santa Ana River recharge between Imperial Highway and the OCWD rubber diversion dam; irrigation return flows; urban runoff; and underflow beneath the Santa Ana River and Santiago Creek. This latter refers to groundwater that enters the basin at the mouth of Santa Ana Canyon, the Santiago Creek drainage below Villa Park Dam, and seawater inflow through the gaps.

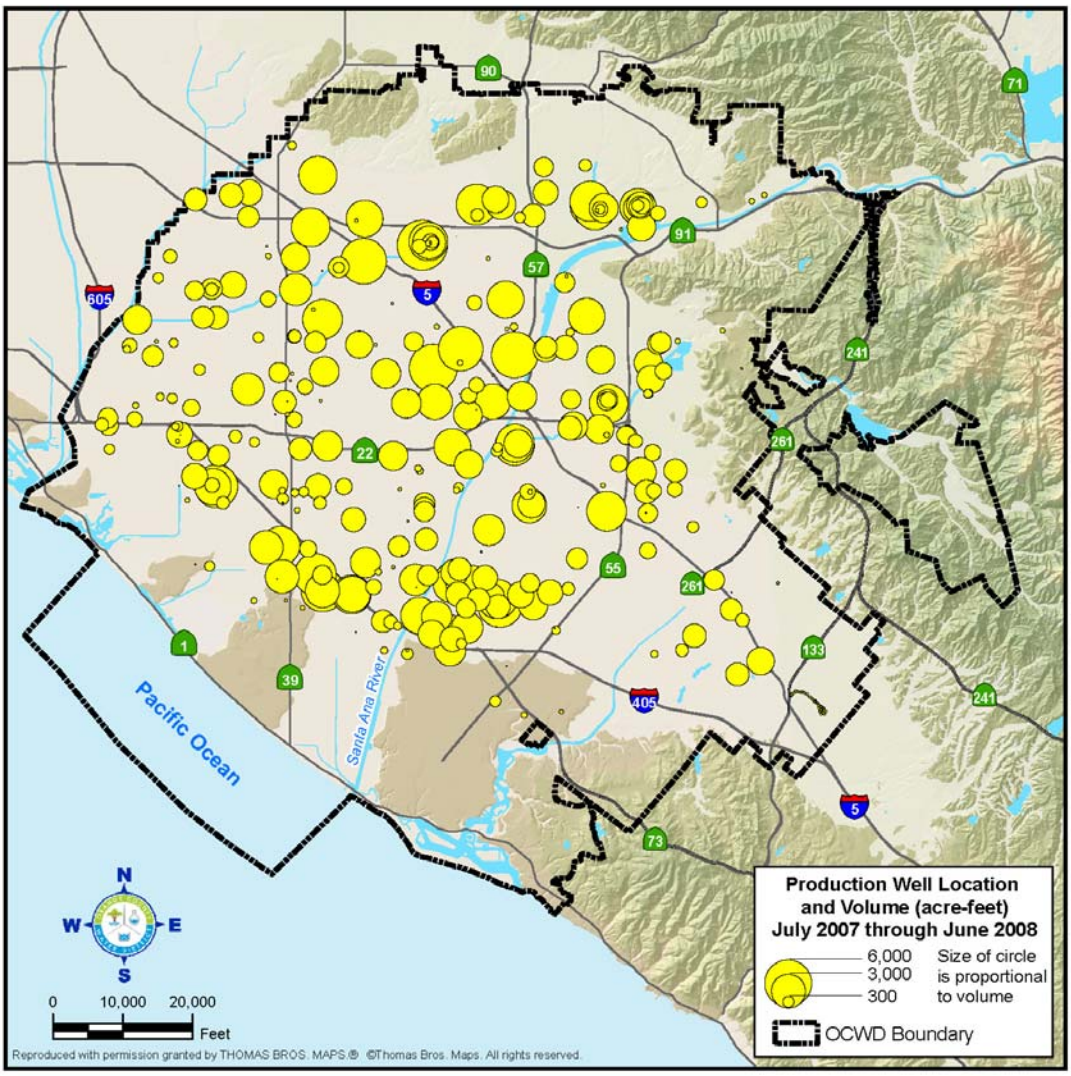
Unmeasured recharge is estimated at an average of 60,000 afy. This number is derived from estimating annual changes in groundwater storage by comparing groundwater elevation changes, after subtracting losses to Los Angeles County. Net incidental recharge is used to refer to the amount of incidental recharge after accounting for groundwater losses, such as outflow to Los Angeles County. This average unmeasured recharge was substantiated during calibration of the Basin Model and is also consistent

with the estimate of 58,000 afy reported by Hardt and Cordes (1971) as part of a U.S. Geological Survey (USGS) modeling study of the basin. Because unmeasured recharge is one of the least understood components of the basin's water budget, the error margin of staff's estimate for any given year is probably in the range of 10,000 to 20,000 af. Since the unmeasured recharge is well distributed throughout the basin, the physical significance (e.g., water level drawdown or mounding in any given area) of over- or underestimating the total recharge volume within this error margin is considered to be minor.

2.3.3 GROUNDWATER PRODUCTION

Groundwater production from the basin, as shown in Figure 2-4, occurs from approximately 450 active wells within the District, approximately 200 of which produce less than 25 afy.

FIGURE 2-4
DISTRIBUTION OF GROUNDWATER PRODUCTION



Groundwater production from approximately 200 large-capacity or large-system wells operated by the 21 largest water retail agencies accounted for an estimated 97 percent of the total production in 2006-07. Large-capacity wells are all metered, as required by the District Act, and monthly individual well production has been documented since 1988. Prior to 1988, per-well production data were recorded semi-annually.

Groundwater production is distributed uniformly throughout the majority of the basin with the exceptions of the Yorba Linda subbasin, the immediate coastal areas, and the foothill margins of the basin, where little to no production occurs. Increases in coastal production would lead to increased stress on the Talbert and Alamitos barriers, requiring additional barrier capacity. Inasmuch as it is technically and economically feasible, future increases in coastal groundwater demand should be addressed by wells constructed inland in areas of lower well density and higher aquifer transmissivity.

The distribution of existing wells and the siting of future wells depend on many different factors, including logistics, property boundaries, hydrogeology, and regulatory guidelines. Logistical considerations include property availability, city and other political boundaries, and proximity to other water facilities. Proximity to existing water transmission pipelines can be extremely important, given the cost of new reaches of pipeline. Hydrogeologic considerations for siting a well may include: thickness of permeable aquifer units, groundwater quality, drawdown interference from nearby wells, seasonal water level fluctuations, and potential impacts to the basin such as seawater intrusion.

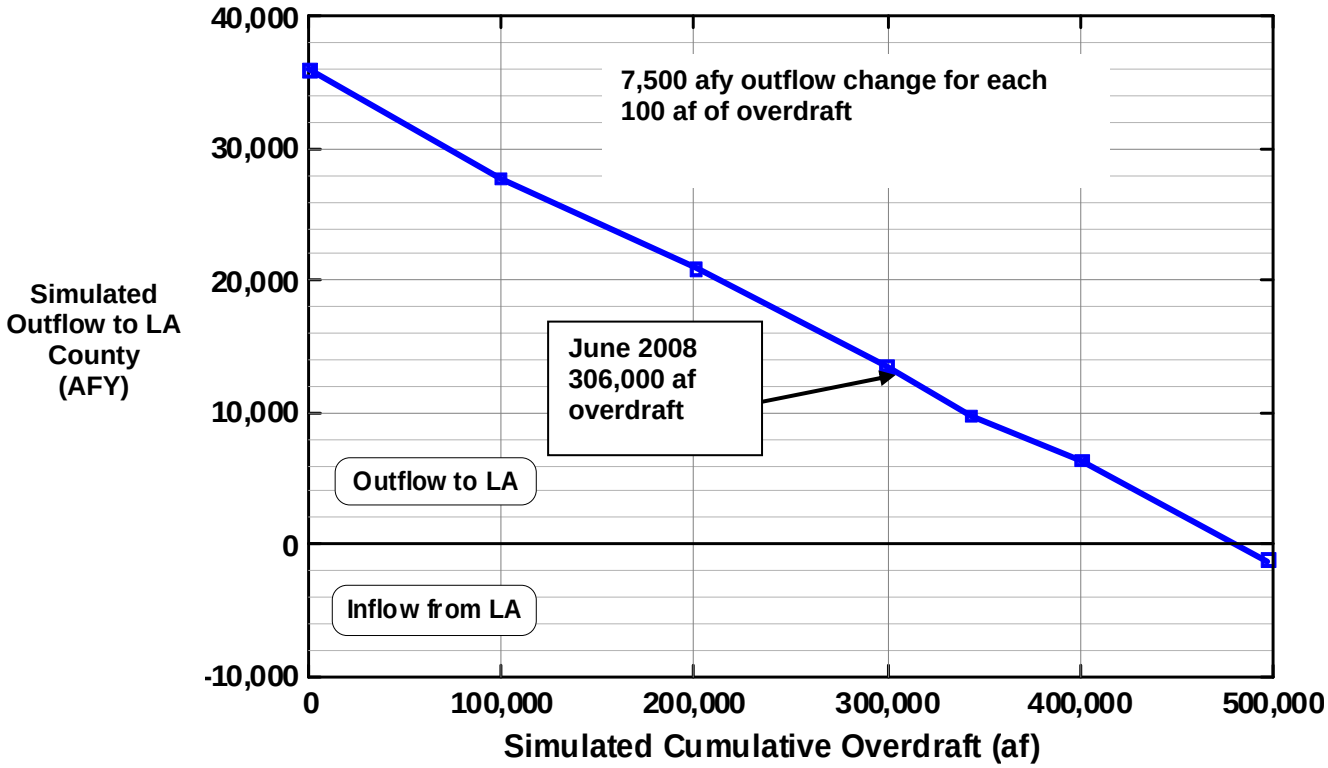
2.3.4 SUBSURFACE OUTFLOW

Groundwater outflow from the basin across the Los Angeles/Orange County line has been estimated to range from approximately 1,000 to 14,000 afy based on groundwater elevation gradients and aquifer transmissivity (DWR, 1967; McGillicuddy, 1989). The Water Replenishment District has also indicated underflow from Orange County to Los Angeles County within the aforementioned range. Underflow varies annually and seasonally depending upon hydrologic conditions on either side of the county line.

Modeling by OCWD indicated that, assuming groundwater elevations in the Central Basin remain constant; underflow to Los Angeles County increases approximately 7,500 afy for every 100,000 af of increased groundwater in storage in Orange County (see Figure 2-5).

With the exception of unknown amounts of semi-perched (near-surface) groundwater being intercepted and drained by submerged sewer trunk lines and unlined flood control channels along coastal portions of the basin, no other significant basin outflows are known to occur.

FIGURE 2-5
RELATIONSHIP BETWEEN BASIN STORAGE AND ESTIMATED OUTFLOW



2.4 GROUNDWATER ELEVATION AND STORAGE CALCULATION

OCWD estimates annual changes in the amount of groundwater stored in the basin using groundwater elevation measurements and aquifer storage coefficients for the three primary aquifer systems in the basin. This three-layer method involves measuring the water levels at the end of each water year at nearly every production and monitoring well in the basin. Water level measurements are contoured, as shown in Figure 2-6, and then digitized into the Geographic Information System (GIS). The GIS is then used to subtract the previous year's water level maps from the current water year, resulting in a water level change contour map for each of the three aquifer layers. Figure 2-7 shows the water level change for the principal aquifer (layer 2). For each of the three aquifer layers, the GIS is then used to multiply these water level changes by a grid of aquifer storage coefficients from OCWD's calibrated basin groundwater model. This results in a storage change volume for each of the three aquifer layers, which are totaled to provide a net annual storage change for the basin.

A more detailed description of the three-layer methodology is presented in OCWD's *Report on Evaluation of Orange County Groundwater Basin Storage and Operational Strategy* (February 2007).

FIGURE 2-6
JUNE 2008 WATER LEVELS

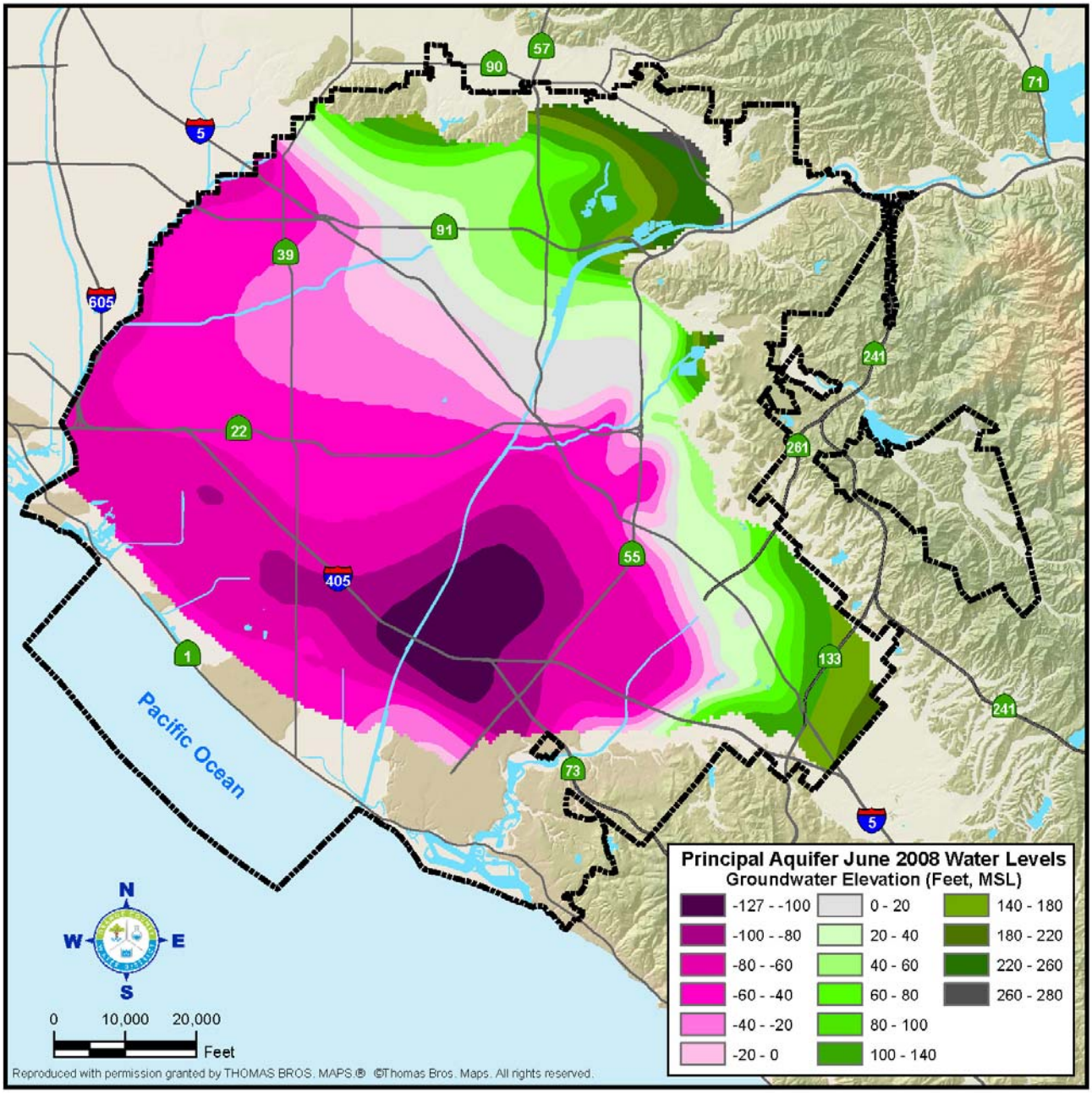
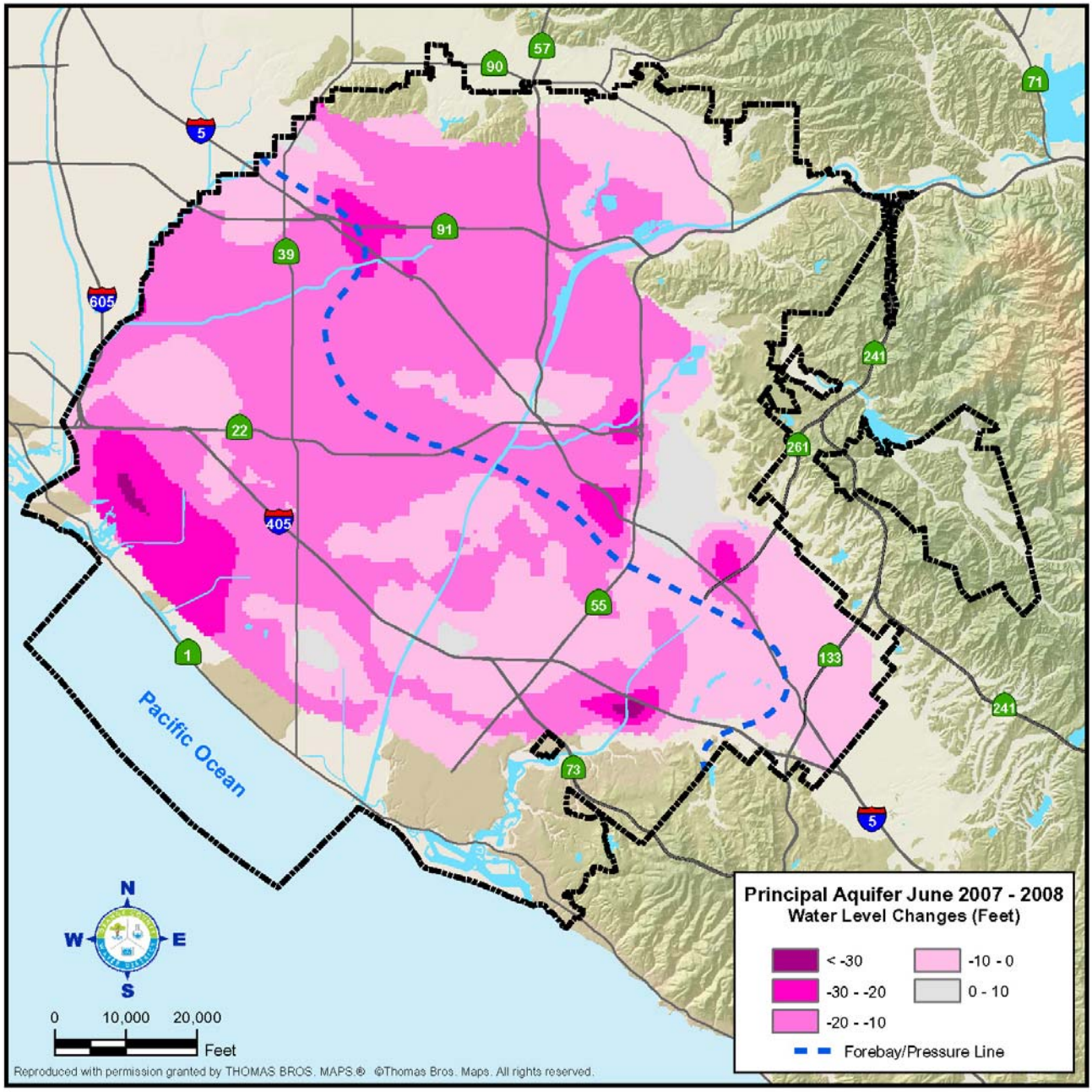


FIGURE 2-7
WATER LEVEL CHANGES

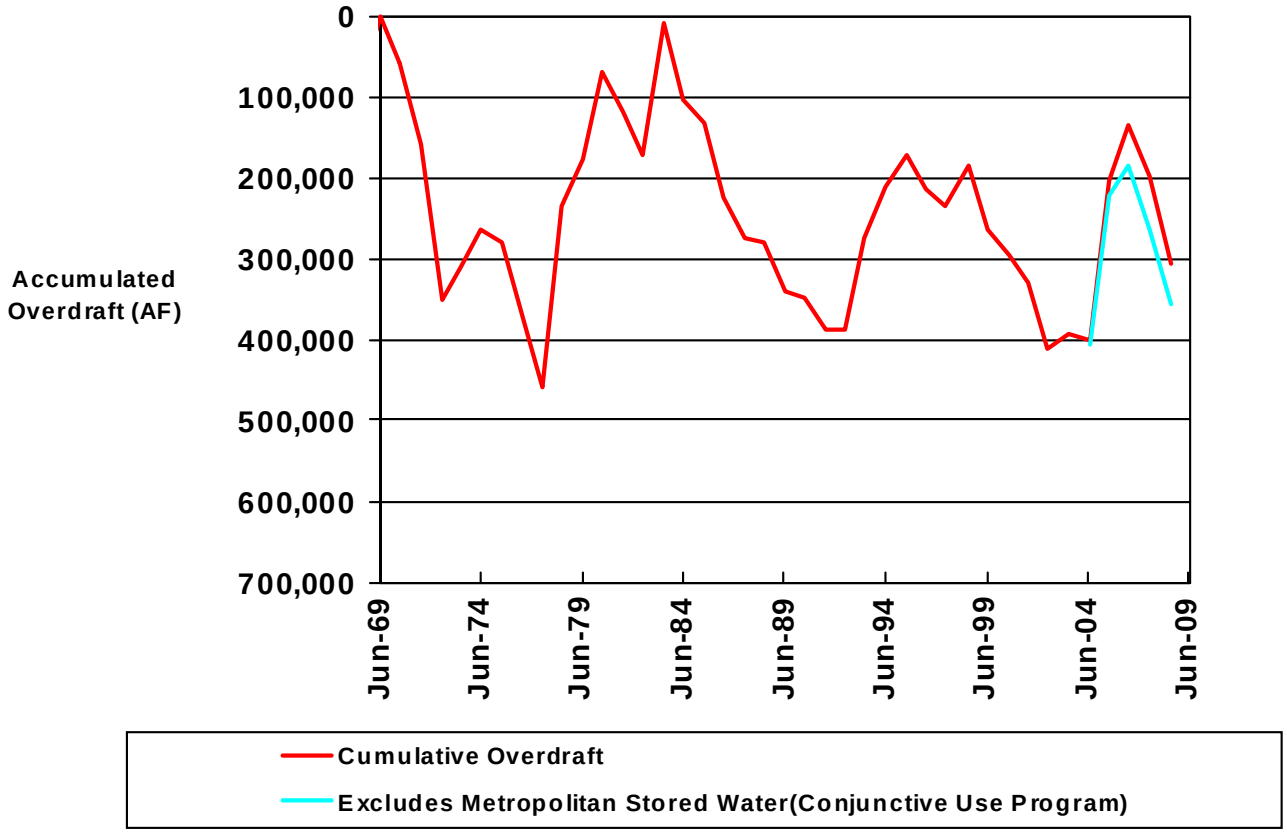


2.5 ACCUMULATED OVERDRAFT CALCULATION

OCWD estimates that the basin can be operated on a short-term basis with a maximum accumulated overdraft (storage reduction from full condition) of approximately 500,000 af without causing irreversible seawater intrusion and land subsidence.

The estimated maximum historical accumulated basin overdraft of 500,000 to 700,000 af occurred in 1956-57 (DWR, 1967; OCWD, 2003). Until 2007, water level elevations in November 1969 were used as the baseline to represent near-full conditions. The net decrease in storage from 1969 conditions represented the accumulated overdraft. Since 2004, OCWD has participated in Metropolitan's Conjunctive Use Program. This program allows for the storage of Metropolitan water in the Orange County groundwater basin. Figure 2-8 illustrates the basin accumulated overdraft since 1962. The accumulated overdraft including the Metropolitan Conjunctive Use water is shown in red. The blue line indicates the basin accumulated overdraft calculated without Metropolitan's stored water.

FIGURE 2-8
ACCUMULATED BASIN OVERDRAFT



2.5.1 DEVELOPMENT OF NEW METHODOLOGY

The traditional full-basin benchmark of 1969 was revised in 2007. A new methodology was developed to calculate accumulated overdraft and storage change. The need for this new methodology was driven by the record-setting wet year of 2004-05, in which an unprecedented storage increase of 170,000 af was estimated by OCWD staff.

During that year, water levels throughout the basin rose approximately 30 feet overall, approaching a near-full condition. Analysis showed that groundwater in storage in November 2005 was only 40,000 af less than the full basin 1969 benchmark. However, the traditional method of cumulatively adding the annual storage change each year to the previous year's accumulated overdraft produced an accumulated overdraft of approximately 190,000 acre-feet for November 2005. The discrepancy of 150,000 af in the two different calculations indicated that the current condition could not be properly rectified back to the 1969 benchmark. This brought to light three important discoveries:

- The traditional storage change calculation contained considerable uncertainty that when cumulatively added over tens of years, led to a large discrepancy in the accumulated overdraft relative to 1969.
- Water level conditions in 1969 no longer represent a full basin, particularly because of changes in pumping and recharge conditions.
- A more accurate storage change calculation should be based on water level changes and storage coefficients for each of the three major aquifer systems.

In February 2007, the District adopted an updated approach to defining the full basin condition and calculating storage changes. This updated approach includes:

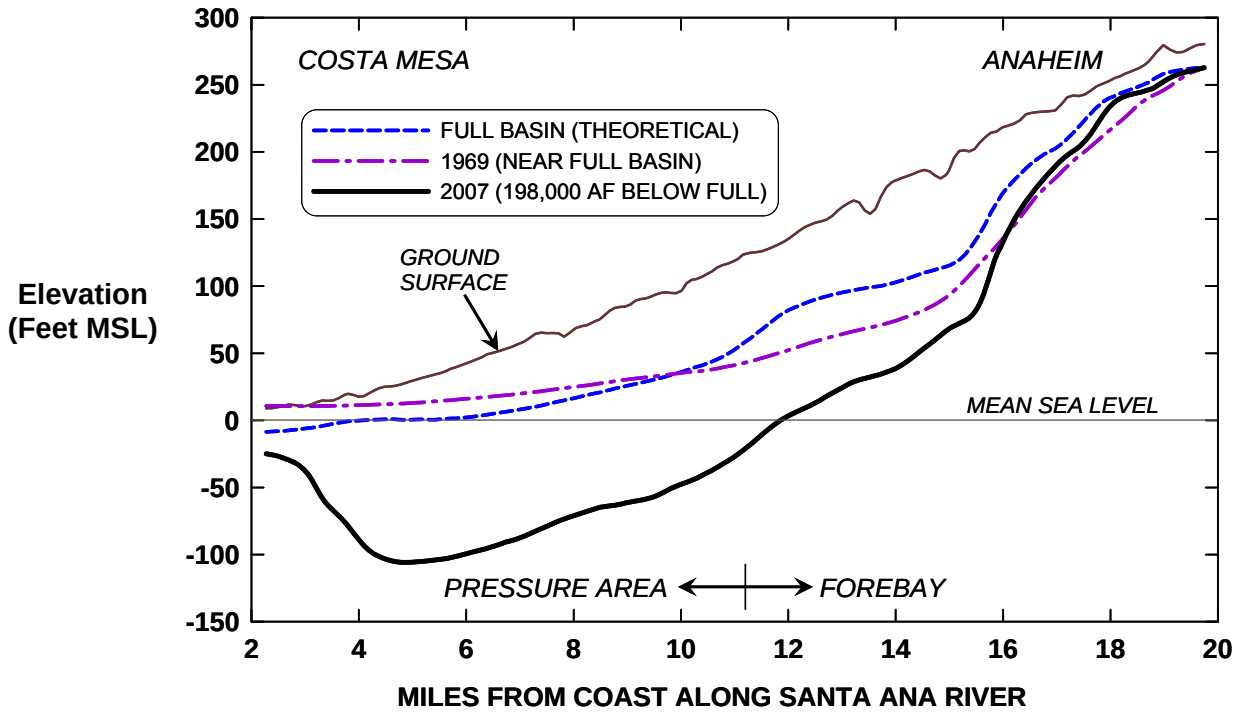
- A new full-basin groundwater level based on the following prescribed conditions:
  - Observed historical high water levels
  - Present-day pumping and recharge conditions
  - Protective of seawater intrusion
  - Minimal potential for mounding at or near recharge basins
- Calculation of the amount of groundwater in storage in each of the three major aquifer systems.

A more detailed description of this new methodology is presented in OCWD's *Report on Evaluation of Orange County Groundwater Basin Storage and Operational Strategy* (February 2007), which is included as Appendix D.

2.6 ELEVATION TRENDS

Groundwater elevation profiles for the principal aquifer, generally following the Santa Ana River from Costa Mesa to the Anaheim Forebay area, are shown in Figure 2-9. The groundwater elevation profiles represent the newly-calculated full basin condition, 1969 conditions (formerly considered full), and 2007 conditions. A comparison of these profiles shows that groundwater elevations in the Forebay recharge area are relatively close while elevations in 2007 are significantly lower in the central and coastal portions of the basin than the full or 1969 conditions.

FIGURE 2-9
PRINCIPAL AQUIFER HISTORICAL GROUNDWATER ELEVATION PROFILES



The lowering of coastal area groundwater levels relative to groundwater levels further inland in the Forebay translates into a steeper hydraulic gradient, which drives greater flow from the Forebay to the coastal areas. However, the lowering of coastal water levels also increases seawater intrusion potential.

Figure 2-10 presents average groundwater elevations for the principal aquifer in the Forebay, coastal areas, and the total basin on November 1 of each year, when groundwater levels are somewhat intermediate between the late summer low and late winter high. Average values were calculated using a 1,000-foot square grid and the groundwater elevation contour map prepared each year. Groundwater elevations were estimated at each grid point using the groundwater elevation contours, and the average values were calculated for each of the three areas.

A comparison of the groundwater level trends in Figure 2-10 to the changes in accumulated overdraft in Figure 2-8 provides insights into the basin's response during filling and emptying cycles. From November 2003 to November 2005, the basin's accumulated overdraft reduced 220,000 af due to the near-record high precipitation in water year 2004-05. During this period of refill, average groundwater levels in the coastal area increased approximately 20 feet, while groundwater levels in the Forebay increased approximately 40 feet. Between November 2005 and November 2007, basin accumulated overdraft increased approximately 100,000 af as groundwater withdrawals exceeded recharge due to several factors, including near-record low precipitation. Average groundwater levels during this period fell by 40 feet in the Forebay and coastal areas.

FIGURE 2-10
AVERAGE PRINCIPAL AQUIFER GROUNDWATER ELEVATIONS FOR THE FOREBAY, TOTAL BASIN, AND COASTAL AREA

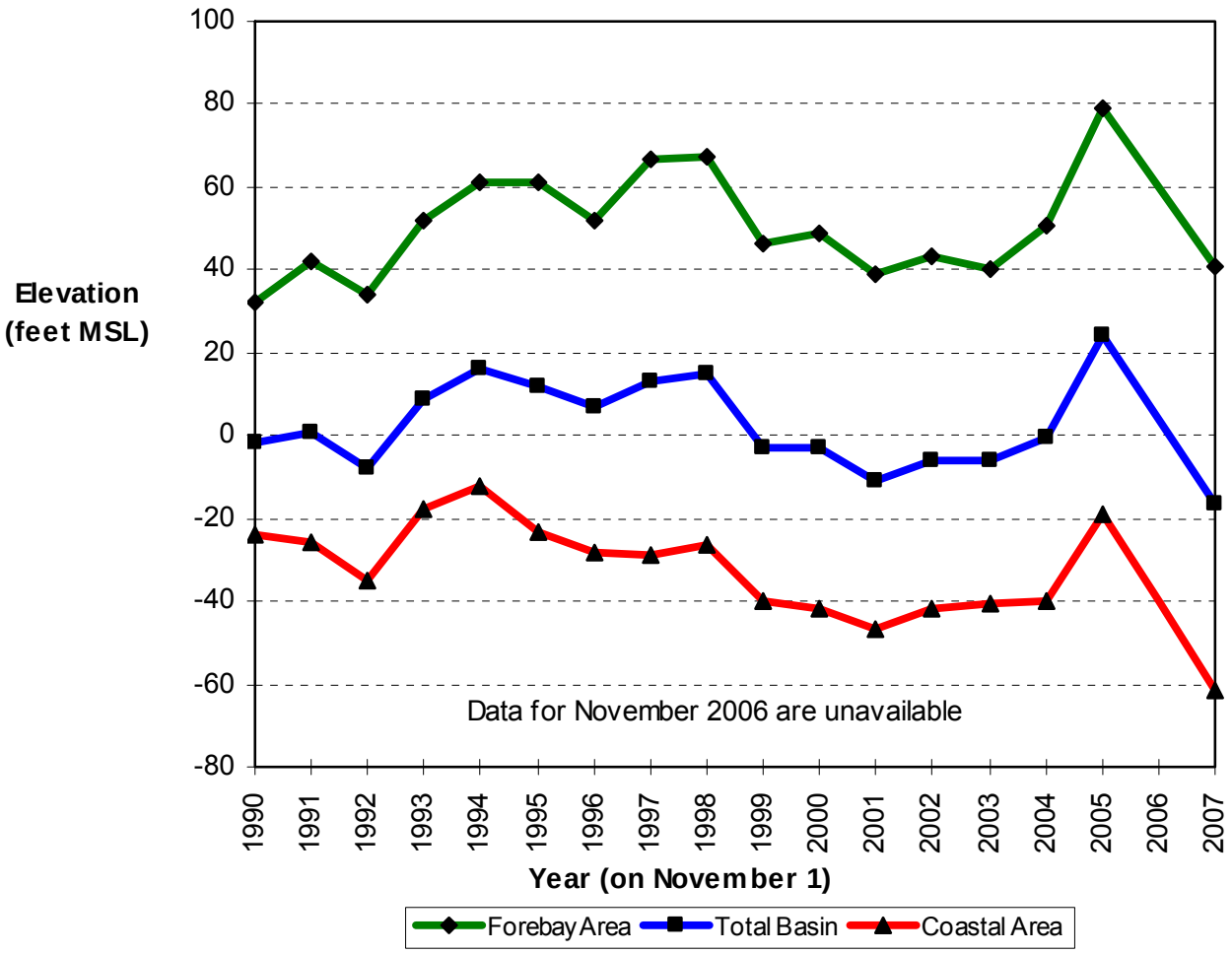


Figure 2-11 shows the locations of four wells, A-27, SA-21, SAR-1, and OCWD-CTG1, with long-term groundwater level data. Figure 2-12 presents water level hydrographs and locations of wells A-27 and SA-21, representing historical conditions in the Forebay and Pressure area, respectively. The hydrograph data for well A-27 near Anaheim Lake date back to 1932 and indicate that the historic low water level in this area occurred in 1951-52. The subsequent replenishment of Colorado River water essentially refilled the basin by 1965. Water levels in this well reached an historic high in 1994 and have generally remained high as recharge has been nearly continuous at Anaheim Lake since the late 1950s.

The hydrograph for well SA-21 indicates that water levels in this area have decreased since 1970. In addition, the magnitude of the seasonal water level fluctuations has approximately doubled from pre-1990 to the present. The increased water level fluctuations are due to a combination seasonal water demand-driven pumping and participation in the Metropolitan Short-Term Seasonal Storage Program by local

Producers (Boyle Engineering and OCWD, 1997), which encouraged increased pumping from the groundwater basin during summer months when Metropolitan was experiencing high demand for imported water. Although this program did not increase the amount of pumping from the basin on an annual basis, it did result in greater water level declines during the summer.

FIGURE 2-11
LOCATION OF LONG-TERM GROUNDWATER ELEVATION HYDROGRAPH

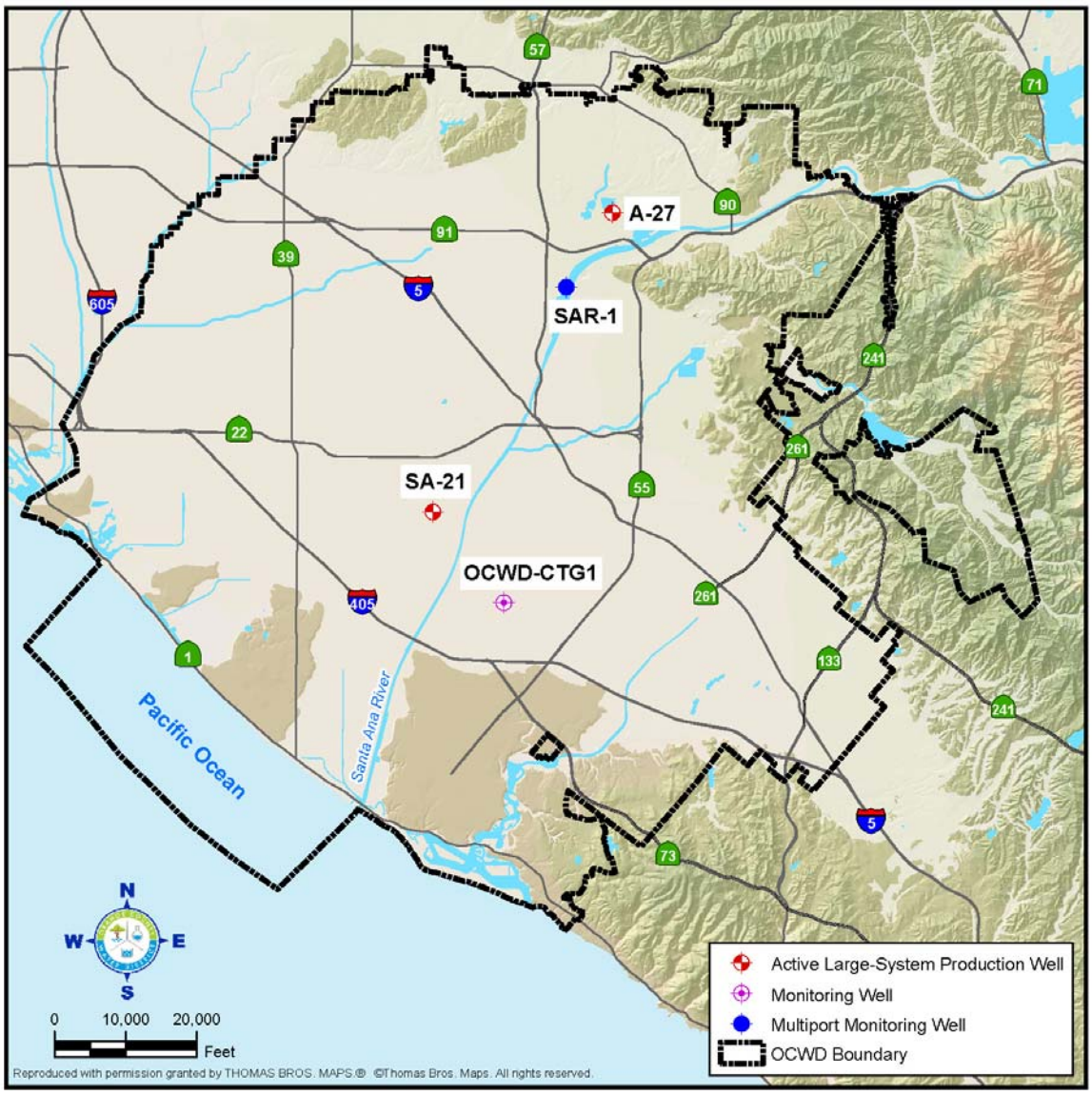
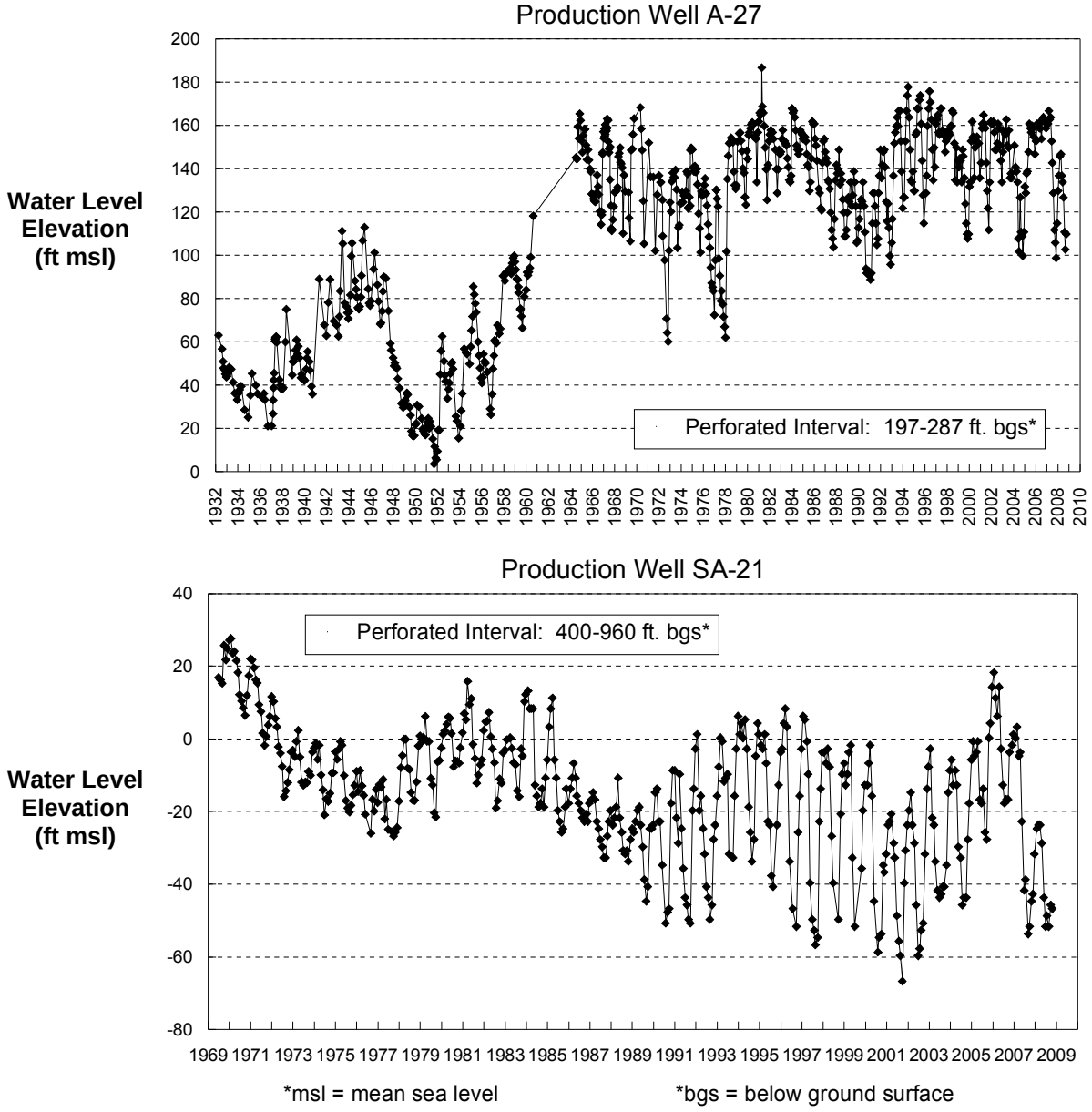


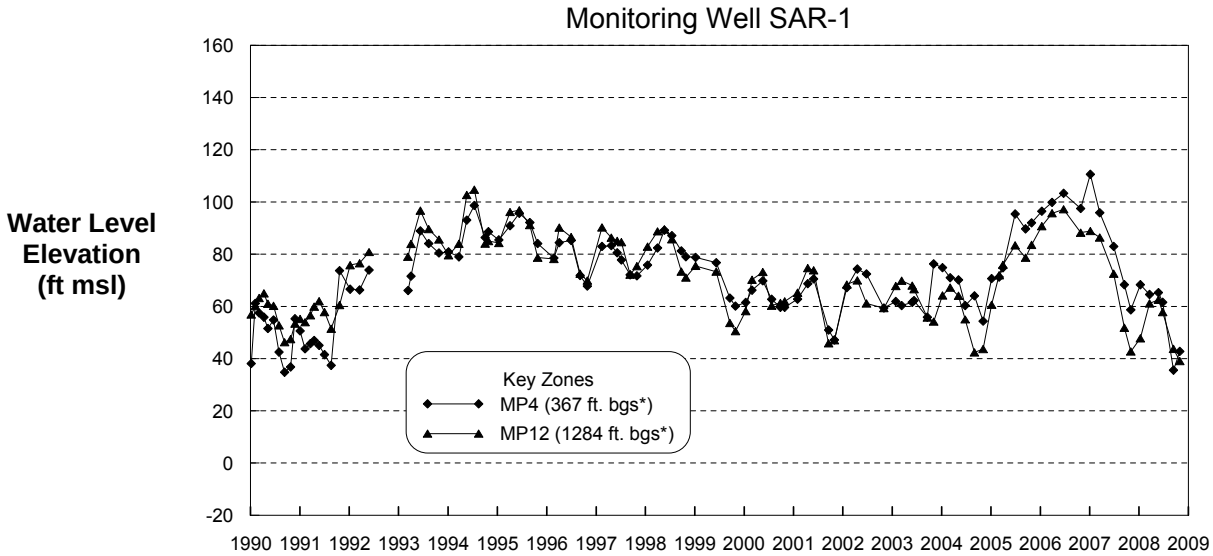
FIGURE 2-12
WATER LEVEL HYDROGRAPHS OF WELLS A-27 AND SA-21

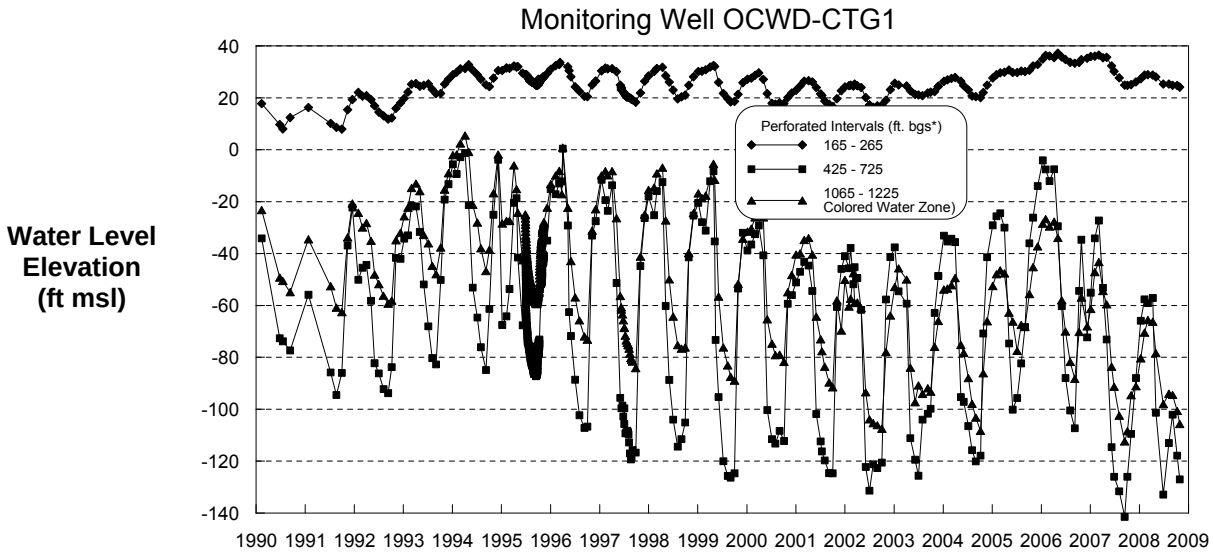


*msl = mean sea level *bgs = below ground surface

Figure 2-13 presents water level hydrographs and locations of two OCWD multi-depth monitoring wells, SAR-1 and OCWD-CTG1, showing the relationship between water level elevations in aquifer zones at different depths. The hydrograph of well SAR-1 in the Forebay exhibits a similarity in water levels between shallow and deep aquifers, which indicates the high degree of hydraulic interconnection between aquifers characteristic of much of the Forebay.

FIGURE 2-13
WATER LEVEL HYDROGRAPHS OF WELLS SAR-1 AND OCWD-CTG1





*msl = mean sea level *bgs = below ground surface

The hydrograph of well OCWD-CTG1 is typical of the Pressure Area in that a large water level distinction is observed between shallow and deep aquifers, indicating the effects of a clay/silt layer that restricts vertical groundwater flow. Water levels in the deepest aquifer zone at well OCWD-CTG1 have higher elevations than overlying aquifers, in part, because few wells directly produce water from these zones, primarily due to their associated colored water.

2.7 LAND SUBSIDENCE

Subsidence of the ground surface has been associated with groundwater withdrawal in many regions of the world. In the case of thick sedimentary groundwater basins comprised of alternating "confined" or "pressure" aquifers (permeable sands and gravels) and aquitards (less permeable silts and clays), the extraction of groundwater reduces the fluid pressure of the saturated pore spaces within the buried sediments. The pressure reduction in the deeper sediments allows the weight of the overlying sediments to compact the deeper sediments, particularly the clays and silts. If groundwater withdrawals cause water level drawdowns to be sustained for several years or more, the incremental amount of sediment compaction can eventually manifest itself in a measurable lowering of the land surface (USGS, 1999).

OCWD commissioned a study by the DWR (1980) to evaluate the potential for land subsidence in the basin. Because the study was limited in scope, its findings were deemed preliminary pending further investigation. Nevertheless, the study cited survey data from the Orange County Surveyor that indicated that the land surface in the city of Santa Ana declined a maximum of 0.84 inch/year from 1956 to 1961. Surveys during the period 1970 to 1976 indicated maximum land surface declines of 0.24 inch/year in Santa Ana. Key findings of the study included the following:

- Subsidence in the City of Santa Ana is apparently related to the removal of groundwater. However, it is not possible to directly correlate observed subsidence and historic water-level declines.
- Subsidence in the vicinity of the City of Huntington Beach can be attributed to the removal of oil.
- Most of the compaction takes place in the fine-grained sediments.
- Water squeezed out of the compacted fine-grained sediments, known as "water of compaction," results in a permanent loss of storage in fine-grained sediments.

Land surface changes (rising and lowering) of similar magnitude to those noted by DWR were reported by Bawden (Bawden et al, 2001) while reviewing satellite radar images for a seismic assessment of Southern California. Bawden reported seasonal land surface changes of up to 4.3 inches (total seasonal amplitude from high to low) in the Los Angeles-Orange County area and a net decline of approximately 0.5 inch/year near Santa Ana over the period 1993 to 1999, which coincides with a period of net withdrawal of groundwater from the basin. Despite the indications of land subsidence to some degree in portions of Orange County, there has been no indication that the suggested land surface changes have caused, or are likely to cause, any structural damage in the area. By maintaining groundwater levels and basin storage within its

historical operating range, the potential for problematic land subsidence is reduced. Conversely, land subsidence could become a problem if the basin was overdrafted beyond the historical operating range.

Groundwater withdrawals are regulated within the basin operating range, which is explained in detail in Section 6.5. In the event that land subsidence becomes a problem in a localized area, OCWD will work with local officials to investigate and remediate the problem.

2.8 GROUNDWATER MODEL DESCRIPTION

In general, a groundwater flow model contains two major components: the mathematical model and the conceptual model. The mathematical model is the computer program used to solve the complex system of equations that govern the flow of groundwater. The conceptual model is the hydrogeologic framework of the area being modeled, obtained by gathering, analyzing, interpreting, and finally integrating all the geologic and hydrologic data for a given area into a conceptual understanding of how the flow system looks and behaves.

For a properly-constructed model, the mathematical model needs to be appropriate for the level of detail inherent in the conceptual model. For a mathematical model solved by numerical methods, the modeled area must be divided into a mesh of grid cells – the smaller the grid cells, generally the more accurate the computations – assuming the hydrogeology can be reasonably-defined at the grid cell level of detail. Based on all the input data, the model calculates a water level elevation and fluxes for each and every grid cell of the modeled area at a given point in time.

OCWD's basin model encompasses the entire basin and extends approximately three miles into the Central Basin in Los Angeles County to provide for more accurate model results than if the model boundary stopped at the county line (see Figure 2-14). As noted previously in this chapter, the county line is not a hydrogeologic boundary, i.e., groundwater freely flows through aquifers that have been correlated across the county line.

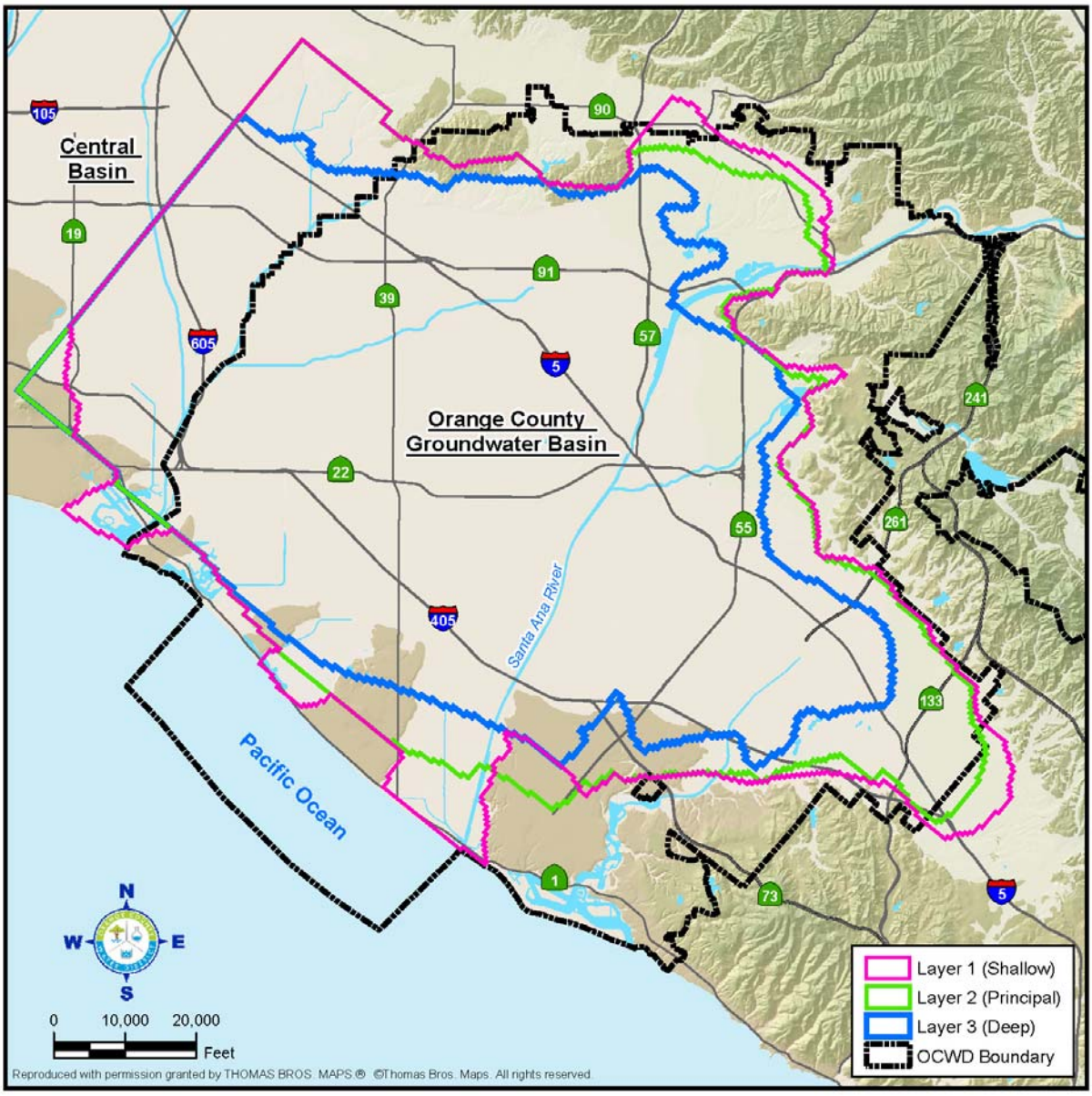
Coverage of the modeled area is accomplished with grid cells having horizontal dimensions of 500 feet by 500 feet (approximately 5.7 acres) and vertical dimensions ranging from approximately 50 to 1,800 feet, depending on the thickness of each model layer at that grid cell location. Basin aquifers and aquitards were grouped into three composite model layers thought sufficient to describe the three distinguishable flow systems referred to as the shallow, principal, and deep aquifer systems. The three model layers comprise a network of over 90,000 grid cells.

The widely-accepted computer program, "MODFLOW," developed by the USGS, was used as the base modeling code for the mathematical model (McDonald and Harbaugh, 1988). Analogous to an off-the-shelf spreadsheet program needing data to be functional, MODFLOW requires vast amounts of input data to define the hydrogeologic conditions in the conceptual model. The types of information that must be input in digital format (data files) for each grid cell in each model layer include the following:

- Aquifer top and bottom elevations

- Aquifer lateral boundary conditions (ocean, faults, mountains)
- Aquifer hydraulic conductivity and storage coefficient/specific yield
- Initial groundwater surface elevation
- Natural and artificial recharge rates (runoff, precipitation, percolation, injection)
- Groundwater production rates for approximately 200 large system and 200 small system wells

FIGURE 2-14
BASIN MODEL EXTENT

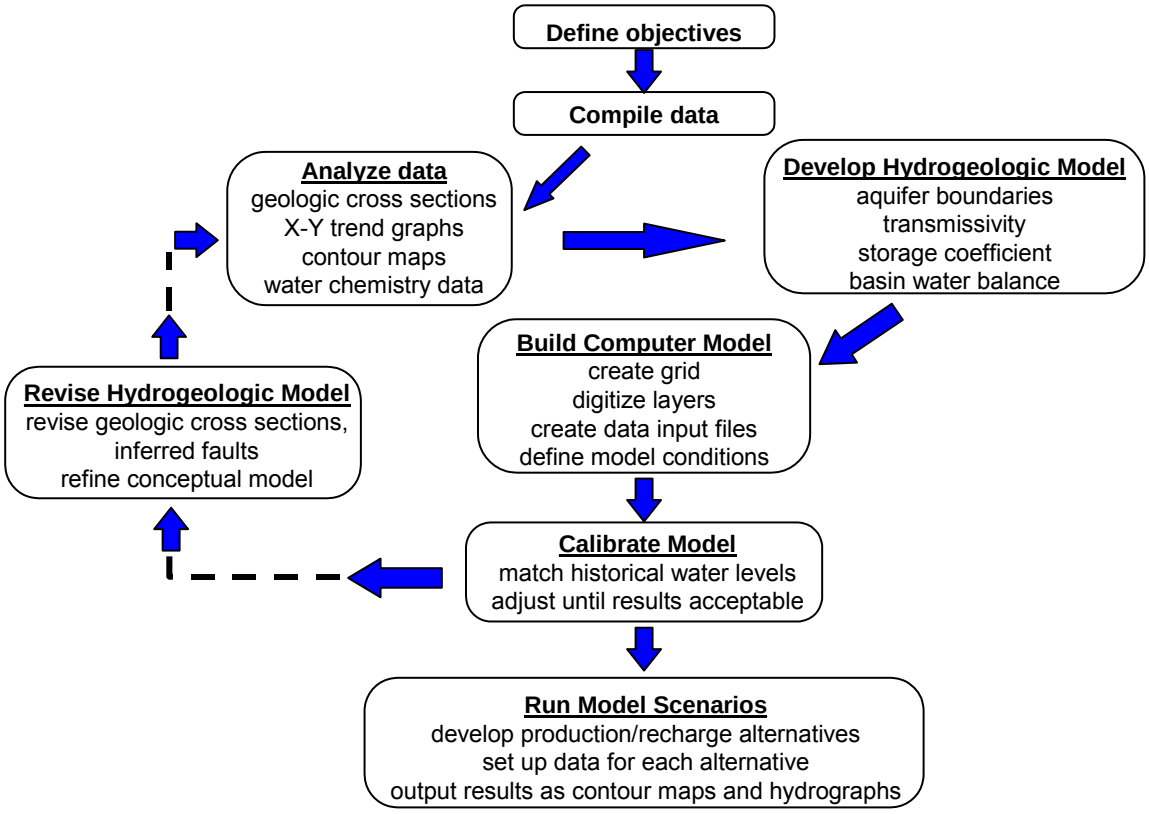


These data originate from hand-drawn contour maps, spreadsheets, and the Water Resources Management System (WRMS) historical database. Because MODFLOW requires the input data files in a specific format, staff developed a customized database and GIS program to automate data compilation and formatting functions. These data pre-processing tasks form one of the key activities in the model development process.

Before a groundwater model can be reliably used as a predictive tool for simulating future conditions, the model must be calibrated to reach an acceptable match between simulated and actual observed conditions. The basin model was first calibrated to steady-state conditions to numerically stabilize the simulations, to make rough adjustments to the water budget terms, and to generally match regional groundwater flow patterns. Also, the steady-state calibration helped to determine the sensitivity of simulated groundwater levels to changes in incidental recharge and aquifer parameters such as hydraulic conductivity. Steady-state calibration of the basin model is documented in more detail in the *OCWD Master Plan Report* (OCWD, 1999).

Typical transient model output consists of water level elevations at each grid cell that can be plotted as a contour map for one point in time or as a time-series graph at a single location. Post-processing of model results into usable graphics is performed using a combination of semi-automated GIS and database program applications. Figure 2-15 presents a simplified schematic of the modeling process.

FIGURE 2-15
MODEL DEVELOPMENT FLOWCHART



Model construction, calibration, and operation were built upon 12 years of effort by OCWD staff to collect, compile, digitize, and interpret hundreds of borehole geologic and geophysical logs, water level hydrographs, and water quality analyses. The process was composed of ten main tasks comprising over 120 subtasks. The major tasks are summarized below:

1. Finalize conceptual hydrogeologic model layers and program GIS/database applications to create properly formatted MODFLOW input data files. Over 40 geologic cross sections were used to form the basis of the vertical and lateral aquifer boundaries.

2. Define model layer boundaries. The top and bottom elevations of the three aquifer system layers and intervening aquitards were hand-contoured, digitized, and overlain on the model grid to populate the model input arrays with a top and bottom elevation for each layer at every grid cell location. Model layer thickness values were then calculated by using the GIS.

3. Develop model layer hydraulic conductivity (K) grids. Estimates of K for each layer were based on (in order of importance): available aquifer test data, well specific capacity data, and lithologic data. In the absence of reliable aquifer test or specific capacity data for areas in Layers 1 and 3, lithology-based K estimates were calculated by assigning literature values of K to each lithology type (e.g., sand, gravel, clay) within a model layer and then calculating an effective K value for the entire layer at that well location. Layer 2 had the most available aquifer test and specific capacity data. Therefore, a Layer 2 transmissivity contour map was prepared and digitized, and the GIS was then used to calculate a K surface by dividing the transmissivity grid by the aquifer thickness grid. Initial values of K were adjusted during model calibration to achieve a better match of model results with known groundwater elevations.

4. Develop layer production factors for active production wells simulated in the model. Many production wells had long screened intervals that spanned at least two of the three model layers. Therefore, groundwater production for each of these wells had to be divided among each layer screened by use of layer production factors. These factors were calculated using both the relative length of screen within each model layer and the hydraulic conductivity of each layer. Well production was then multiplied by the layer factors for each individual well. For example, if a well had a screened interval equally divided across Layers 1 and 2, but the hydraulic conductivity of Layer 1 was twice that of Layer 2, then the calculated Layer 1 and 2 production factors for that well would have been one-third and two-thirds, respectively, such that when multiplied by the total production for this well, the production assigned to Layer 1 would have been twice that of Layer 2. For the current three-layer model, approximately 25 percent of the production wells in the model were screened across more than one model layer. In this context, further vertical refinement of the model (more model layers) may better represent

the aquifer architecture in certain areas but may also increase the uncertainty and potential error involved in the amount of production assigned to each model layer.

5. Develop basin model water budget input parameters, including groundwater production, artificial recharge, and unmeasured recharge. Groundwater production and artificial recharge volumes were applied to grid cells in which production wells or recharge facilities were located. The most uncertain component of the water budget – unmeasured or incidental recharge – was applied to the model as an average monthly volume based on estimates calculated annually for the OCWD *Engineer's Report*. Unmeasured recharge was distributed to cells throughout the model, but was mostly applied to cells along margins of the basin at the base of the hills and mountains. The underflow component of the incidental recharge represents the amount of groundwater flowing into and out of the model along open boundaries. Prescribed groundwater elevations were assigned to open boundaries along the northwest model boundary in Los Angeles County; the ocean at the Alamitos, Bolsa, and Talbert Gaps; the mouth of the Santa Ana Canyon; and the mouth of Santiago Creek Canyon. Groundwater elevations for the boundaries other than the ocean boundaries were based on historical groundwater elevation data from nearby wells. The model automatically calculated the dynamic flow across these open boundaries as part of the overall water budget.

6. Develop model layer storage coefficients. Storage coefficient values for portions of model layers representing confined aquifer conditions were prepared based on available aquifer test data and were adjusted within reasonable limits based on calibration results.

7. Develop vertical leakance parameters between model layers. Vertical groundwater flow between aquifer systems in the basin is generally not directly measured, yet it is one of the critically-important factors in the model's ability to represent actual basin hydraulic processes. Using geologic cross-sections and depth-specific water level and water quality data from the OCWD multi-depth monitoring well network, staff identified areas where vertical groundwater flow between the modeled aquifer systems is either likely to occur or be significantly impeded, depending on the relative abundance and continuity of lower-permeability aquitards between model layers. During model calibration, the initial parameter estimates for vertical leakance were adjusted to achieve closer matches to known vertical groundwater gradients.

8. Develop groundwater contour maps for each model layer to be used for starting conditions and for visual comparison of water level patterns during calibration. Staff used observed water level data from multi-depth and other wells to prepare contour maps of each layer for November 1990 as a starting point for the calibration period. Care was taken to use wells screened within the appropriate vertical interval representing each model

layer. The hand-drawn contour maps were then digitized and used as model input to represent starting conditions.

9. Perform transient calibration runs. The nine-year period of November 1990 to November 1999 was selected for transient calibration, as it represented the period corresponding to the most detailed set of groundwater elevation, production, and recharge data. The transient calibration process and results are described in Section 2.8.1.

10. Perform various basin production and recharge scenarios using the calibrated model. Criteria for pumping and recharge, including facility locations and quantities, were developed for each scenario and input for each model run.

2.8.1 MODEL CALIBRATION

Calibration of the transient basin model involved a series of simulations of the period 1990 to 1999, using monthly flow and water level data. The time period selected for calibration represents a period during which basic data required for monthly transient calibration were essentially complete (compared to pre-1990 historical records). The calibration period spans at least one "wet/dry" rainfall cycle. Monthly water level data from almost 250 target locations were used to determine if the simulated water levels adequately matched observed water levels. As shown in Figure 2-16, the calibration target points were densely distributed throughout the basin and also covered all three model layers.

After each model run, a hydrograph of observed versus simulated water levels was created and reviewed for each calibration target point. In addition, a groundwater elevation contour map for each layer was also generated from the simulated data. The simulated groundwater contours for all three layers were compared to interpreted contours of observed data (November 1997) to assess closeness of fit and to qualitatively evaluate whether the simulated gradients and overall flow patterns were consistent with the conceptual hydrogeologic model. November 1997 was chosen for the observed versus simulated contour map comparison since these hand-drawn contour maps had already been created for the prior steady state calibration step. Although November 1997 observed data were contoured for all three layers, the contour maps for Layers 1 and 3 were somewhat more generalized than for Layer 2 due to a lower density of data points (wells) in these two layers.

Depending on the results of each calibration run, model input parameters were adjusted, including hydraulic conductivity, storage coefficient, boundary conditions, and recharge distribution. Time-varying head boundaries along the Orange/Los Angeles County line were found to be extremely useful in obtaining a close fit with observed historical water levels in the northwestern portion of the model. Fifty calibration runs were required to reach an acceptable level of calibration in which model-generated water levels were within reasonable limits of observed water level elevations during the calibration period. Figures 2-17 through 2-19 show examples of hydrographs of observed versus simulated water levels for three wells used as calibration targets.

FIGURE 2-16
BASIN MODEL CALIBRATION WELLS

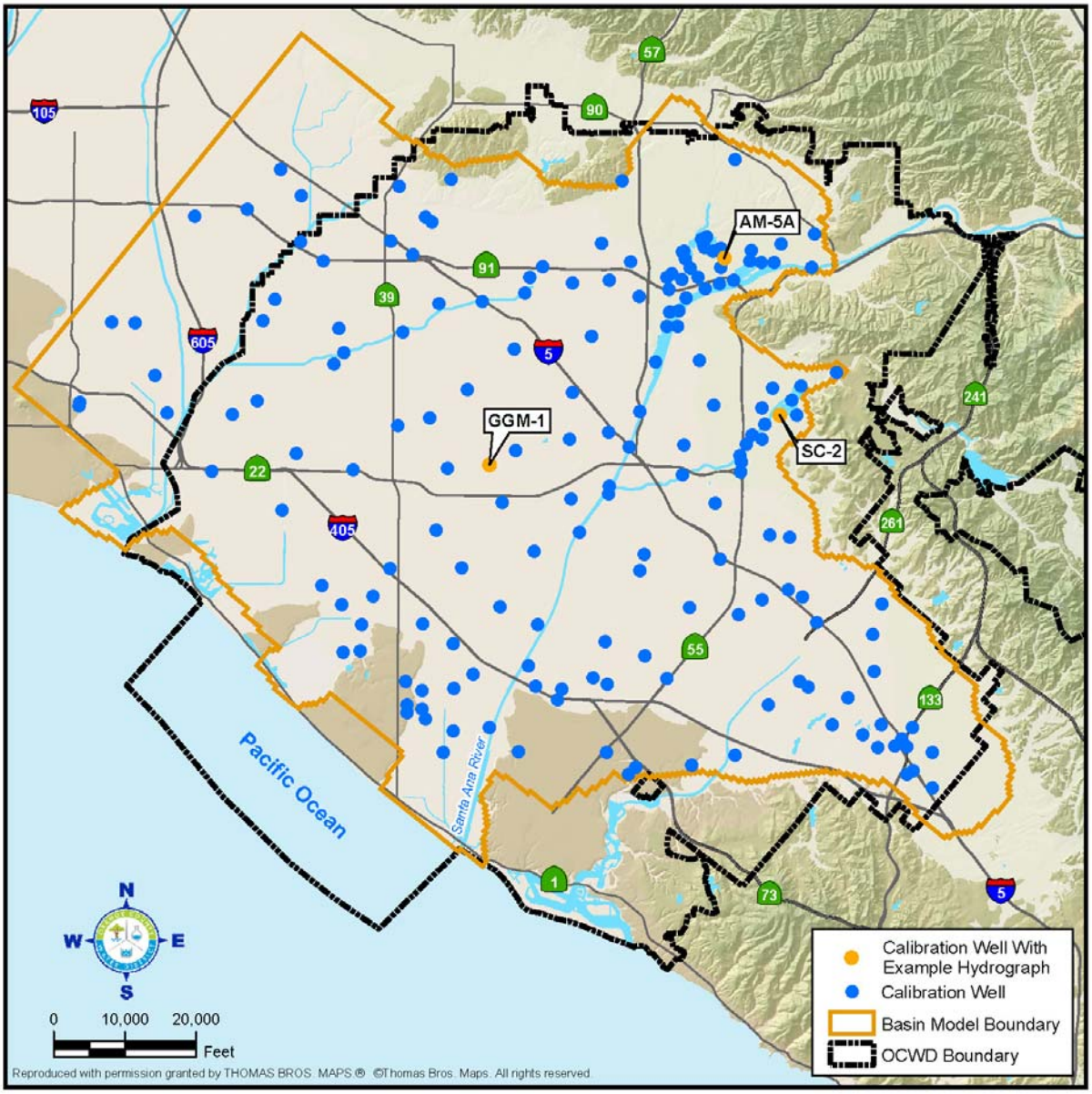


Figure 2-17
CALIBRATION HYDROGRAPH FOR MONITORING WELL AM-5A
(Model Layer 1 -- Anaheim Forebay)

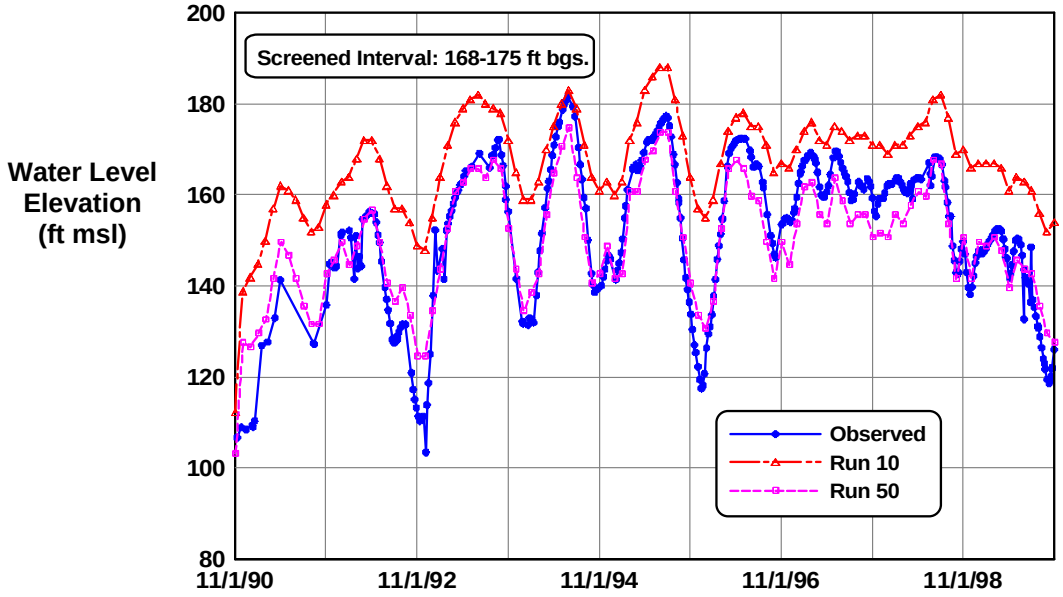


FIGURE 2-18
CALIBRATION HYDROGRAPH FOR MONITORING WELL SC-2
(Model Layer 2 -- Santiago Pit Area)

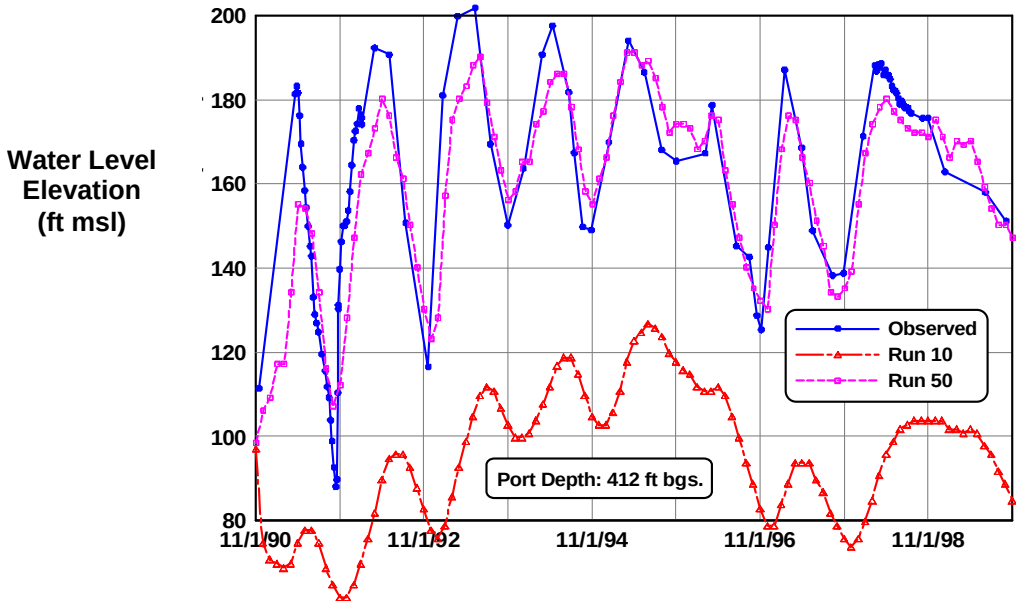
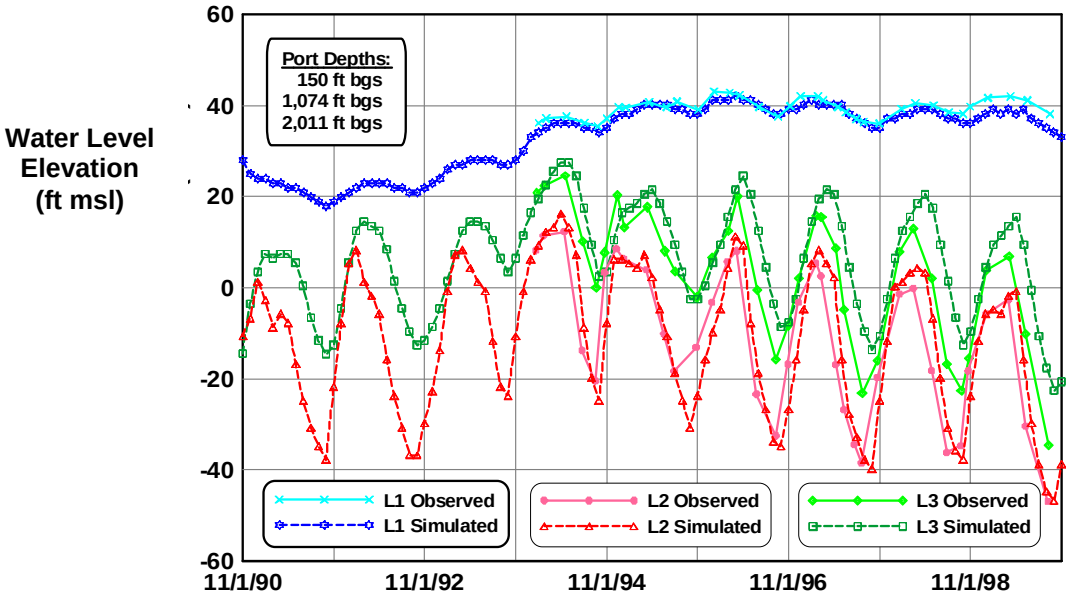


FIGURE 2-19
CALIBRATION HYDROGRAPH FOR MONITORING WELL GGM-1

(All Three Model Layers -- Garden Grove)



Noteworthy findings of the model calibration process are summarized below:

- The model was most sensitive to adjustments to hydraulic conductivity and recharge distribution. In other words, minor variations in these input parameters caused significant changes in the model water level output.
- The model was less sensitive to changes in storage coefficient, requiring order-of-magnitude changes in this parameter to cause significant changes in simulated water levels, primarily affecting the amplitude of seasonal water level variations.
- The vast amount of observed historical water level data made it readily evident when the model was closely matching observed conditions.
- Incidental (unmeasured) recharge averaging approximately 70,000 afy during the 1990-1999 period appeared to be reasonable, as the model was fairly sensitive to variations in this recharge amount.
- Groundwater outflow to Los Angeles County was estimated to range between 5,000 and 12,000 afy between 1990 and 1999, most of this occurring in Layers 1 and 3.
- Groundwater flow at the Talbert Gap was inland during the entire model calibration period, indicating moderate seawater intrusion conditions. Model-derived seawater inflow ranged from 500 to 2,700 afy in the Talbert Gap and is consistent with chloride concentration trends during the calibration period that indicated inland movement of saline groundwater in these areas.
- Model-derived groundwater inflow from the ocean at Bolsa Gap was only 100-200 afy due to the Newport-Inglewood Fault zone, which offsets the Bolsa

aquifer and significantly restricts the inland migration of saline water across the fault.

- Model adjustments (mainly hydraulic conductivity and recharge) in the Santiago Pits area in Orange significantly affected simulated water levels in the coastal areas.
- Model reductions to the hydraulic conductivity of Layer 2 (Principal aquifer system) along the Peralta Hills Fault in Anaheim/Orange had the desired effect of steepening the gradient and restricting groundwater flow across the fault into the Orange area. These simulation results were consistent with observed hydrogeologic data indicating that the Peralta Hills Fault acts as a partial groundwater barrier.
- Potential unmapped faults immediately downgradient from the Santiago Pits appear to restrict groundwater flow in the Principal aquifer system, as evidenced by observed steep gradients in that area, which were reproduced by the model. As with the Peralta Hills Fault, an approximate order-of-magnitude reduction in hydraulic conductivity along these suspected faults achieved the desired effect of reproducing observed water levels with the model.

2.8.2 MODEL ADVISORY PANEL

The model development and calibration process was regularly presented to and reviewed by a Model Advisory Panel. This technical panel consisted of four groundwater modeling experts who were familiar with the basin and highly qualified to provide insight and guidance during the model construction and calibration process. Twelve panel meetings were held between 1999 and 2002. The panel was tasked with providing written independent assessments of the strengths, weaknesses, and overall validity and usefulness of the model in evaluating various basin management alternatives. Two memoranda were prepared: one at the completion of the steady-state model calibration and steady-state scenarios (Harley et al., 1999) and one at the completion of the transient model calibration and initial transient basin operational scenarios (Harley et al., 2001). Key conclusions and findings of the panel regarding the transient model are summarized below.

- Transient modeling has substantially improved the overall understanding of processes and conditions that determine how and why the basin reacts to pumping and recharge. This improved understanding, coupled with the model's ability to simulate existing and possible future facilities and alternative operations, significantly improves the District's potential ability to enhance and actively manage basin water resources.
- Modeling has helped verify major elements of the basin conceptual model and has been instrumental in clarifying:
  - Variations in the annual water balance
  - Hydrostratigraphy of the basin
  - Horizontal flow between basin subareas

  - The potential degree of interconnection and magnitude of vertical flow between major aquifers
  - The potential hydraulic significance of the Peralta Hills Fault in the Anaheim Forebay
  - Variations in aquifer hydraulic properties
  - The relative significance of engineered versus natural recharge and groundwater outflow within the basin
  - Numerous other issues and conditions.
- The ability of the model to simulate known and projected future conditions will evolve and improve as new data become available and updated calibration runs are completed.
- Parameters used to set up the model appear to be within limits justified by known, estimated, and assumed subsurface conditions based upon available historic data.
- Initial transient calibration completed using a nine-year calibration period (1990-1999) is considered adequate to confirm the initial validity of the model for use in evaluating a variety of potential future projects and conditions.
- Areas of the basin that could benefit from future exploration, testing, monitoring, analysis and/or additional model calibration were identified.
- The model is not considered appropriate for assessing detailed local impacts related to new recharge facilities or well fields. These impacts should be assessed using more detailed local submodels and by conducting detailed field studies.
- The model does not, nor is it intended to, address water supply availability, cost, water quality, or land subsidence.

Recommendations of the panel included suggestions that thorough documentation be prepared on model configuration and calibration and that the model calibration period be extended as new data become available.

2.8.3 TALBERT GAP MODEL

Between 1999 and 2000, OCWD contracted with Camp Dresser & McKee Inc. to develop a detailed groundwater flow model of the Talbert Gap and surrounding area for the purpose of evaluating and estimating the amount and location of fresh water injection wells needed to control seawater intrusion under current and projected future basin conditions. The Talbert Gap modeling effort was undertaken as part of the design scope of work for Phase 1 of the GWR System, which included expansion of the existing Talbert Barrier. The configuration and initial calibration of the Talbert Gap Model and further model refinement and calibration were documented by Camp Dresser & McKee Inc. (2000, 2003).

Consistent with the Basin Model Advisory Panel's findings, OCWD determined that a more detailed model of the Talbert Gap was necessary to evaluate the local water level changes associated with various potential injection barrier alignments and flow rates. The Talbert model comprises an area of 85 square miles, 13 Layers (seven aquifers

and six aquitards), and 509,000 grid cells (250 feet x 250 feet horizontal dimensions). Figures 2-20 and 2-21 show the model area and layering schematic, respectively.

FIGURE 2-20
TALBERT GAP MODEL AND BASIN MODEL BOUNDARIES

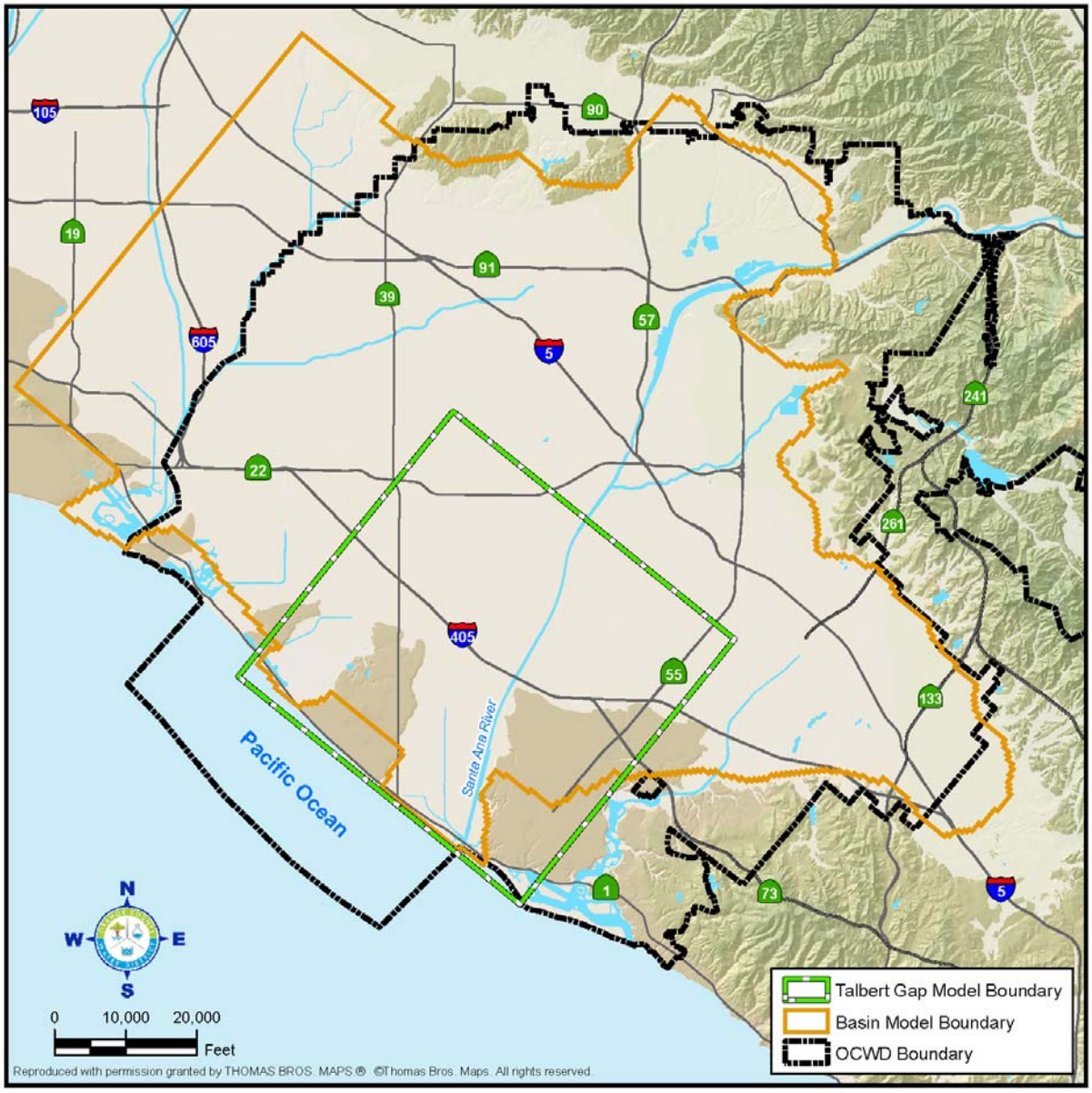
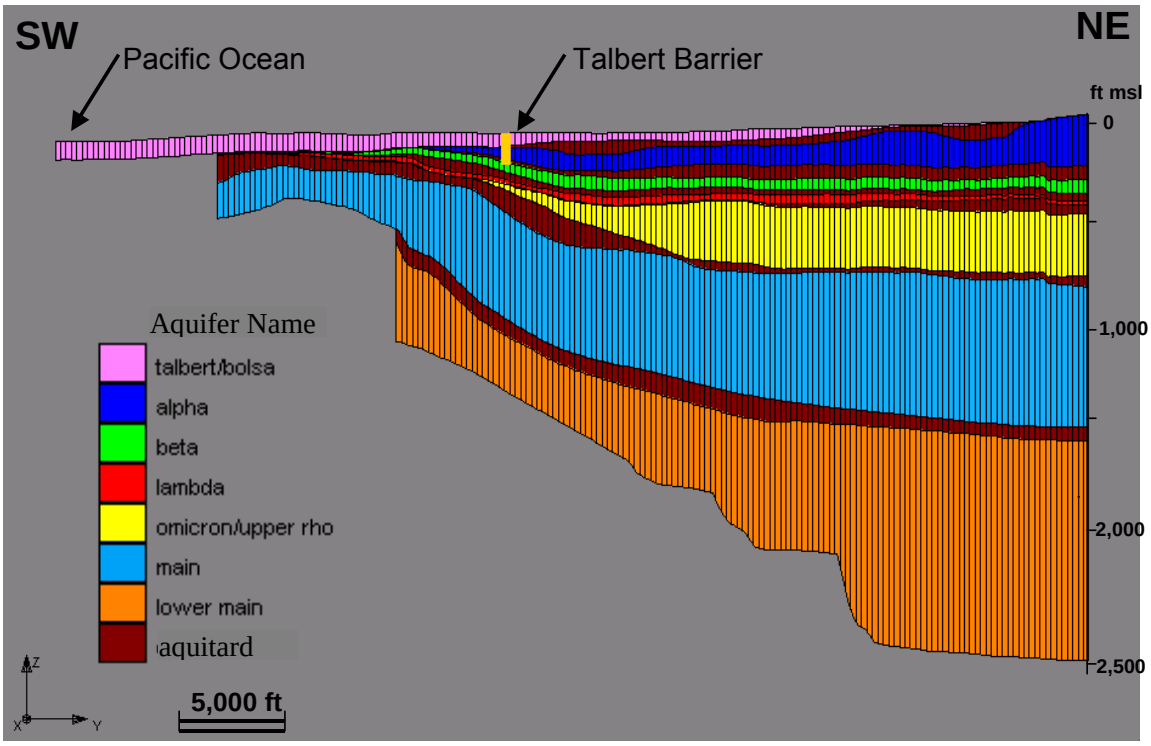


FIGURE 2-21
TALBERT GAP MODEL AQUIFER LAYERING SCHEMATIC



Key findings of the Talbert Gap model are summarized below.

- Depending on the amount of basin production, particularly near the Talbert Barrier, 30 mgd (approximately 34,000 afy) of injection will substantially raise water levels, yet may not be sufficient to fully prevent seawater intrusion in the Talbert Gap. Additional injection wells beyond those planned for Phase 1 of the GWR System may be required.
- Under projected 2020 conditions, the future Talbert Barrier may require an annual average injection rate of up to 45 mgd based on the results of existing analyses. This estimated future injection requirement will be further evaluated as additional data are collected.
- The Talbert model inland boundaries do not coincide with hydrologic or geologic features, e.g., recharge area, faults. Therefore, simulated water levels are highly influenced by the time-varying water levels specified along the boundaries. For future Talbert model predictive runs, the basin model should be used to generate water levels that can then be specified along the inland Talbert model boundaries.
- The Talbert model was less sensitive to adjustment hydraulic conductivity and storage coefficient than the basin model, primarily because of the stronger influence of the specified-head boundaries in the Talbert model.

3 GROUNDWATER MONITORING

OCWD conducts a comprehensive monitoring program of the groundwater basin and surface water supplies in the watershed to properly manage water supplies and to safeguard the basin's water quality. This section describes OCWD's basin monitoring programs, including the following:

- **Groundwater monitoring locations;**
- **Water sample collection and analysis procedures;**
- **Monitoring of production rates, groundwater elevation, groundwater quality, and recharge water quality; and**
- **Seawater intrusion monitoring and prevention.**

3.1 Introduction

For its size, the Orange County groundwater basin is one of the world's most extensively monitored. The District's comprehensive monitoring program tracks dynamic basin conditions including groundwater production, storage, elevations, and water quality.

OCWD's monitoring program has helped improve groundwater management throughout the basin by:

- Establishing on an annual basis the safe and sustainable level of groundwater production.
- Determining the extent of seawater intrusion and subsequently building improvements to seawater barriers to prevent and reverse such intrusion.
- Discovering areas of groundwater contamination to protect public health and beneficial use of groundwater, and to begin remediation efforts at an early stage.
- Assuring that the groundwater basin is managed in full compliance with all relevant laws and regulations.

3.2 Collection and Management of Monitoring Data

Data are collected through a vast network of production and monitoring wells at frequencies necessary for short- and long-term trend analyses. The wells are located throughout the basin to enable not only analysis of the basin as a whole but also to focus on local or sub-regional investigations. Multi-depth monitoring wells provide depth-specific water level and quality data allowing analysis of the basin's multiple-aquifer configuration.

The network of nearly 700 municipal drinking water, private domestic, industrial, irrigation, and monitoring wells is used to collect data for a variety of purposes. A list of

each OCWD monitoring well with well type, cased depth, and top and bottom perforation is shown in Appendix E. Figure 3-1 shows the locations of over 200 production wells that extract groundwater for municipal use. Monthly individual well production rates for large-capacity wells have been collected since 1988. Monitoring wells, shown in Figure 3-2, are operated by OCWD to supplement the water quality data collected at production wells and to fill data gaps.

FIGURE 3-1
PRODUCTION WELL LOCATIONS

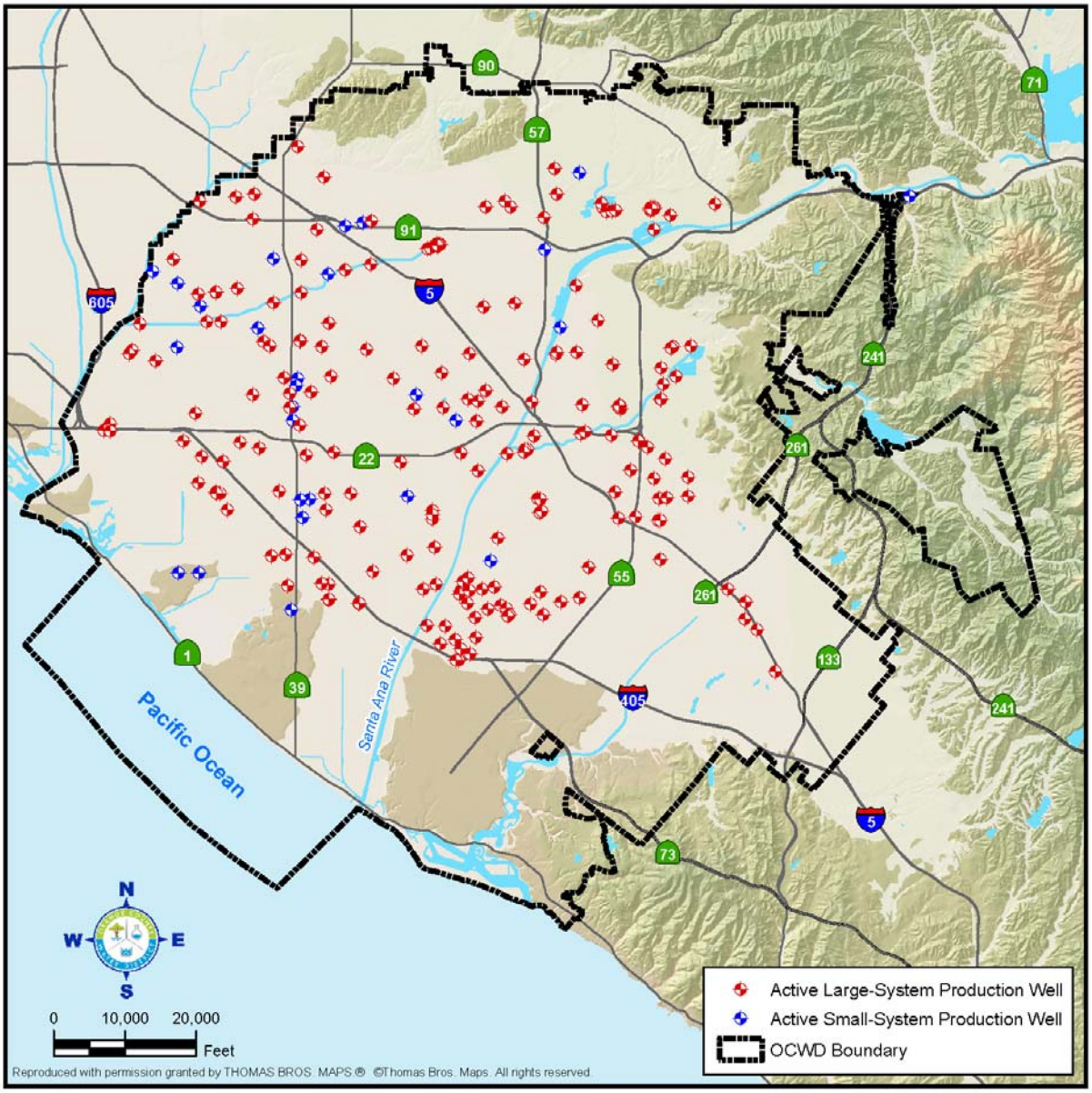
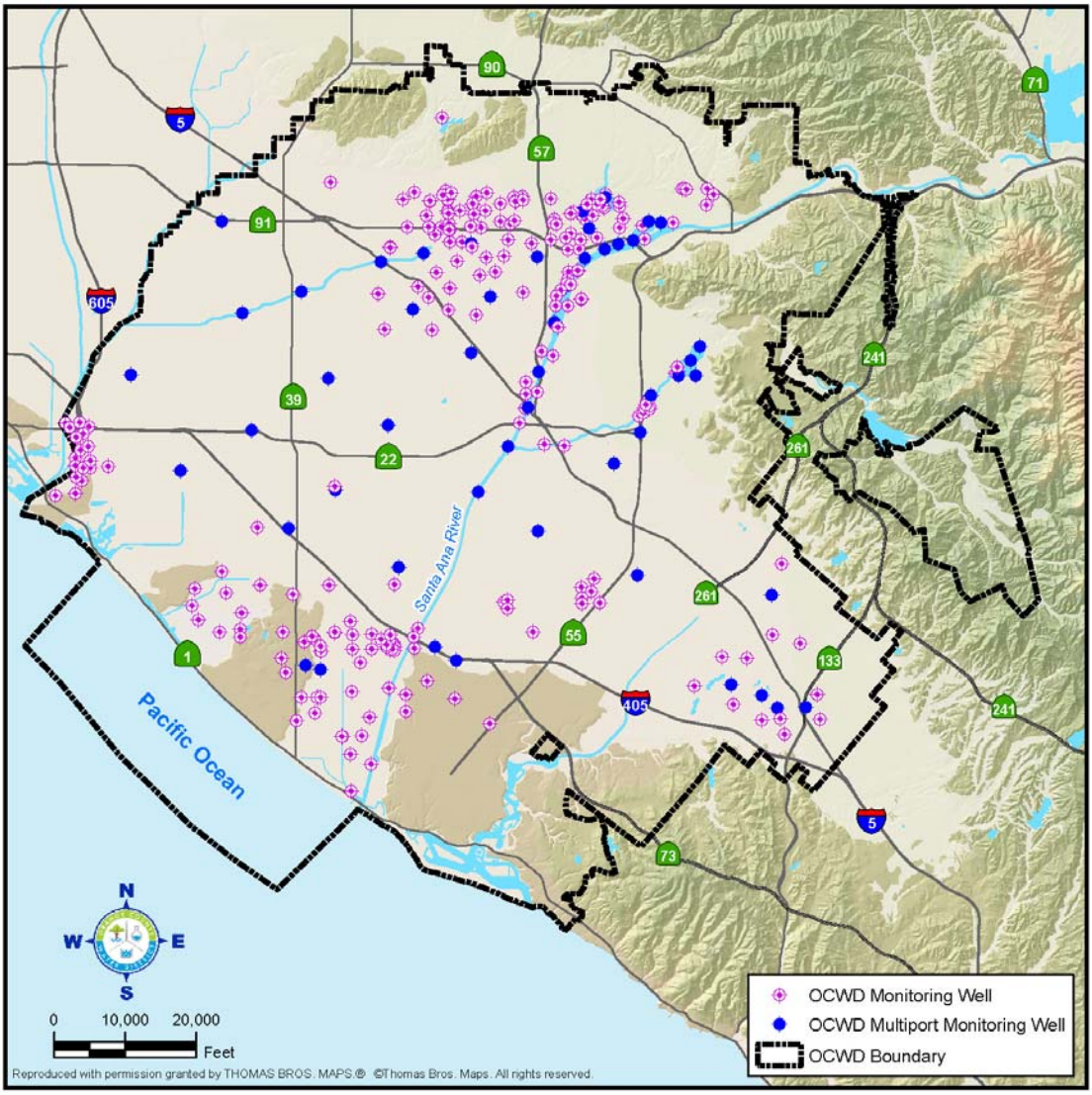


FIGURE 3-2
OCWD MONITORING WELL LOCATIONS



Note: Monitoring wells constructed and/or owned by other entities besides OCWD are not shown.

Data collected in OCWD's monitoring program are stored in the District's electronic database, the Water Resources Management System (WRMS). WRMS contains comprehensive well information, current and historical data, as well as information on sub-surface geology, groundwater modeling, and water quality. This database provides for subsequent retrieval and analysis of data or preparation of data reports and data submittals to other agencies.

3.3 Water Sample Collection and Analysis

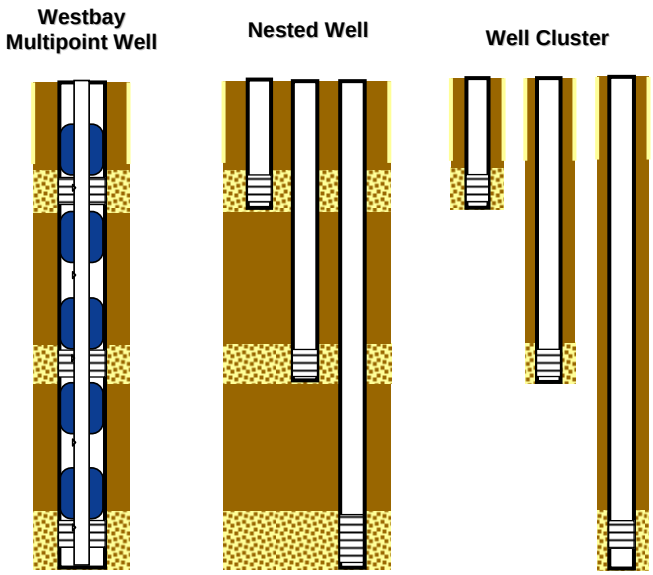
OCWD's laboratory is state-certified to perform bacteriological, inorganic, and organic analyses (see Figure 3-3). The District utilizes state-certified contractor laboratories to analyze asbestos, dioxin, and radiological samples. Analytical methods approved by the California Department of Public Health (CDPH) or U.S. Environmental Protection Agency (EPA) are used for analyzing water quality samples for the drinking water compliance program. As new chemicals are regulated, the OCWD laboratory develops the analytical capability and becomes certified in the approved method to process compliance samples. The amount of samples taken is dynamic, ranging from 600 to 1,700 samples in any given month.

Water quality samples are collected in the field in accordance with approved federal and state procedures and industry-recognized quality assurance and control protocols to ensure that sampled water is representative of ambient groundwater (or surface water) conditions.

Water samples are collected in method-specific containers, stored in coolers at approximately 4°C, and delivered to state-certified laboratories, researchers, or contract laboratories for analysis. The majority of samples are delivered to the laboratory on the day of sample collection. When samples must be shipped, they are sent overnight for next-day delivery. Site conditions, field measurements of selected water quality parameters (temperature, pH, electrical conductivity, and dissolved oxygen), and other relevant sample observations are recorded in field notebooks at each sampling location, and a chain-of-custody form is completed for each sample collected per site. Sampling occurs in a variety of terrains and occasionally in inclement weather and outside normal business hours.

FIGURE 3-3
OCWD'S STATE CERTIFIED NEW LABORATORY

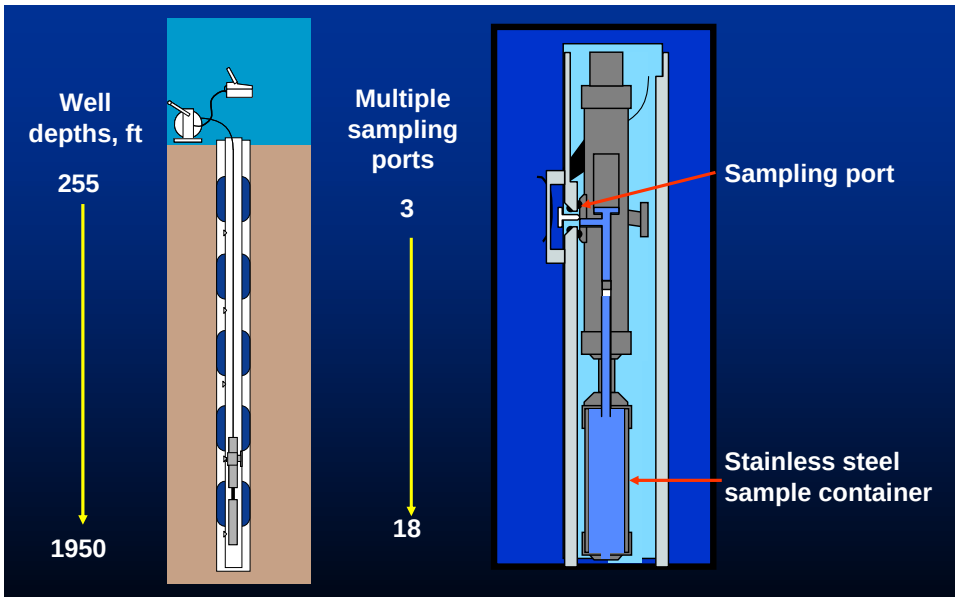
FIGURE 3-4
THREE COMMON MONITORING WELL DESIGNS



Production wells that provide water for drinking water, irrigation/agriculture, and industrial uses generally have well screens located in the permeable, water-bearing zones that may tap multiple aquifers. Therefore, water quality samples collected from these wells may represent water from one or more aquifers; some permeable zones may provide greater contribution than others to the overall water sample. In contrast, monitoring wells are designed and constructed with well screens placed at a specific depth and length to provide water quality at desired zones within an aquifer. Figure 3-4 illustrates the three monitoring well designs used for basinwide water quality monitoring activities: multi-point, nested, and cluster.

The multi-point well is a Westbay well design that contains a single casing with sampling ports located at specific depths in the underlying aquifers (Figure 3-5). Individual sampling points are hydraulically separated by packers. A computer-assisted sampling probe is used to collect a water sample at the desired depth. The sampling port has direct hydraulic connection between the port and the aquifer, allowing groundwater to flow into a detachable stainless steel sample container. OCWD has more than 50 multi-point wells ranging from a few hundred feet to over 2,000 feet in depth.

FIGURE 3-5
MULTIPORT WELL DESIGN DETAIL



A nested well design consists of a single borehole with individual monitoring wells screened at specific depths and completed in the borehole. A cluster is represented by individual monitoring wells completed with single casings at targeted depths within close proximity of each other. A "single point" monitoring well is one individual monitoring well that typically is screened over about 10 to 30 feet of sediments. The primary difference between the multi-point wells and the nested, cluster or single-point monitoring wells is the method of sample collection. Westbay multi-point wells do not require purging of groundwater prior to sample collection. In contrast, single point monitoring wells use a submersible pump to purge groundwater from the well and the surrounding formation until "ambient" or steady state conditions are obtained as determined by steady, continuous field measurements of pH, electrical conductivity, and temperature.

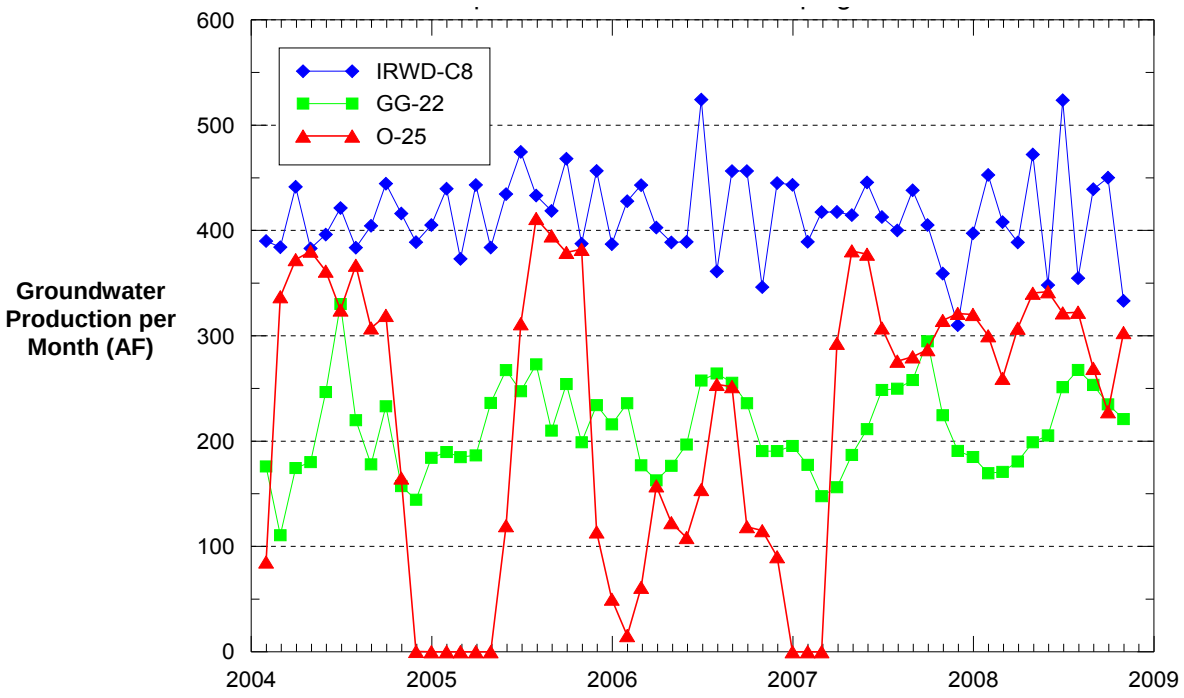
Between forty to nearly 2,000 gallons of groundwater may be purged from a monitoring well prior to sample collection. Generally, a truck equipped with one or more submersible pumps and a portable generator is used to purge and sample groundwater from single-point monitoring wells. Portable submersible pump and reel systems provide additional flexibility to increase the efficiency of sampling monitoring wells without dedicated pumps. One truck is outfitted with a dual system of submersible pumps and environmental hoses installed separately on hydraulic booms to sample two wells simultaneously (see Figure 3-6).

FIGURE 3-6
DUAL BOOM WATER QUALITY SAMPLING VEHICLE

3.4 Production and Groundwater Elevation Monitoring

Approximately 200 large-capacity municipal supply wells account for 97 percent of production. Large-capacity well owners, who are required by the District Act to report to OCWD every six months, voluntarily report monthly groundwater production for each of their wells. The production volumes are verified by OCWD field staff. Data are used to assess the Replenishment Assessment, quantify total basin pumping, calibrate the basin model described in Section 2.8, and to evaluate seasonal groundwater level fluctuations. As an example, Figure 3-7 illustrates seasonal groundwater production trends in three municipal wells.

FIGURE 3-7
EXAMPLES OF SEASONAL WELL PUMPING PATTERNS



Groundwater elevation (or level) data are measured at least semi-annually at nearly every production and monitoring well. Over 1,000 individual measurement points are monitored for water levels on a monthly or bi-monthly basis to evaluate short-term effects of pumping or recharge operations. More frequent water level measurements are collected at selected monitoring wells in the vicinity of OCWD's recharge facilities, seawater barriers, and areas of special investigation where drawdown, water quality impacts, or contamination are of concern. The number of municipal wells that are monitored varies from year to year depending on well maintenance, abandonment, new well construction, and related factors.

3.5 Water Quality Monitoring

In 2008, nearly 14,000 groundwater samples were collected and analyzed to comply with state and federal regulations and to enable OCWD to monitor the water quality of the basin. OCWD conducts the EPA/CDPH compliance sampling and reporting for Producers wells. The number of water quality samples varies each year in response to regulatory requirements and to gain a better understanding of the basin, as shown in Figure 3-8. A summary of the well types, the number of wells, and the number of sample points is presented in Table 3-1.

FIGURE 3-8
GROUNDWATER AND SURFACE SITE SAMPLES COLLECTED BY OCWD

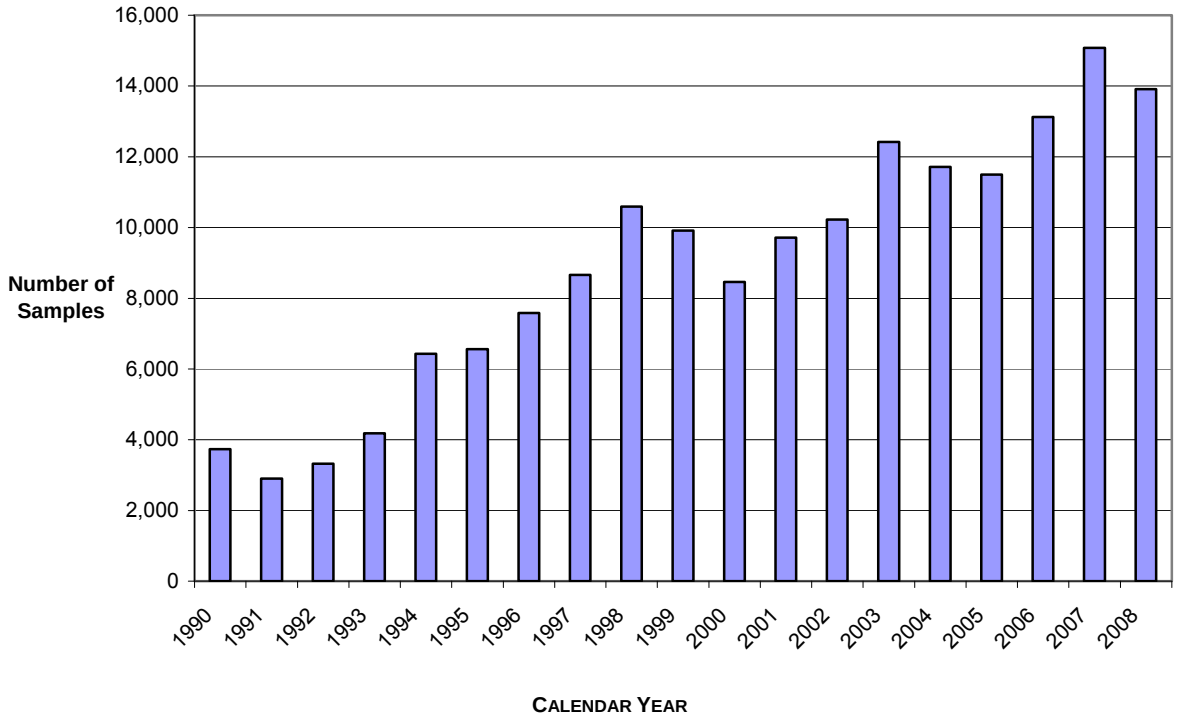


TABLE 3-1
DISTRIBUTION OF WELLS IN BASINWIDE MONITORING PROGRAM

Well Type	No. of Wells	No. of Individual Sample Points
Drinking Water Wells	228	228
Industrial And Irrigation wells	123	123
OCWD Monitoring Wells (excluding seawater monitoring)	254	728
OCWD Seawater Intrusion Monitoring Wells	93	244
Total	**698**	**1323**

Samples collected throughout the basin are used to monitor the impacts of basin extraction, determine the effectiveness of the seawater intrusion barriers, assess the impacts of historic and current land uses, and serve as a sentinel or early warning of emerging contaminants of concern. The District's comprehensive water quality monitoring programs fall roughly into three categories: (1) compliance with permits and drinking water regulations, (2) OCWD Board approved projects for research and other purposes, and (3) basin management.

3.5.1 DRINKING WATER REGULATIONS

The Federal Safe Drinking Water Act (SDWA) directs the EPA to set health-based standards (maximum contaminant levels or MCLs) for drinking water to protect public health against both naturally-occurring and man-made contaminants. EPA administers the SDWA at the federal level and establishes MCLs for bacteriological, inorganic, organic, and radiological constituents (U.S. Code Title 42, and Code of Federal Regulations Title 40). California administers and enforces the federal program and has adopted its own SDWA, which may contain more stringent state requirements (California Health and Safety Code, Section 116350 and related sections). The regulations implementing the California SDWA are referred to as the Title 22 Drinking Water Standards.

Since the 1970s, the number of chemicals regulated in groundwater sources has increased more than four-fold. OCWD monitors more than 100 regulated and unregulated chemicals at a specified monitoring frequency established by regulation as shown in Table 3-2.

Typically, about one-third of the drinking water wells are sampled every year for general minerals, metals, and secondary MCL constituents (color, odor, TDS, sodium, chloride, alkalinity, etc.). VOCs and nitrate are sampled annually at every well. Quarterly monitoring is required if VOCs are detected or if nitrate concentrations exceed 50 percent of the MCL. In addition, OCWD monitors wells routinely for selected chemicals on the unregulated lists, chemicals with Notification Levels, or new chemicals of concern.

Analyses for synthetic organic chemicals (SOCs) including tests for herbicides, pesticides, plasticizers, and other semi-volatile organics require use of twelve or more analytical methods. Newly-constructed wells are monitored for SOCs for four consecutive quarters to provide seasonal data for CDPH to assess the long-term monitoring frequency in their vulnerability assessment.

In addition to the regulated chemicals, both EPA and the CDPH require monitoring for unregulated chemicals. Unregulated chemicals do not have an established drinking water standard, but are new priority chemicals of concern. Monitoring provides information regarding their occurrence and levels detected in drinking water supply wells as the first assessment step to determine if the establishment of a standard (MCL) is necessary. Wells must be sampled twice within twelve months to comply with the unregulated chemical monitoring rules.

TABLE 3-2
MONITORING OF REGULATED AND UNREGULATED CHEMICALS

DPH Title 22 Drinking Water Monitoring Frequency -- Regulated Chemicals			
Chemical Class	**Frequency**	**Monitoring Notes**	**Comments**
Inorganic - General Minerals	Once every 3 years		
Inorganic - Trace Metals	Once every 3 years		
Nitrate and nitrite	Annually	New wells sampled quarterly for 1st year	
Detected ≥ 50% MCL	Quarterly		
Perchlorate		New wells sampled quarterly for 1st year	
Detected ≥ DLR	Quarterly	Detection limit = 4 ppb	
Non-detect at < DLR	Once every 3 years		OCWD will monitor at least annually
Volatile organic chemicals (VOC)	Annually	New wells sampled quarterly for 1st year	
Detected VOC	Quarterly		
Synthetic organic chemicals (SOC)		New wells sampled quarterly for 1st year; if non-detect, susceptibility waiver for 3 years	
Atrazine and simazine	Once every 3 years		
Radiological		New wells sampled quarterly for 1st year (initial screening) to determine reduced monitoring frequency for each radionuclide	
Detected at > 1/2 MCL ≤ MCL	Once every 3 years	Per radionuclide	Reduced monitoring after initial year
Detected at ≤ 1/2 MCL	Once every 6years	Per radionuclide	Reduced monitoring after initial year
Non-detect at < DLR	Once every 9 years	Per radionuclide	Reduced monitoring after initial year
EPA and DPH Unregulated Chemicals			
DHS : 4-Inorganic and 5-organic chemicals	Two required samples: (1) Vulnerable period: May-Jun-Jul-Aug-Sep (2) 5 to 7 months before or after the sample collected in the vulnerable period. No further testing after completing the two required sampling events	Monitoring completed for existing wells in 2001- 2003; new wells tested during 1st year	DHS UCMR - required testing for all new wells
EPA UCMR1 - List 1: 1-Inorganic and 10-organic chemicals			EPA UCMR1 - no longer required by EPA; sampling period was 2001-2003; received waiver April '08 from DPH of non vulnerable so no further testing required. New wells were being tested since 2001 to Apr. 08 (waiver granted by DPH)
EPA UCMR1 - List 2: 13-Organic chemicals			
EPA UCMR2 - List 1: 10 organic chemicals		All water utilities serving >10,000 people. Monitoring period: 2008- 2010	Current EPA program: Jan 2008 - Dec. 2010
EPA UCMR2 - List 2: 15 organic chemicals		All water utilities serving population >100,000 and EPA selected systems serving <100,000 population. Monitoring period: 2008- 2010	

3.5.2 MONITORING FOR CONTAMINANTS IN THE BASIN

OCWD has taken a proactive role in monitoring the basin for VOCs for over twenty years. This extensive monitoring program that tests agricultural, industrial, private, and domestic wells, led to the discovery of the El Toro MCAS solvent plume, discussed in Section 5.5. In response to the detection of VOCs in Anaheim and Fullerton over 100 monitoring wells, many in cluster well configuration were drilled to provide a broad range of monitoring points to define the areal extent of VOC contamination.

Monitoring wells are sampled as frequently as quarterly in areas of localized high concentrations of solvents and annually at other locations. Other chemicals are added to the monitoring program when concern arises. In the case of the North Basin

Groundwater Protection Project, described in Section 5.8, OCWD monitors for VOCs, 1,4-dioxane, and other constituents.

Monitoring gaps for regulated and unregulated chemicals occur in areas within Irvine where drinking water wells were not operating on a regular basis. OCWD's fills the data gaps with the non-potable well monitoring program. Monitoring wells and accessible agricultural wells are sampled for volatile organics, general minerals, and selected chemicals of concern to provide water quality information in this area of the basin.

3.6 Seawater Intrusion Monitoring and Prevention

Monitoring and preventing the encroachment of seawater into fresh groundwater zones along coastal Orange County is a major basin management issue. Seawater encroachment also represents a key factor in determining the basin operating range in terms of the maximum accumulated overdraft. Besides seawater intrusion, other identified sources of coastal groundwater salinity include connate water (water trapped in the pore spaces of sediments at the time of deposition) and brines disposed of at the ground surface during past oil production (Poland et al., 1956; DWR, 1961; DWR, 1968; J.M. Montgomery, 1974). The primary avenues for seawater intrusion into the basin are permeable sediments underlying topographic lowlands or "gaps" between the erosional remnants or "mesas" of the Newport-Inglewood Uplift, as shown in Figure 3-9. The susceptible locations are the Talbert, Bolsa, Sunset, and Alamitos Gaps.

Seawater intrusion through the Alamitos and Talbert Gaps is controlled via the operation of seawater barriers consisting of injection wells. The Alamitos Barrier has been operated since 1965 under a joint funding agreement between OCWD and Los Angeles County Department of Public Works (LACDPW) and a joint management committee consisting of OCWD, LACDPW, and other local stakeholders including the Water Replenishment District, City of Long Beach, and Golden State Water Company. OCWD has operated the Talbert Seawater Barrier since 1975. Flow and pressure readings are used to maximize total injection without over pressurizing the wells.

A coastal seawater monitoring program assesses the effectiveness of the Alamitos and Talbert Barriers and tracks salinity levels in the Bolsa and Sunset Gaps. Over 425 monitoring and production wells are sampled semi-annually to assess water quality conditions during periods of lowest production (winter) and peak demands (summer). Monthly water levels are measured in many of the coastal wells to evaluate seasonal effects of pumping and the operation of the injection barrier. A small subset of coastal wells is equipped with pressure transducers and data loggers for twice daily measurement and recording of water level conditions.

Key groundwater monitoring parameters used to determine the effectiveness of the barriers include water level elevations, chloride, TDS, electrical conductivity, and bromide. Groundwater elevation contours for the aquifers most susceptible to seawater intrusion are prepared to evaluate the freshwater mound developed by the barrier injection wells and to determine if it is sufficient to prevent the inland movement of saline water. The Talbert Gap chloride concentration contours shown in Figure 3-10 illustrate both the historical inland progression of groundwater salinity and its recent

reversal due to injecting large volumes of water and basin management practices employed in the last four years.

FIGURE 3-9
SEAWATER BARRIER LOCATIONS

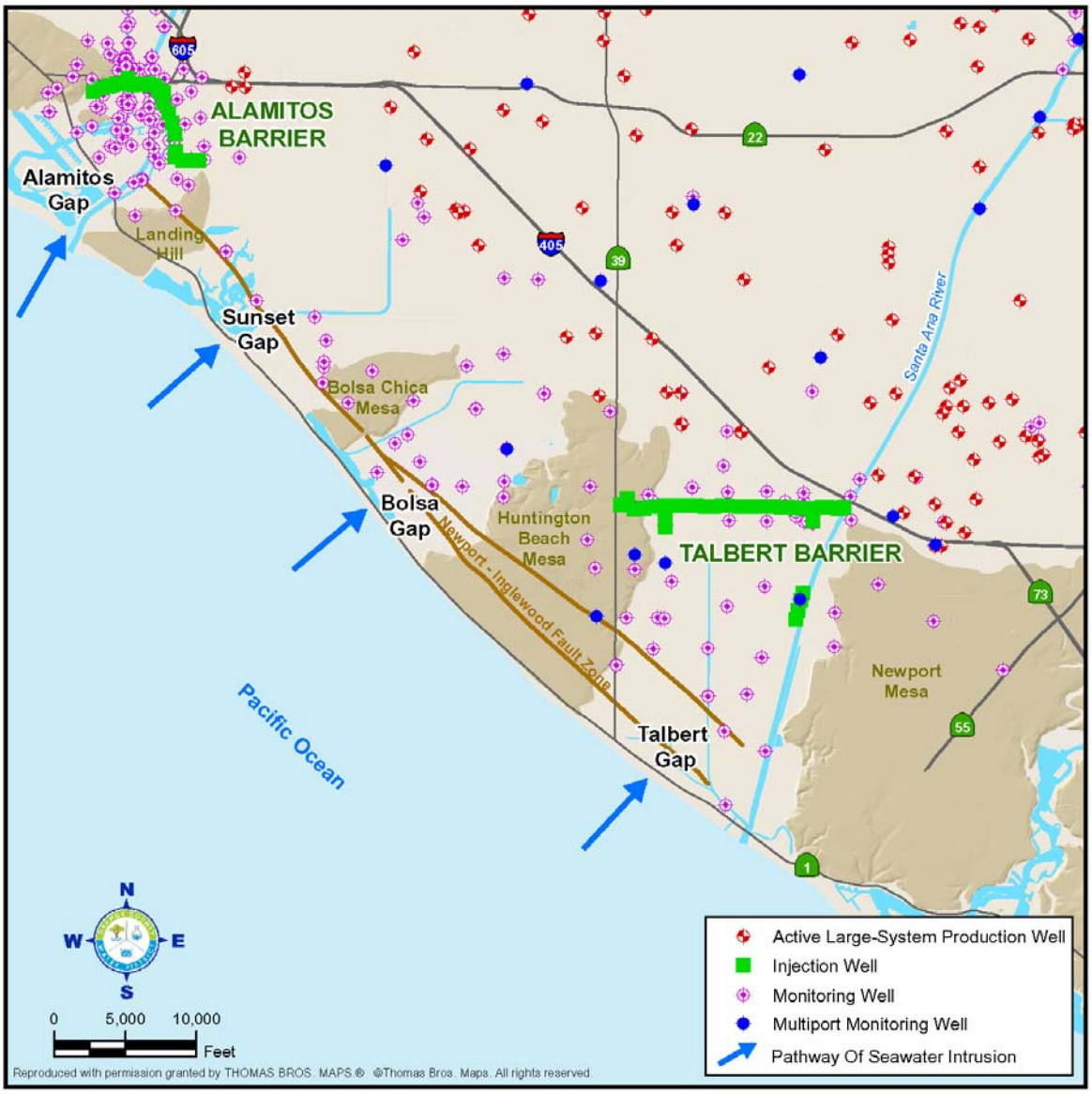
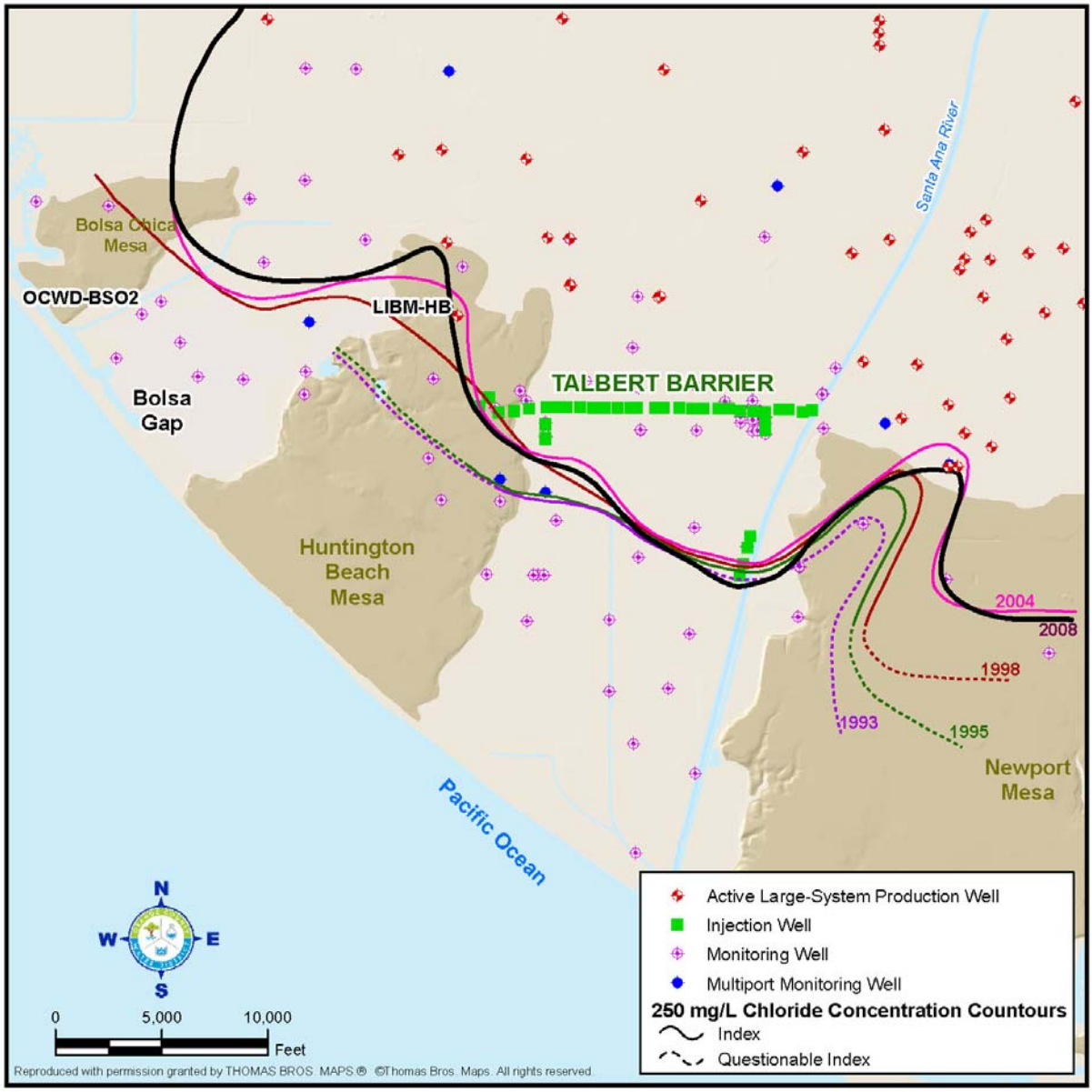
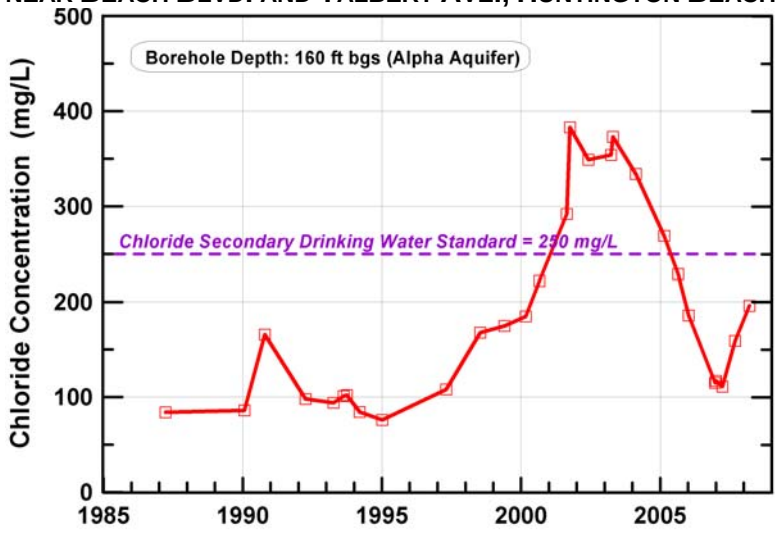


FIGURE 3-10
LANDWARD MOVEMENT OF 250 MG/L CHLORIDE CONCENTRATION CONTOUR



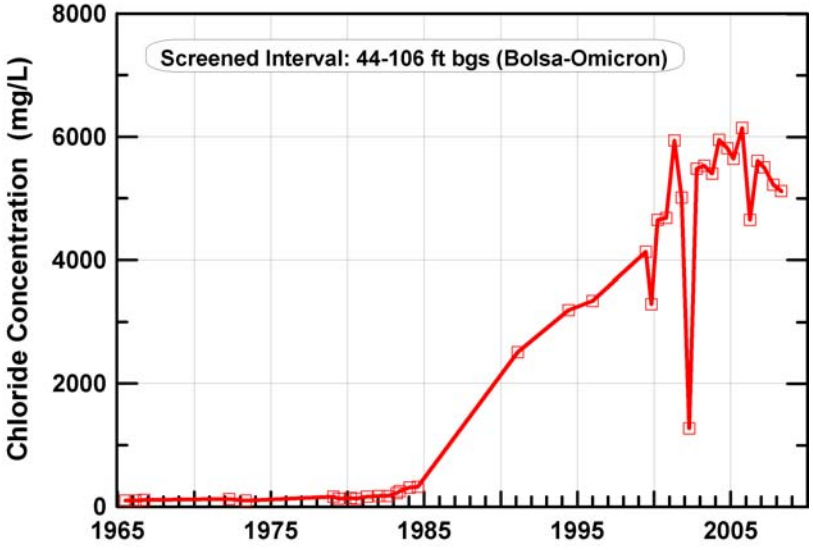
In addition to contour maps, OCWD staff prepares and reviews chloride concentration trends at individual wells to identify and evaluate intrusion in specific aquifer zones, Chloride concentration trend charts for two of those wells are shown in Figure 3-11 with their locations shown in Figure 3-10.

FIGURE 3-11
EXAMPLE CHLORIDE CONCENTRATION TREND CHARTS
DOMESTIC WELL LIBM-HB
NEAR BEACH BLVD. AND TALBERT AVE., HUNTINGTON BEACH



CALENDAR YEAR

MONITORING WELL OCWD BSO-2/1
BOLSA CHICA AREA, NEAR WINTERSBURG CHANNEL



CALENDAR YEAR

3.7 Monitoring Quality of Recharge Water

OCWD conducts an extensive program to monitor the quality of the water recharged into the groundwater basin. This includes monitoring of the Santa Ana River surface water and other recharge water supplies.

3.7.1 SANTA ANA RIVER WATER QUALITY

Since the quality of the surface water that is used for recharge may affect groundwater quality, a routine monitoring program is maintained to continually assess ambient river water quality conditions. Characterizing the quality of the Santa Ana River and its impact on the basin is necessary to verify the sustainability of continued use of river water for recharge and to safeguard a high-quality drinking water supply for Orange County.

On-going monthly surface water monitoring of the Santa Ana River is conducted at Imperial Highway near the diversion of the river to the off-river recharge basins and at a site below Prado Dam. Sampling frequencies for selected river sites and recharge basins are shown in Table 3-3.

TABLE 3-3
SURFACE WATER QUALITY SAMPLING FREQUENCY WITHIN ORANGE COUNTY

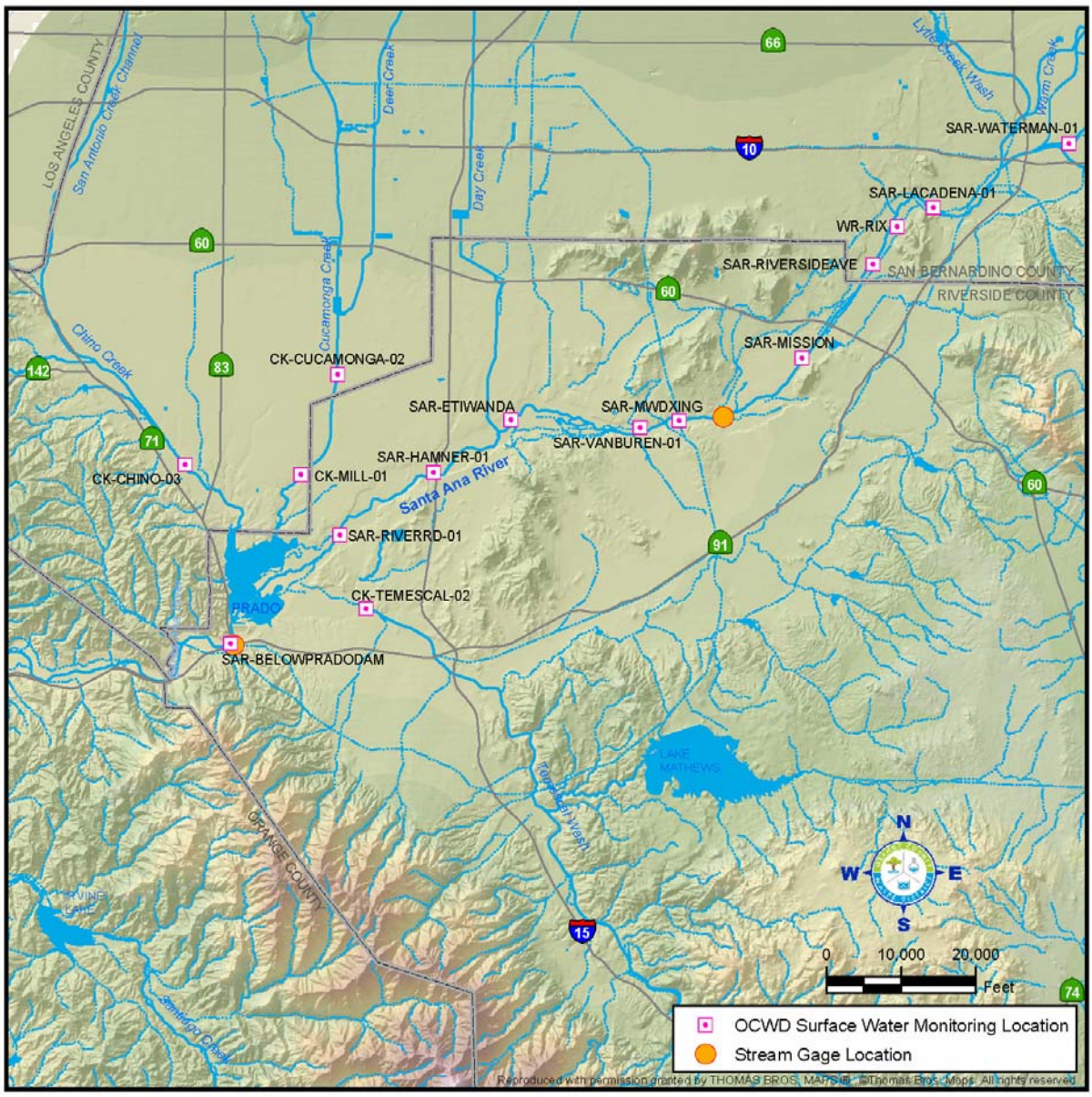
Category	SAR Below Dam	SAR Imperial Hwy	Anaheim Lake	Kraemer/ Miller Basin
General Minerals	M	M	M	Q
Nutrients	M	M	M	Q
Metals	Q	Q	Q	Q
Microbial	M	M	M	M
Volatile organic compounds (VOC)	M	M	M	Q
Semi-volatile organic compounds (SOC)	Q	Q	Q	Q
Total organic halides (TOX)	M	M	M	
Radioactivity	Q	Q	Q	Q
Perchlorate	M	M	M	Q
Chlorate	M	M	M	Q
Iodine		Q	Q	
NDMA Formation Potential (NDMA-FP)		Q	Q	

M = monthly, Q = quarterly

Note: NDMA-FP and iodine are focused testing initiated in late 2007 and will continue through 2009. Data will be reviewed to determine if monitoring should continue or incorporated into the long-term monitoring program.

General minerals, nutrients, and selected other constituents are monitored monthly, and radioactivity constituents, metals, volatile organics, and semi-volatile organics (e.g., pesticides and herbicides) are monitored quarterly. Several points on the river and key tributaries to the river above Prado Dam, as shown in Figure 3-12 are also monitored annually for general minerals and nutrients.

FIGURE 3-12
OCWD SURFACE WATER MONITORING LOCATIONS ABOVE PRADO DAM



3.7.1.1 Santa Ana River Water Quality and Health Study

In 2004, OCWD completed the Santa Ana River Water Quality and Health (SARWQH) study (OCWD, 2004). This voluntary study was conducted from 1994 to 2004 at a cost of $10 million. The study was initiated due to OCWD's concerns about the high percentage of treated wastewater discharges into the non-storm flows of the Santa Ana River.

The goal of the SARWQH Study was to apply advanced water quality characterization methods to assess the quality of Santa Ana River water and the groundwater after Santa Ana River water is used to recharge the groundwater basin. The multi-disciplinary study design included an examination of hydrogeology, microbiology, inorganic and organic water chemistry, toxicology and public health. The organic water chemistry component included an analysis of trace (low concentration) constituents and dissolved organic compound (DOC) characterization. Analyses and research in the SARWQH Study were conducted by scientists, researchers, and water quality experts from numerous organizations, including Stanford University, Lawrence Livermore National Laboratory, USGS, Oregon State University, and Metropolitan Water District.

The results of this extensive study confirmed that current recharge practices using Santa Ana River water are protective of public health. Findings from the SARWQH Study provided information necessary for the planning and permitting of other OCWD projects, such as the GWR System. Results are also helping to shape the CDPH proposed regulations for groundwater recharge.

At the request of OCWD, the National Water Research Institute (NWRI) conducted an independent review of the results from the SARWQH Study. NWRI assembled a group of experts in the fields of hydrogeology, water chemistry, microbiology, and the other requisite fields to form the Scientific Advisory Panel. This Panel met annually during the study to review the results and provide recommendations on future work. The panel also prepared a final report (NWRI, 2004) that concluded:

> "Based on the scientific data collected during the SARWQH Study, the Panel found that:
>
> - The SAR met all water-quality standards and guidelines that have been published for inorganic and organic contaminants in drinking water.
> - No chemicals of wastewater origin were identified at concentrations that are of public health concern in the SAR, in water in the infiltration basins, or in nearby groundwaters.
>
> The constituents that were considered included non-regulated chemicals (e.g., pharmaceutically active chemicals) and contaminants of concern that arose during the course of the SARWQH study (e.g., n-Nitrosodimethylamine [NDMA]).
>
> The unprecedented classification of the major components of DOC and the transformations that occur within these chemical classes as water moves downstream and into the aquifer provided significant new evidence to support the conclusion that the product water is suitable for potable

consumption and is also becoming comparable to other sources of drinking water, such as the Colorado River, in its organic profile."

3.7.2 REPLENISHMENT WATER FROM METROPOLITAN

When the District purchases replenishment water from Metropolitan and it is delivered at Anaheim Lake, the water is blended with Santa Ana River water. OCWD samples this blended water for general minerals, nutrients, and other selected constituents. The District may also sample for radioactive constituents, metals, volatile organics, and semi-volatile organics (e.g., pesticides and herbicides).

3.7.3 GROUNDWATER REPLENISHMENT SYSTEM

Recharge water produced by the GWR System is extensively monitored daily, weekly, and quarterly for general minerals, metals, organics, and microbiological constituents as shown in Table 3-4. Focused research-type testing has been conducted on organic contaminants and selected microbial species (i.e., protozoa, coliphage, etc.)

TABLE 3-4
GROUNDWATER REPLENISHMENT SYSTEM PRODUCT WATER QUALITY MONITORING

Category	Testing Frequency
General Minerals	M
Nitrogen Species (NO3, NO2, NH3, Org-N) and TDS	W
Metals	Q
Inorganic chemicals	Q
Microbial	D
Total Organic Carbon (TOC)	D
Non-volatile synthetic organic compounds (SOCs)	Q
Disinfection Byproducts	Q
Radioactivity	Q

D = Daily, W = twice weekly, M = monthly, Q = quarterly,

After the GWR System water is recharged, the water is monitored in the groundwater basin. The District uses an array of monitoring wells in the Talbert Gap and in Anaheim to monitor the water quality. As part of the construction of the GWR System, three new monitoring wells were constructed to complement the District's existing monitoring wells network.

3.7.4 INTEGRATED GROUNDWATER AND SURFACE WATER MONITORING

As part of its recharge water quality monitoring program, the District monitors groundwater quality at selected monitoring wells downgradient of the recharge facilities where the subsurface rate of travel of recharge water is known. These wells provide an indication of groundwater quality as recharge water flows away from the recharge

basins. Recharge water samples are collected in coordination with these targeted groundwater samples so that the changes in water quality with time after recharge can be assessed. This allows for evaluations of water quality for parameters such as nitrate as the water is infiltrated and subsequently flows in the subsurface.

This integration of groundwater and surface water monitoring was established based on recharge water tracer studies conducted with water recharge at Anaheim Lake, Kraemer Basin, and the Santa Ana River (Clark et. al, 2004).

3.8 Publication of Data

In addition to collecting and managing data in the District's WRMS as described previously in this section, OCWD analyzes and reports data in a number of regular publications as shown in Table 3-5 below.

TABLE 3-5
DATA COLLECTION AND REPORTING

Report	Frequency of Publication	Contents
Engineer's Report on the Groundwater Conditions, Water Supply and Basin Utilization in the Orange County Water District	Annual	Basin hydrology, groundwater conditions, total groundwater production, groundwater levels, coastal groundwater conditions, calculation of basin accumulated overdraft, supplemental water purchases; required by the District Act
Santa Ana River Water Quality Monitoring Report	Annual	Surface water quality data for the Santa Ana River
Groundwater Replenishment System and Talbert Barrier Report	Annual	Data related to the operation of the Groundwater Replenishment System and the Talbert Seawater Intrusion Barrier; required by RWQCB permit
Santa Ana River Watermaster Report	Annual	Amounts of Santa Ana River flows at Prado Dam and Riverside Narrows; required by 1969 stipulated judgment
Managed Aquifer Recharge	Annual beginning 2009	Total amount of managed recharge, recharge data for each recharge basin, sources of and quantities of recharge water supplies

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4 RECHARGE WATER SUPPLY MANAGEMENT

OCWD manages the District's recharge facilities to maximize groundwater recharge. Efficiently operating existing groundwater recharge basins and facilities and expanding recharge operations where feasible are major District objectives. This section:

- **Describes the operations of the OCWD recharge facilities;**
- **Explains seawater intrusion barrier operations; and**
- **Discusses the sources of recharge water supplies.**

4.1 Recharge Operations

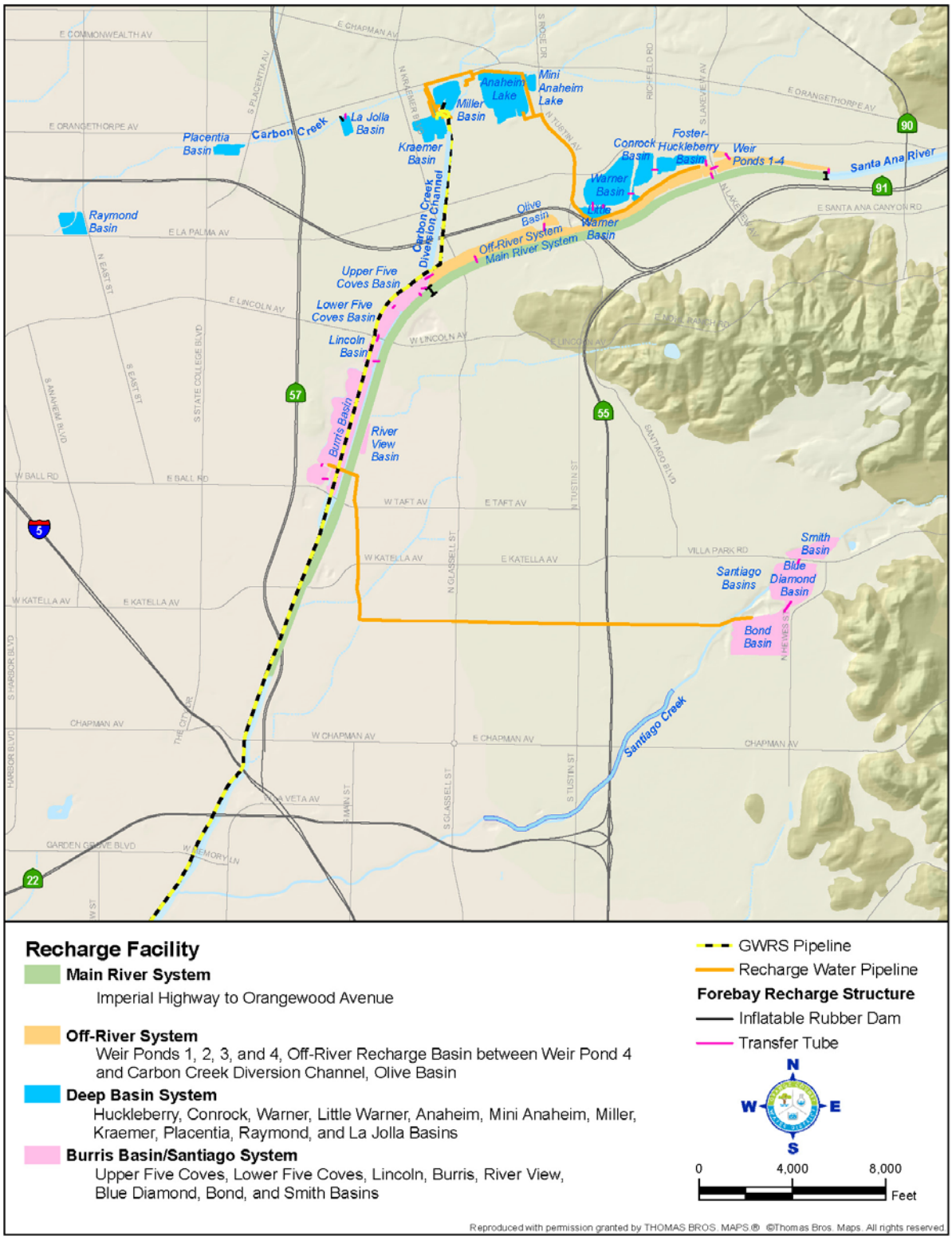
Recharging water into the basin, through natural and artificial means, is essential to support pumping from the basin. Although the amount of recharge and total pumping may not be the same each year, over the long-term the amount of recharge needs to be similar to total pumping. The basin's primary source of water for groundwater recharge is flow from the Santa Ana River. The Santa Ana River is the largest coastal stream in southern California with a length of 80 miles and a drainage area of 2,470 square miles (Blomquist, 1988). OCWD diverts river flows into recharge basins located in and adjacent to the Santa Ana River and its main Orange County tributary, Santiago Creek. Other sources of recharge water supplies include natural recharge, recycled water, and imported water.

OCWD currently operates 1,067 acres of recharge facilities located in and adjacent to the Santa Ana River and Santiago Creek. OCWD recharge facilities are shown in Figure 4-1. Active or managed recharge of groundwater began in 1949, in response to increasing drawdown of the basin and, consequently, the serious threat of seawater intrusion contaminating groundwater. The first imported water used to recharge the basin was Colorado River water purchased from Metropolitan.

In 1953, OCWD began making improvements in the Santa Ana River bed and areas adjacent to the river to increase recharge capacity. These improvements included modifying river channels and construction of off-channel recharge basins. Expansion of the recharge system has continued to the present time to the point where nearly all Santa Ana River non-stormflows are captured for recharge into the groundwater basin. Sources of recharge water have expanded to include water from Santiago Creek and purified water from the GWR System.

The recharge system consists of a series of recharge basins, also called percolation or spreading basins, whose sidewalls and bottoms allow for percolation into the underlying aquifer. The rate at which water enters from the surface into the ground is the percolation rate (or recharge or infiltration rate). The percolation rate and how it changes through time is the main factor in determining the effectiveness of the recharge facilities.

FIGURE 4-1
OCWD RECHARGE FACILITIES IN ANAHEIM AND ORANGE



Higher percolation rates allow a greater quantity of water to infiltrate into the groundwater basin. Percolation rates tend to decrease with time as the percolation basins develop a thin clogging layer on the basin bottom. The clogging layer develops from fine grain sediment deposition and from biological growth. Percolation rates are restored by mechanical removal of the clogging layer from the basins. Mechanical removal methods that are employed utilize heavy equipment such as dozers, scrapers, and other equipment. Additionally, basin cleaning vehicles are employed in selected basins. These basin cleaning vehicles operate while the basin is in operation.

4.1.1 Prado Basin

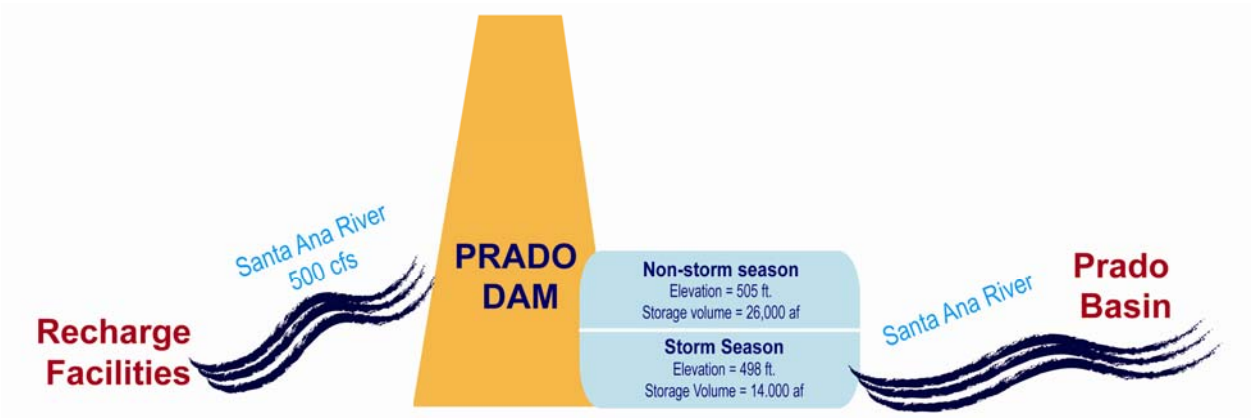
The majority of water recharging the basin is Santa Ana River water that enters Orange County after flowing through the Prado Dam. The dam, shown in Figure 4-2, was built by the U.S. Army Corps of Engineers (ACOE) in 1941 "for flood control and other purposes."

FIGURE 4-2
PRADO DAM AND OCWD PRADO WETLANDS

In the 1960s the ACOE began working with OCWD to conserve base and stormflows behind the dam in order to enable OCWD to divert flows into recharge facilities. In 1994, the ACOE adopted new dam operating procedures to increase water conservation (ACOE, 1994). During non-storm periods, the ACOE now releases water stored behind Prado Dam at rates compatible with OCWD's recharge capacity as long as the stored water does not compromise the use of the dam for flood control purposes.

Although the District's recharge system has the capacity to capture all Santa Ana River baseflows released through the Prado Dam, stormflows occasionally exceed the diversion capacity. OCWD continuously works with the ACOE to manage flow rates in order to maximize the recharge of stormflows. A new Memorandum of Agreement between OCWD and the ACOE, executed in 2006, authorized a four-foot increase in the maximum winter pool elevation. Water now can be stored temporarily behind Prado Dam up to an elevation of 498 feet mean sea level during the flood season, and up to an elevation of 505 feet during the non-flood season, as shown in Figure 4.3.

FIGURE 4-3
MAXIMUM CONSERVATION STORAGE ELEVATIONS ALLOWED BEHIND PRADO DAM



4.1.2 Recharge Facilities in Anaheim and Orange

The District operates 30 recharge facilities in the Cities of Anaheim and Orange and unincorporated areas of Orange County**.** These facilities, listed in Table 4-1, have a combined total storage volume of approximately 26,000 af. For descriptive purposes, they are grouped into four major components: the Main River System, the Off-River System, the Deep Basin System, and the Burris Basin/Santiago System.

TABLE 4-1
AREA AND STORAGE CAPACITIES OF RECHARGE FACILITIES

Facility	Wetted Area (acres)	Max. Storage Capacity (1) (af)
Anaheim Lake	72	2,260
Burris Basin	120	2,670
Conrock Basin	25	1,070
Five Coves Basin: Lower	16	182
Five Coves Basin: Upper	15	164
Foster-Huckleberry Basin	21	630
Kraemer Basin	31	1,170
La Jolla Basin	6.5	26
Lincoln Basin	10	60
Little Warner Basin	11	225
Miller Basin (2)	25	300
Mini-Anaheim Lake	5	13
Off-River Channel: Olive Basin-Carbon Creek Diversion	42	N/A
Off-River Channel: Weir Pond 4-Olive Basin	47	N/A
Olive Basin	5.8	122
Placentia Basin (2)	9	350
Raymond Basin (2)	19	370
River View Basin	3.6	11
Santa Ana River: Ball Road - Orangewood Ave.	59	N/A
Santa Ana River: Five Coves Dam-Ball Road	74	N/A
Santa Ana River: Imperial Hwy -Five Coves Dam	158	N/A
Santiago Basins: Bond Basin	86	8,380
Santiago Basins: Blue Diamond Basin	79	5,020
Santiago Basins: Smith Basin	22	320
Santiago Creek: Santiago Basins -Hart Park (3)	2.6	N/A
Warner Basin	70	2,620
Weir Pond 1	6	28
Weir Pond 2	9	42
Weir Pond 3	14	160
Weir Pond 4	4	22
Totals	**1,067**	**26,215**

Notes:
1. Maximum (Max.) storage capacity is typically not achieved for most facilities due to need to reserve buffer space for system flow and level fluctuations.
2. Owned by Orange County Flood Control District (OCFCD). Max. storage capacity shown is maximum flood control storage.
3. Various owners, including OCFCD, City of Orange, and Metropolitan.

4.1.2.1 Main River System

Water released at the Prado Dam naturally flows downstream and percolates through the river's 300-400 foot wide unlined channel bottom that consists of sandy, permeable sediment. The Main River System consists of approximately 291 acres along a six-mile reach of the Santa Ana River Channel, just west of Imperial Highway to Orangewood Avenue. Downstream of Orangewood Avenue shallow, low-permeability clay layers reduce the ability to recharge river water.

The upstream portion of the Main River System begins at the Imperial Inflatable Dam. The Imperial Inflatable Dam and Bypass Structure is one of the District's key control structures. It allows the District to divert Santa Ana River water from the Main River System into the Off-River System.

The Imperial Inflatable Dam, installed in 1993, is seven feet in diameter and 300 feet long, as shown in Figure 4-4. It is constructed of rubberized fabric that is inflated with air. When the stormflow rate exceeds approximately 1,500 cubic feet per second (cfs), the dam is deflated and only minimal water can be diverted for recharge. During some flow conditions, from 1,000-2,000 cfs, the dam is partially inflated, allowing some diversion for recharge and the remainder of the water to flow over the dam.

FIGURE 4-4
INFLATABLE DAM ON THE SANTA ANA RIVER

The pooled water behind the inflated dam flows through the bypass structure on the north side of the river. The bypass structure includes a series of steel gates leading to conduits that divert up to 550 cfs of water into the Off-River System. Water passes through trash racks to keep debris out and then flows into Weir Pond 1.

OCWD maximizes recharge in the Main River System by bulldozing a series of sand levees in the river, as shown in Figure 4-5. These levees allow greater percolation by increasing the residence time of water in the permeable section of the river and by spreading the water across the width of the river to maximize the wetted surface area. Typically, water flows at a velocity sufficient to prevent the accumulation of fine sediment and biological growth. The riverbed is also cleaned naturally, when winter and spring stormflows wash out the levees and scour the bottom. When necessary, heavy equipment is used to move sediments in order to restore the high percolation rate. Sand levees remain intact until flows exceed approximately 350 cfs, at which time they erode and water flows from bank to bank in the riverbed. Although percolation is believed to remain high during these high flow conditions, rates are difficult to measure.

FIGURE 4-5
SAND LEVEES IN THE SANTA ANA RIVER

The Santa Ana River bed percolation rate has been declining by approximately one percent per year for the last 20 years due to the coarsening of the river bed that is a common problem in river beds downstream of dams. This occurs because sand that would naturally flow down the river is trapped behind Prado Dam. The reduction in the amount of sand in the river bed causes sediments to become less conducive to percolation, particularly in the area closest to Imperial Highway.

4.1.2.2 Off-River System

The Imperial Inflatable Dam and Bypass Structure diverts Santa Ana River water flows from the Main River System into the Off-River System. This system includes four ponds called 'Weir Ponds' and a channel called the 'Off-River recharge basin'. Weir Ponds 1, 2, 3, and 4 are used to remove sediment from the Santa Ana River water diverted at the Imperial Inflatable Dam. The Weir Ponds have a surface storage of approximately 200 acre-feet. At the most downstream Weir Pond, Weir Pond 4, water can flow into the Off-River Recharge Basin, the Huckleberry Basin, or the Warner Bypass Pipeline. The Off-River Recharge Basin consists of a shallow, sandy bottom, 200-foot wide channel that runs parallel to the Main River System for approximately 2.3 miles from the Imperial Inflatable Dam down to the Carbon Creek Diversion Channel. The Off-River Recharge Basin is separated from the Main River System by a levee. Water in the Off-River Recharge Basin can be diverted into Olive Basin, which is located near Tustin Avenue.

4.1.2.3 Deep Basin System

The Deep Basin System consists of the Warner Basin Sub-system (Foster-Huckleberry, Conrock , Warner, and Little Warner Basins), along with Anaheim Lake, Mini Anaheim, and Miller, Kraemer, La Jolla, Placentia, and Raymond Basins. Up to 400 cfs of water can be diverted into Foster-Huckleberry and then into Conrock and Warner Basins. These recharge basins range in depth from 10 to 60 feet. Portions of their side-walls and bottoms are composed of natural, sandy, permeable materials that allow water to percolate into the aquifer. Percolation rates vary depending on the size and depths of the basins; rates slow significantly as fine-grained sediment particles accumulate on the basin bottoms. Most of the basins in this system can be drained and cleaned with equipment, shown in Figure 4-6, to remove this clogging layer, thereby restoring percolation rates and increasing recharge efficiency.

FIGURE 4-6
CLEANING OF RECHARGE BASINS

When the Warner Basin Sub-system is full, flows into the system are reduced to approximately 250 cfs. This maximizes percolation and allows the remainder of the water to be piped to the other downstream basins (Anaheim Lake, Mini Anaheim Lake, Miller, Kraemer, La Jolla, Placentia, and Raymond). Placentia and Raymond basins are owned by Orange County Public Works and can only be used during the non-flood season. Water is conveyed to these two basins using the Carbon Creek Channel.

The Five Coves Inflatable Dam is located on the Santa Ana River approximately three miles downstream of the Imperial Inflatable Dam. It was installed by OCWD in 1994 to divert flows into Five Coves, Lincoln, and Burris Basins. The dam is essentially the same size and construction as Imperial Inflatable Dam. Excess flows above 100 cfs and less than 500 cfs can be diverted at the dam; during storm events, flows over 500 cfs are lost to the ocean beyond this dam.

4.1.2.4 Burris Basin/Santiago System

The Burris Basin/Santiago System consists of 354 acres of shallow and deep recharge basins. The system begins at the confluence of the Santa Ana River and the Carbon Canyon Diversion Channel and ends at the Santiago Basins in Orange. It consists of Upper Five Coves, Lower Five Coves, Lincoln, Burris (shown in Figure 4-7) and River View Basins, the Santiago Basins (Blue Diamond Basin, Bond Basin, and Smith Basin), and Santiago Creek five miles east of the river.

The Five Coves Inflatable Rubber Dam diverts up to 500 cfs of flow from the Santa Ana River into Upper Five Coves Basin. This water can then flow sequentially into Lower

Five Coves Basin, Lincoln Basin, and Burris Basin. From there, the Burris Basin Pump Station can pump up to 230 cfs of water through the 66-inch diameter Santiago Pipeline to the Santiago Basins and Santiago Creek. Once Burris and the Santiago Basins are full, the flow must be reduced to match the Santiago Basins' percolation rate of approximately 125 cfs.

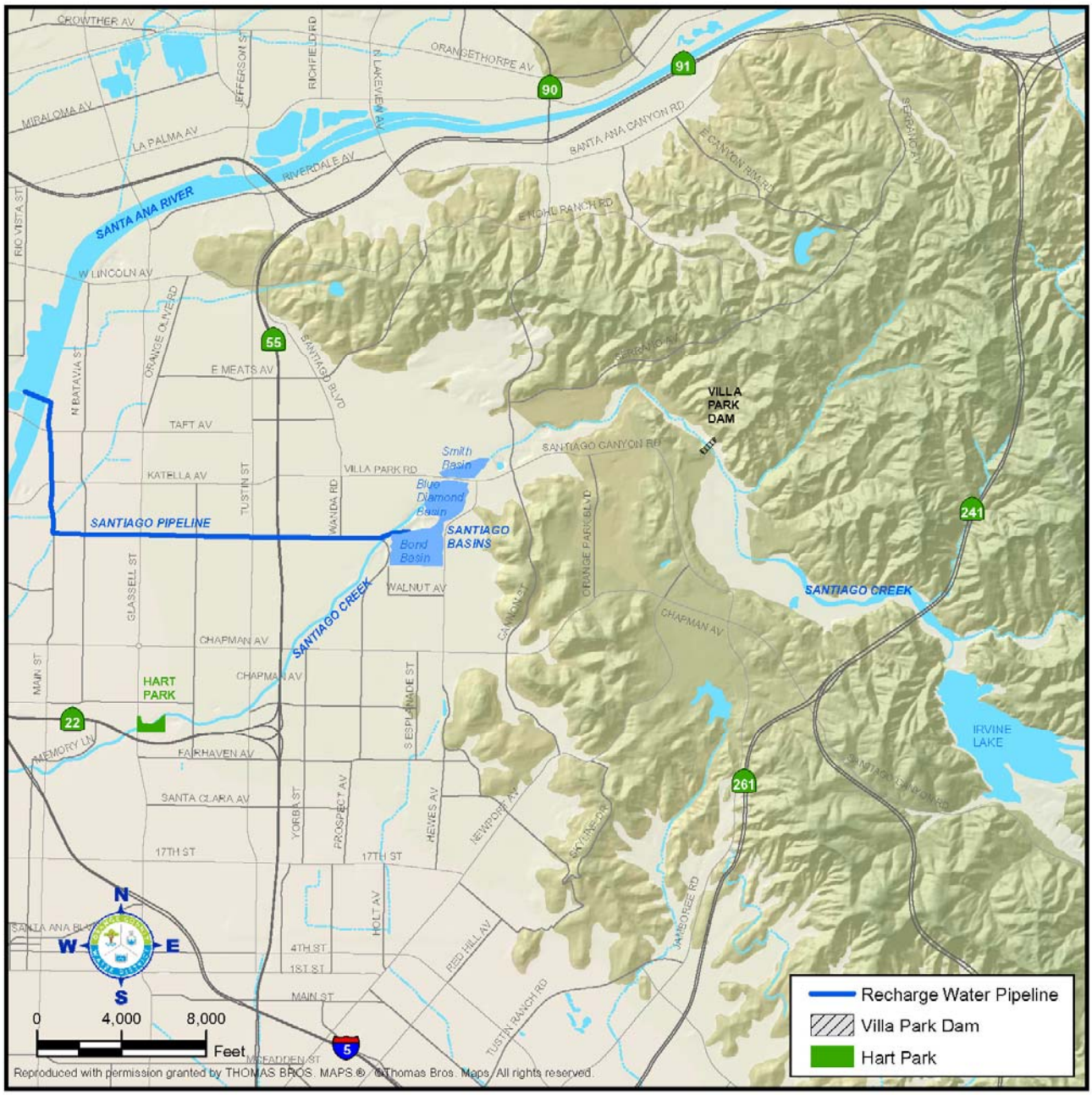
FIGURE 4-7
BURRIS BASIN

Santiago Creek, a tributary to the Santa Ana River, shown in Figure 4-8, is the primary drainage for the northwest portion of the Santa Ana Mountains. The creek extends from the mountains, through the City of Orange to its confluence with the Santa Ana River in the City of Santa Ana. Two dams along the river impound flows. Santiago Dam, which creates Irvine Lake, is owned by the Irvine Ranch and Serrano Water Districts. Villa Park Dam is primarily a flood control dam owned and operated by the Orange County Flood Control District.

OCWD's Santiago Basins are located downstream of Villa Park Dam. Here Santiago Creek flows are supplemented by water diverted from the Santa Ana River through the Santiago Pipeline. These former gravel pits recharge up to approximately 125 cfs when full. When the Santiago Basins are full, overflow from the basins flows down the sandy and rocky Santiago Creek bed. Natural percolation through the creek bottom into the groundwater basin occurs until water reaches Hart Park in the City of Orange.

The Santiago Basin Pump Station, completed in 2003, provides greater flexibility in managing recharge operations. Pumps placed in the bottom of Bond Basin move water out of the Santiago Basin into Santiago Creek or back down into the Santiago Pipeline where water can be discharged to the River View Basin or back to Burris Basin. River View Basin is located on the east side of the Santa Ana River adjacent to Burris Basin. Pumping water to and from the Santiago Basins increases the quantity of groundwater recharge and creates capacity in the Santiago Basins for storage of water from winter storms.

FIGURE 4-8
SANTIAGO CREEK STORAGE AND RECHARGE AREAS



4.2 Sources of Recharge Water

Water supplies used to recharge the groundwater basin are listed in Table 4-2.

TABLE 4-2
SOURCES OF RECHARGE WATER SUPPLIES

Water Supply		Source of Recharge Water Supply	Recharge location
Santa Ana River	Baseflow	Perennial flows from the upper watershed in Santa Ana River; predominately treated wastewater discharges	OCWD recharge basins and the Santa Ana River
	Stormflow	Precipitation from upper watershed flowing in Santa Ana River through Prado Dam	OCWD recharge basins and the Santa Ana River
Santiago Creek		Santiago Creek	OCWD recharge basins; natural percolation in Santiago Creek
Natural Recharge		Precipitation and flows from Orange County foothills	Throughout the basin
Purified Water	Groundwater Replenishment System	GWR System treatment facility	Injected into Talbert Barrier; Kraemer and Miller basins
	Water Replenishment District of Southern CA	Water purified at the Leo J. Vander Lans Treatment Facility	Injected into Alamitos Barrier
Imported Water and Supplemental Water	Metropolitan Water (untreated)	State Water Project and Colorado River Water	Various recharge basins
	Metropolitan Water (treated)	State Water Project and Colorado River Water through the Diemer Water Treatment Plant	Injected into Talbert and Alamitos Barriers
	Arlington Desalter	Purified water from Arlington Desalter released to Santa Ana River above Prado Dam	OCWD recharge basins
	San Bernardino Valley Municipal Water District	Surplus groundwater released into the Santa Ana River in San Bernardino	OCWD recharge basins
	Western Municipal Water	Surplus groundwater released into the Santa Ana River in Riverside	Released into the Santa Ana River above Prado Dam to OCWD recharge basins
In Lieu Replenishment Water	Metropolitan Water District of Southern California	Treated imported water used to replace pumping of groundwater, when available	Water is delivered directly to Producers

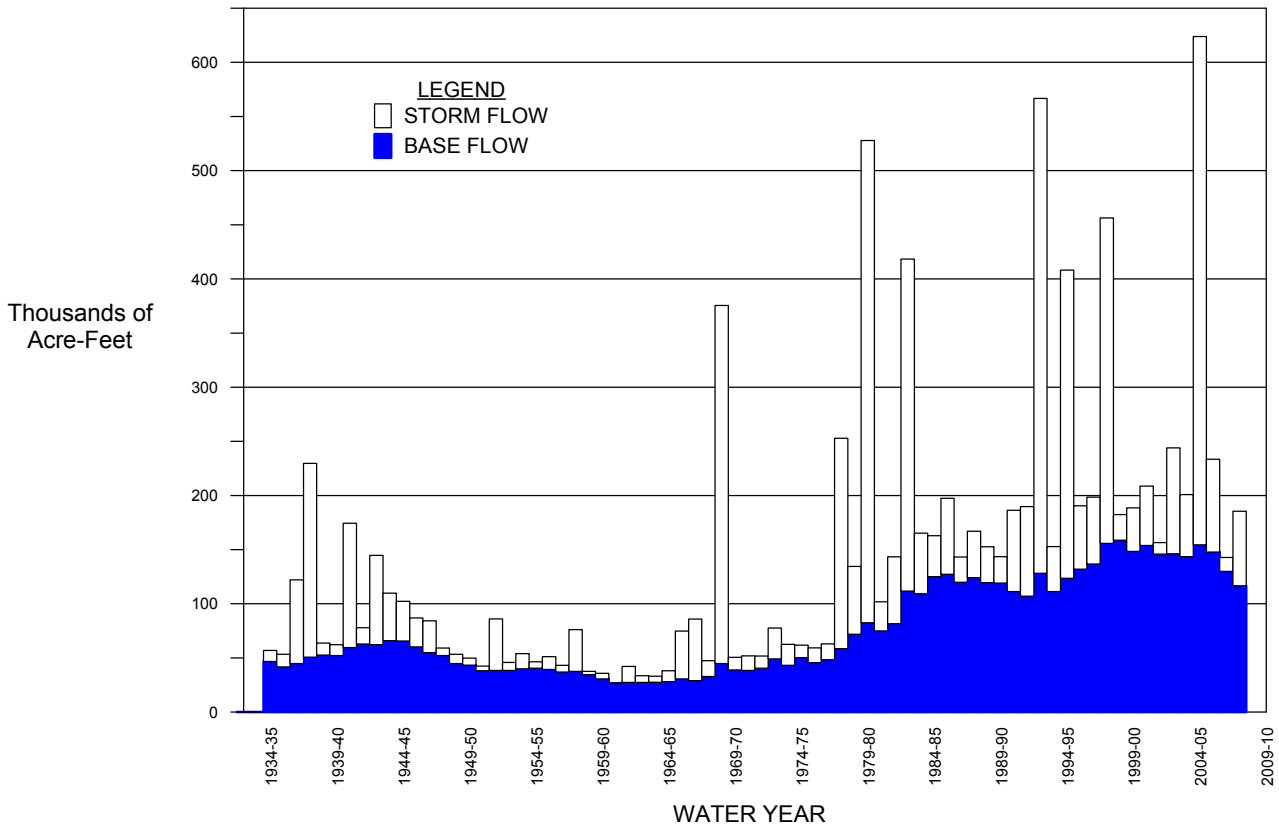
4.2.1 Santa Ana River

The primary source of water to recharge the basin is Santa Ana River flows. A large amount of the baseflow water, especially in the summer months, is composed of tertiary-treated wastewater discharges from wastewater treatment facilities upstream of Prado Dam.

OCWD has legal rights to a minimum of 42,000 afy of Santa Ana River baseflow. The minimum amount of Santa Ana River baseflow was established in a legal agreement entered into by OCWD and upstream water agencies in 1969. This agreement is commonly referred to as the '1969 Judgment.'

From the 1970s to the mid-1990s, the rate of Santa Ana River baseflow increased from approximately 50,000 afy to 150,000 afy. This is attributed primarily to population increases in the area above Prado Dam, which resulted in additional treated wastewater discharges from upstream communities. Figure 4-9 illustrates historic baseflow in the Santa Ana River at Prado Dam for the period from water year 1934-35 to 2006-07.

FIGURE 4-9
SANTA ANA RIVER FLOWS AT PRADO DAM



Source: Santa Ana River Watermaster 2009

In December 2008, the State Water Resources Control Board (SWRCB) approved the issuance of a permit to OCWD to appropriate 362,000 afy from the Santa Ana River. The SWRCB also agreed to hold an additional 143,000 afy in abeyance for OCWD for possible future projects. This provides an opportunity for OCWD to pursue long-term projects and complete environmental analysis and planning of those projects by 2023. Provided that this is completed by 2023, OCWD can seek the additional rights without the need to restart the water rights application process.

The volume of water recharged into the basin from Santa Ana River stormflows changes yearly due to variations in the amount of precipitation and the timing of precipitation and stormflow. Although stormflows average approximately thirty-three percent of the total Santa Ana River flows, only approximately half of that amount is recharged at OCWD's spreading facilities. This is primarily because the magnitude of stormflow releases from Prado Dam often greatly exceeds the District's diversion and recharge capacity. While the estimated maximum percolation capacity of the recharge basins is 500 cfs, the rate of Santa Ana River stormflow can reach up to 3,000 cfs or more, roughly six times the recharge capacity. The volume of water lost to the ocean can reach 5,000 af/day or more. Although it is common to have some loss to the ocean every year, during wet years losses can be great; in water year 1997-98, the District lost approximately 270,000 af of Santa Ana River stormflows to the ocean.

Figure 4-10 shows the precipitation at San Bernardino, indicating the variation of precipitation from year to year.

FIGURE 4-10
PRECIPITATION AT SAN BERNARDINO

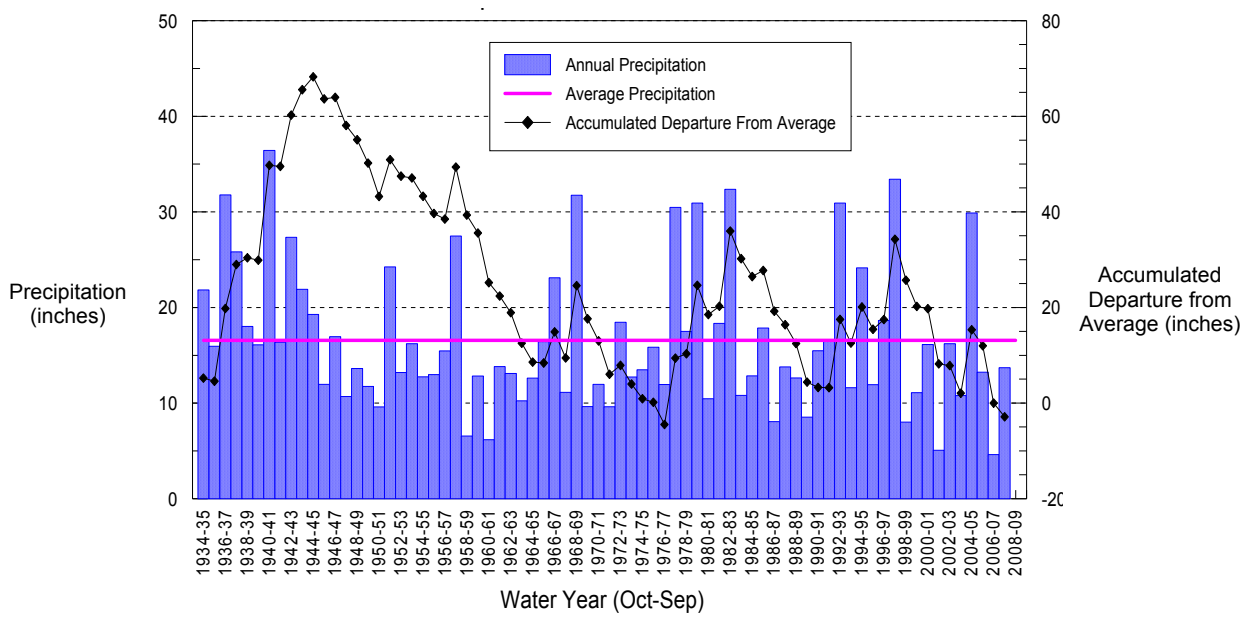
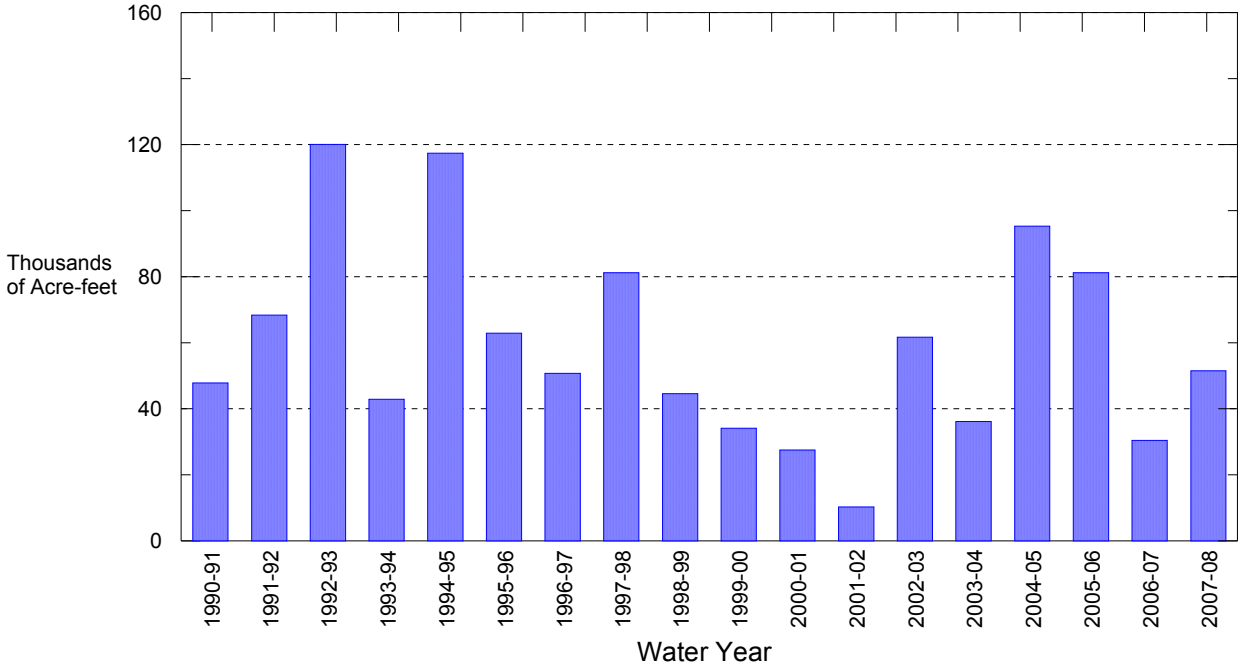


Figure 4-11 shows the amount of Santa Ana River stormflow recharged by the District for the past eighteen years. Based on the data in this figure, an average of 50,000 afy of stormflow has been captured and recharged. Precipitation in the form of snow accumulating in the upper watershed's mountains usually allows for greater recharge as snow melting over time provides a steady baseflow for recharge. Maximizing the capacity to store stormwater at Prado Dam for groundwater recharge also aids OCWD's efforts to maintain good water quality. Stormwater usually has lower total dissolved solids and nitrate concentrations than Santa Ana River baseflow, so blending stormwater with other sources of recharge water improves water quality.

FIGURE 4-11
STORMFLOW RECHARGED IN THE BASIN



4.2.2 Santiago Creek

Most of the natural flow of Santiago Creek is captured behind the impoundments described earlier. Water released into the creek flows downstream and recharges into the groundwater basin. Since 2000, OCWD has operated the Santiago Creek Recharge Project. A permit from the SWRCB (permit 19325) allows OCWD to collect and store up to 33,560 afy from Santiago Creek. Using controlled releases into the creek, up to approximately 15 cfs is recharged between the Santiago Basins and Hart Park in the City of Orange. In 2008, OCWD completed a project to grade the channel to smooth out the channel bottom. Over time the creek flows became confined to a relatively small notch in the channel. Removing this low-flow channel allowed water to spread out and cover a larger surface area, which increased the recharge rate.

In 2008-09, three monitoring wells were constructed to assess recharge conditions and water quality along Santiago Creek and the Santiago Basins. These wells will provide important information regarding recharge from the creek and the Santiago Basins.

4.2.2.1 Natural Recharge

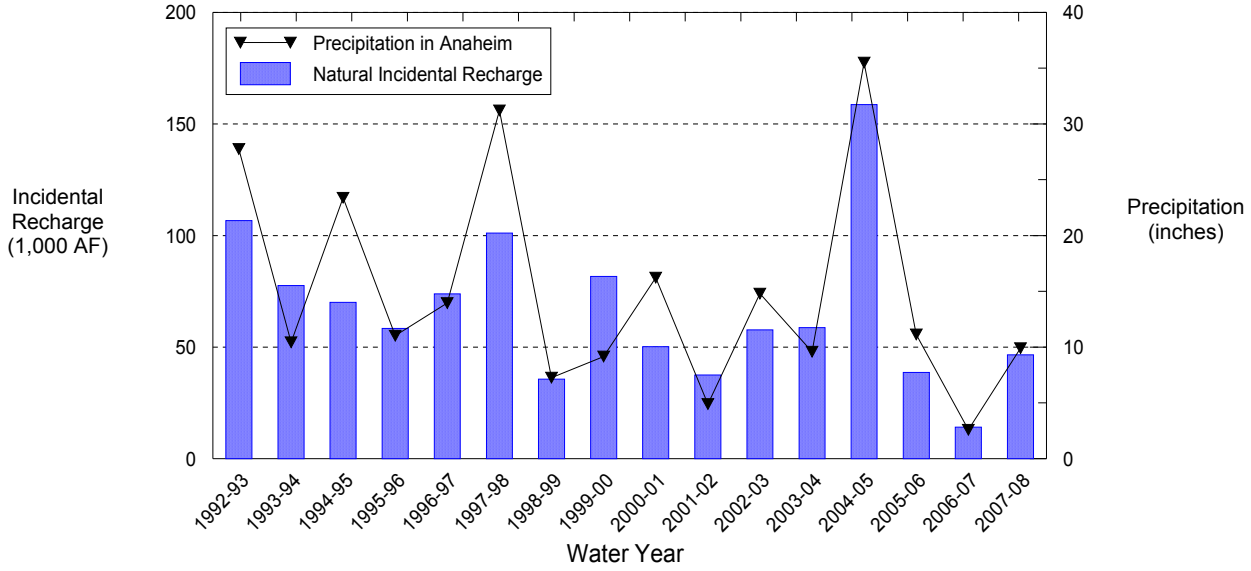
Natural infiltration of recharge, also referred to as incidental recharge, occurs from subsurface inflow from the local hills and mountains, infiltration of precipitation and irrigation water, unmeasured recharge from small flood control channels, and groundwater underflow to and from Los Angeles County and the ocean. Natural incidental recharge occurs outside the District's control.

Net incidental recharge refers to the net amount of incidental recharge that occurs after accounting for subsurface outflow to Los Angeles County. As described in Section 2, an increase in the accumulated overdraft in the basin decreases the estimated amount of outflow to Los Angeles County.

Estimated net incidental recharge and precipitation in Anaheim is shown in Figure 4-12. On average, approximately 60,000 af of net incidental recharge occurs each year. In very wet years such as 2004-2005, the amount of incidental recharge can be 100,000 afy or more.

The increase of impermeable surfaces reduces the amount of natural infiltration. New industrial, commercial, and residential developments may divert storm flows into channels that drain to the ocean instead of percolating into the ground. Decades of development with the emphasis on flood protection have encouraged rapid, efficient removal of stormwater. Concerns about the reduction in natural recharge as well as water quality impacts from landscape irrigation runoff and storm flow have increased interest in low-impact development (LID), the on-site capture and management of runoff. Utilization of LID, such as dry-wells, swales, wetlands, and other engineered systems can lead to an increase the rate of incidental recharge. Increasing infiltration, however, could have negative impacts if percolation of poor quality water would adversely impact the basin's water quality.

FIGURE 4-12
NET INCIDENTAL RECHARGE



4.2.3 Purified Water

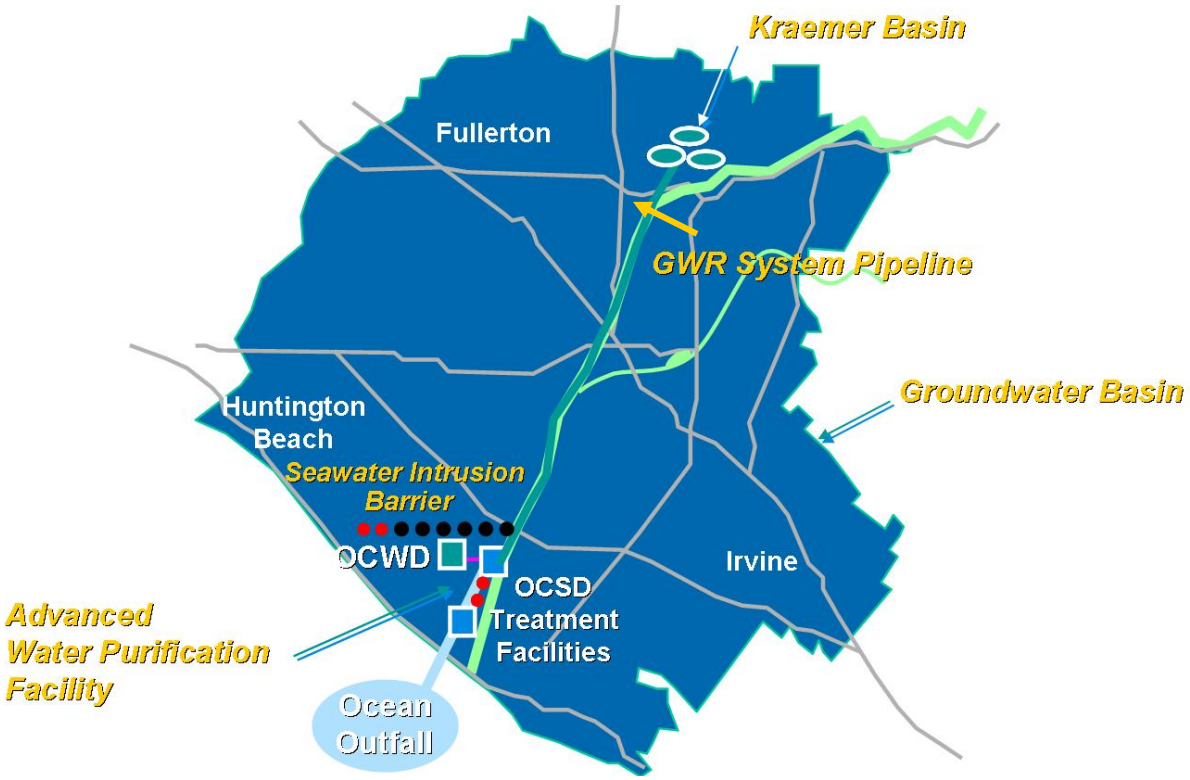
OCWD has been purifying wastewater to recharge the basin since 1975. Water Factory-21 (WF-21), in operation from 1975 to 2004, purified treated wastewater to provide a source for the Talbert Barrier. In 2008, the GWR System replaced WF-21 and began operation to provide water for groundwater recharge in Anaheim as well as for the Talbert seawater intrusion barrier.

4.2.3.1 Groundwater Replenishment System

The GWR System is a joint project of OCWD and the OCSD. The GWR System creates a new source of recharge water that will increase the reliability and sustainability of local groundwater supplies.

The GWR System augments existing groundwater supplies by producing up to 72,000 afy of purified water to recharge the basin and provide a reliable supply of water for the Talbert Seawater Barrier. As shown in Figure 4-13, the GWR System consists of three major components: (1) Advanced Water Treatment (AWT) facilities and pumping stations, (2) a pipeline connection from the treatment facilities to existing recharge basins, and (3) expansion of the Talbert Barrier.

FIGURE 4-13
GROUNDWATER REPLENISHMENT SYSTEM MAP



Secondary-treated effluent from the OCSD Wastewater Reclamation Plant No. 1 in Fountain Valley is pumped to the AWT facilities instead of to the ocean for disposal. The advanced water purification plant purifies the water with microfiltration (MF); reverse osmosis (RO); and advanced oxidation processes (AOP), which consist of ultraviolet (UV) and hydrogen peroxide (H_2O_2).

The first step in the tertiary treatment process is MF membrane treatment. MF is a low-pressure membrane process that removes small suspended particles, protozoa, bacteria and some viruses from the water. Sodium hypochlorite, a bleach solution, is added to the MF feedwater to minimize MF membrane fouling.

Next, the MF filtrate is fed to the RO treatment system. Dissolved contaminants and minerals, including dissolved organics, total dissolved solids, silica, and virus, are removed in the RO treatment process.

The water then undergoes UV and H_2O_2 treatments. UV light penetrates the cell walls of microorganisms, preventing replication and inducing cell death. This provides an additional barrier of protection against bacteria and viruses. More importantly, UV with H_2O_2 oxidizes organic compounds. At this point, the product water is so pure that it can not be moved in conventional pipes. Small amounts of minerals are added back into the water so that it is stable in the concrete pipes.

Although the GWR System is capable of producing 72,000 afy of water, the first year of operation actually produced less than 45,000 af of water. Operation of the system is limited by the supply of secondary-treated wastewater from OCSD. OCSD is in the process of constructing a pump station, scheduled to be completed before the end of 2009, which will help provide additional flow into the GWR System. When the pump station becomes operational, District staff expects to operate the GWR System to full capacity.

In addition, OCSD anticipates that construction of an expansion to their secondary treatment processes will be complete in late 2011. With this increase of available supply of wastewater, OCWD plans to expand the GWR System. The initial expansion will be designed to increase production by 17,000 to 20,000 afy of water.

4.2.3.2 Talbert and Alamitos Barriers

The GWR System is the primary source of water used for injection at the Talbert Barrier. An additional source of water for the barrier is treated potable water purchased from Metropolitan. Water for the Alamitos Barrier is supplied from two sources: imported water from Metropolitan and purified wastewater purchased from the Water Replenishment District of Southern California (WRD) under a joint cost sharing agreement with OCWD, as explained in Section 4.2.4.2.

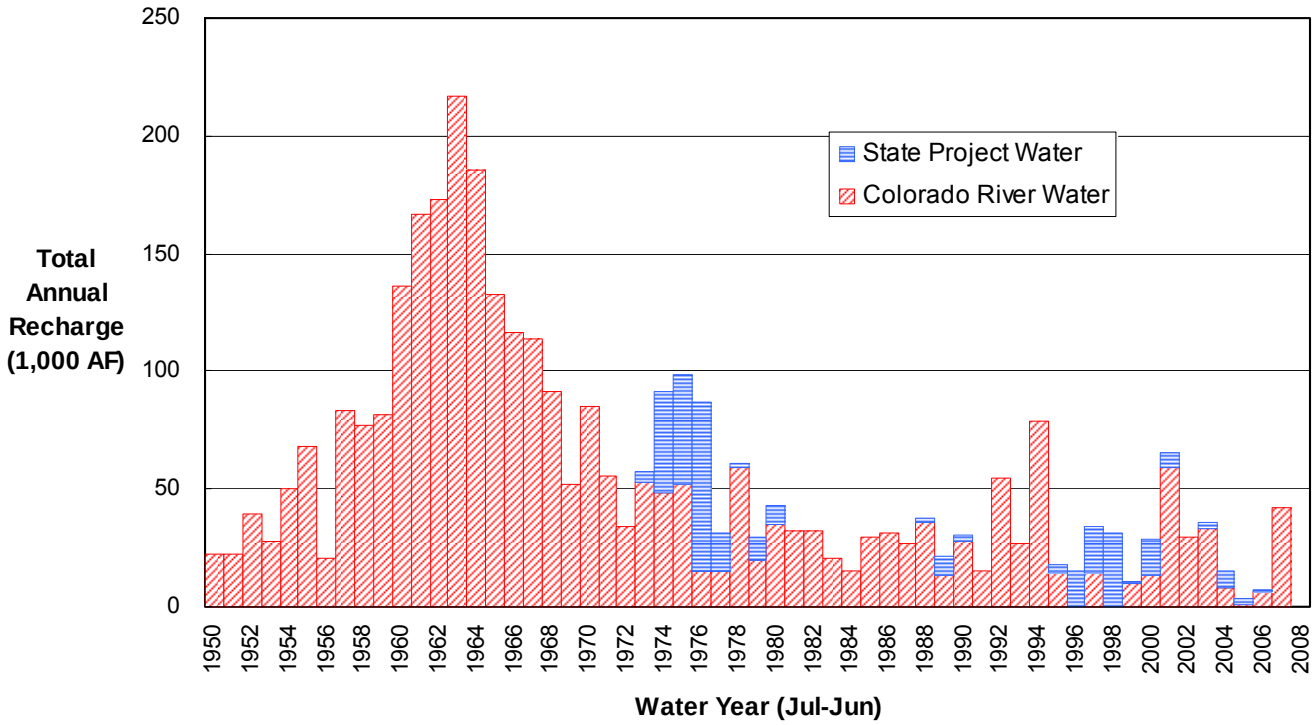
4.2.4 Imported Water

Water purchased by OCWD for recharge comes from a number of sources. This recharge water is also referred to as replenishment water, supplemental water or imported water. Total annual recharge of imported water from 1937 to 2008 is shown in Figure 4-14.

Metropolitan provides untreated replenishment water to the District when excess supplies are available. These supplemental supplies are an unreliable source of recharge water as they are typically unavailable to purchase during droughts. OCWD receives State Water Project (SWP) water from Northern California at a number of locations. Water released through a connection in Claremont flows down San Antonio Wash to Chino Creek, which drains into the Santa Ana River. Colorado River water can be delivered via the Santa Ana River upstream of OCWD's main recharge basins. A blend of SWP water and Colorado River waters can also be received directly into Anaheim Lake.

The District typically has recharge capacity available to receive this water during the summer/fall months. However, these supplies by nature are more frequently available during the winter season, which is when the District's recharge facilities are being used to capture and recharge Santa Ana River flows. The District can usually take between 50 cfs to 200 cfs (100 - 400 af/day) of direct replenishment water depending upon the operating condition of the recharge facilities.

FIGURE 4-14
ANNUAL RECHARGE OF IMPORTED WATER FROM METROPOLITAN, 1950-2008



4.2.4.1 Upper Watershed Imported Water

OCWD has historically entered into agreement with water agencies in the upper watershed to pay for excess upper watershed water that the agencies pump into the Santa Ana River that reaches Prado Dam. This water is captured for recharge in the OCWD facilities. The sources listed here are only available when the supplying water

agency has excess supplies. During times of drought, these sources become less available.

- The Arlington Desalter. When potable consumption does not match the output of the Arlington Desalter in Riverside, the District may purchase the excess water for groundwater recharge.
- The Bunker Hill Basin groundwater pump out project in San Bernardino is a cooperative project with the San Bernardino Valley Municipal Water District. The project was constructed to mitigate the negative impacts of high groundwater levels. Groundwater is pumped from the Bunker Hill Basin into the Santa Ana River.
- Western Municipal Water District provides to OCWD up to 7,000 afy of recharge water when available. This water is discharged into the Santa Ana River and is recharged into the groundwater basin in the District's recharge system.

4.2.4.2 Alamitos Seawater Intrusion Barrier Source Water

The WRD manages groundwater for nearly four million residents in 43 cities of southern Los Angeles County. The City of Long Beach, under contract with WRD, operates the Leo J. Vander Lans Treatment Facility, an advanced water treatment facility that treats effluent water from the Sanitation District of Los Angeles County using MF, RO, and UV treatment. About 2.7 million gallons of purified water are blended with imported water and pumped into the Alamitos Seawater Barrier.

4.2.4.3 In Lieu Replenishment Water

When recharge capacity is unavailable, OCWD can also receive replenishment water via an In-lieu program. In-lieu recharge refers to the practice of increasing groundwater storage by providing interruptible potable water supplies to a user who relies on groundwater as a primary supply. This treated potable water is made available to Producers who, in turn, use the supply in place of pumping an equal supply of groundwater. This program is revenue neutral for Producers and helps recharge the groundwater basin in a targeted manner.

4.3 Recharge Studies and Evaluations

The District has an ongoing program to assess enhancements in existing recharge facilities, evaluate new recharge methods, and analyze potential new recharge facilities.

4.3.1 OCWD RECHARGE ENHANCEMENT WORKING GROUP (REWG)

The REWG is composed of staff from several departments that works to maximize the efficiency of existing recharge facilities and evaluate new concepts to increase recharge capacity. REWG, with staff from recharge operations, hydrogeology, engineering, research and development, regulatory affairs, and the planning departments, meets on a regular basis to review new data and evaluate potential new projects.

Proposed projects, such as reconfiguration of existing basins, operational improvements to increase flexibility in the management of the basins, alternative basin cleaning methods, potential sites for new basins, and control of sediment concentrations, are discussed and prioritized.

4.3.2 COMPUTER MODEL OF RECHARGE FACILITIES

OCWD is in the process of developing a computer model of the District's recharge system in Anaheim and Orange. The model will simulate Prado Dam operations, Santa Ana River flow, and each recharge facility in order to model how the recharge system operates in conjunction with storage of water behind Prado Dam and flows from the Santa Ana River. This planning tool will be used to evaluate various conditions including estimating recharge benefits if new recharge facilities are constructed, existing facilities are improved, increased storage is achieved at Prado Dam, or baseflow changes occur in the Santa Ana River.

Output from the model will include:

- Amount of water in storage at Prado Dam and storage and recharge rates at each recharge facility;
- Amount of water that could not be recharged and the frequency of water loss to the ocean;
- Optimal amount of cleaning operations; and
- Available (unused) recharge capacity.

The model will be constructed so that it can be operated by District staff from a desktop personal computer using a graphical user interface.

4.4 Improvements to Recharge Facilities

The District regularly evaluates potential projects to improve the existing recharge facilities and build new facilities. Changes to existing facilities may include:

- improving the ability to transfer water from one recharge basin to another;
- improving the ability to remove the clogging layer that forms on the bottom of the recharge basins;
- removing shallow low-permeability silt or clay layers that occur beneath recharge basins
- improving the shape or configuration of the basin to increase the infiltration rate or ability to clean the basin; and
- converting an existing underperforming recharge basin to a new type of recharge facility.

The District also regularly evaluates building new facilities. This effort includes:

- evaluating existing flood control facilities that could be utilized to increase recharge;

- evaluating potential sites for purchase and subsequent construction of new recharge facilities; and
- evaluating potential dual-use sites, where a subsurface recharge system could be built and remain compatible with the existing use, such as building a subsurface infiltration gallery under a parking lot.

4.4.1 RECHARGE FACILITIES IMPROVEMENTS 2004-2008

The following projects were completed between 2004 and 2008 by OCWD to improve recharge operations:

La Jolla Basin

OCWD purchased land along Carbon Creek east of Placentia Basin and west of Kraemer Basin and constructed a new 6-acre recharge basin. Water is diverted from Carbon Creek using a rubber dam. The six-foot deep basin can be easily drained by gravity flow back to Carbon Creek when necessary for maintenance. The basin was placed on line in 2008 and is expected to recharge as much as 9,000 afy.

Olive Basin Intake Structure Improvements

Prior to acquisition by OCWD, the Olive Basin was mined for sand and gravel. A corrugated metal transfer tube was installed to convey Santa Ana River water into the basin. However, this transfer tube was located mid-way up the side of the basin and the flow discharging into the basin eroded the sidewalls, causing sediment to rapidly clog the basin. Improvements that were completed in 2007 included the installation of a new transfer pipe and concrete box set at the bottom of the basin to allow water to flow into the basin from the bottom.

Mini-Anaheim Recharge Basin Modifications

Improvements to this small basin made in 2005 increased the efficiency of moving Santa Ana River water into the basin. A new pipeline also was constructed to allow discharge of imported water directly into the basin.

Kraemer-Miller Basins Pipeline Improvements

An existing 48-inch pipe in Kraemer Basin was replaced due to the potential for pipe failure that would have resulted in damage to adjacent property and a reduction in recharge capacity from loss of ability to fill the basin. An inlet pipe was installed in Miller basin.

Lincoln-Burris Exploratory Wells

Monitoring wells were constructed to characterize the ability of the natural sediments along the west walls of Lincoln and Burris Basins to percolate water. Data collected were used to support a feasibility study of re-contouring the Burris Basin to allow periodic cleaning of the western side wall in order to increase percolation rates.

Warner Basin Dam

In order to clean Warner Basin, staff would construct an earthen dike to allow the draining of the basin while simultaneously transferring water to Anaheim Lake, Miller Basin, and Kraemer Basin. In 2007, a rubber dam was installed within the finger channel of the Little Warner Basin to eliminate the need to build the earthen dike each time the basin needed cleaning.

Santiago Creek Recharge Enhancement

The recharge capacity of Santiago Creek was increased by grading the creek bed upstream of Hart Park in the City of Orange. Prior to grading, a low-flow channel developed in the channel bottom. Water flow was confined to this low-flow channel, limiting the amount of groundwater recharge. The grading project completed in 2008 created a flat cross-section allowing for flows to spread out over a larger surface area, thereby increasing groundwater recharge.

4.5 Potential Projects to Expand Recharge Operations

The District's *Long-Term Facilities Plan* (2009) contains a list of potential new projects to expand recharge operations. Projects that are included range from those in the conceptual phase to those in the process of construction to improve operations of recharge facilities and to increase the amount of water recharged into the groundwater basin are described in this section.

Desilting Improvement Program

The build up of sediment in recharge basins decreases infiltration rates and increases the need for basin cleanings. Approaches are being evaluated to remove sediment from Santa Ana River water in order to increase the performance of current recharge facilities. A feasibility study identified proposed treatment systems for pilot testing.

Mid-Basin Injection

As the GWR System is expanded an increased supply of recharge water will be available. In order to recharge this supply of water, a mid-basin injection project is being considered. This would involve using high quality GWR System water for direct injection into the Principal aquifer in the central portions of the Basin. By directly injecting water into the Principal aquifer where most of the pumping occurs, low groundwater levels due to pumping can be reduced. Also, mid-basin injection would reduce the recharge requirement in Anaheim and Orange area recharge basins, thus providing more capacity to recharge Santa Ana River water.

Santiago Creek Enhanced Recharge

Two improvements to Santiago Creek in the City of Orange are being considered to enhance recharge capacity. One project consists of cutting a water conveyance channel through a concrete-lined creek channel to deliver a flow of water downstream of Hart Park. The geology in this lower stretch of the creek is being studied to determine if the recharge would be beneficial to the groundwater

basin. The second project would investigate the feasibility of constructing three small new recharge basins adjacent to Santiago Creek.

Subsurface Recharge

The subsurface recharge project would involve constructing horizontal recharge systems beneath areas with existing improvements, such as parks or school athletic fields. These infiltration galleries would allow percolation of recharge water through perforated pipes buried in gravel-filled trenches. Since there is no feasible way to clean the galleries, the source water would come from the GWR System, treated Metropolitan water, or filtered Santa Ana River water.

Recharge Basin Rehabilitation

All of the recharge basins are subject to clogging due to the accumulation of sediments contained in recharge water. To maintain recharge rates, the basins are periodically drained, allowed to dry, and then mechanically cleaned using heavy equipment. This process removes most of the clogging layer but also removes a portion of the underlying layer of clean sand from the basin bottom. Some of the fine-grained clogging material on the basin sides remains while the bottom of the basin progressively deepens. Although cleaning procedures have been improved to minimize the burial of fine-grained clogging material, previous cleaning practices have left an irregular mantle of fine-grained material in the upper one to two feet of some recharge basins. This may be remedied by over-excavating and replacing removed sediments with clean sand.

Burris and Lincoln Basins Reconfiguration

Modifications to Burris and Lincoln Basins will improve recharge capability. Plans include excavating low-permeability sediments from Lincoln Basin and the northern end of Burris Basin, reconfiguring the conveyance of water into Burris Basin, and expanding the size of Lincoln Basin. Also, a pilot transfer well will be drilled to transfer groundwater from the Shallow Aquifer to the Principal Aquifer at the southern end of Burris Basin.

Five Coves and Lincoln Basins Bypass Pipeline

Santa Ana River flows are diverted into the Upper Five Coves Basin by an inflatable dam. Transfer pipes convey surface flows from the Upper Five Coves to the Lower Five Coves Basin. Construction of a pipeline within the Lower and Upper Five Coves, Lincoln, and Burris basins would allow water transfers between the four basins. This would allow the Upper Five Coves, Lower Five Coves, and Lincoln Basins to be isolated and taken out of service to conduct cleaning operations, while maintaining flow of water to Burris and Santiago Basins. In the current system, inflow to Burris Basin has to be terminated to allow cleaning of the other four basins.

Santiago Basins Pump Station

A pump station was constructed to dewater the Santiago Basins to increase storm flow capture and percolation, to make storage available for winter season use, to provide water to the Santiago Creek for percolation, and to increase

operational flexibility by pumping water back to Burris Basin when necessary. Two of the four installed pumps failed to operate so the pump station needs to be redesigned and rebuilt. Reconstructing a pump station for the basins will increase recharge capacity and allow for more flexible and efficient operations.

Placentia and Raymond Basins Improvements

Improvements to Placentia and Raymond Basins that would increase the amount of water recharged in these basins include construction of in-channel diversion structures, modification of inlets to increase flows, installation of submersible pumps, and addition of flow measuring devices, water level sensors, and equipment to remotely control and record water levels and flows.

Santiago Basins Intertie

Constructing a connection between the Bond and Blue Diamond Basins would allow greater flexibility in managing recharge water. Conveyance of water from Blue Diamond Basin to Bond Basin is limited by a dirt berm that separates the two basins. This berm traps approximately 1,500 af of water in Blue Diamond Basin. Improvement would involve either removing a portion of the dirt berm or installing a pipe within the berm between the two basins at the bottom elevation of Blue Diamond Basin.

Olive Basin Pump Station

Improvements to Olive Basin will allow the basin to be drained more rapidly for cleaning. Olive Basin does not have a dewatering pump. An intake structure with a 36-inch diameter fill pipe was constructed to allow water to flow from the Off-River System into the deepest part of the pit. This decreased the amount of sediment stirred up in the basin, thereby increasing the recharge performance. Installation of a pump station and drain pipe will allow for future draining of the basin so that the basin can be cleaned quickly and restored to service.

Prado-Recharge Facilities Model

This project would create a mathematical model of Prado storage, Santa Ana River flow, and each recharge facility. The model would simulate how the recharge system operates in conjunction with Prado storage and the river. It is anticipated that the model would have a time step of one day. The model would allow the evaluation of changes in recharge that would occur if the District were to construct improvements to existing facilities, build new recharge facilities, or achieve increased levels of storage at Prado Dam.

5 WATER QUALITY MANAGEMENT

Water quality protection is a basic tenet of OCWD. The District manages the groundwater basin to protect water quality. This section describes the range of programs conducted by OCWD throughout the watershed including:

- **Implementing OCWD's Groundwater Protection Policy;**
- **Participating in water quality management programs in the watershed;**
- **Managing levels of salinity and nitrate;**
- **Restoring contaminated water supplies;**
- **Developing programs to monitor constituents of emerging concern.**

5.1 Groundwater Quality Protection

The District conducts an extensive program aimed at protecting the quality of the water in the basin. These programs include groundwater monitoring, participating in and supporting voluntary watershed water quality studies and regulatory programs, working with groundwater producers, providing technical assistance, and conducting public education programs.

5.1.1 OCWD GROUNDWATER QUALITY PROTECTION POLICY

OCWD adopted the Groundwater Quality Protection Policy in May 1987, in recognition of the serious threat posed by groundwater contamination; passage was based on the statutory authority granted under Section 2 of the District Act. The objectives of the policy are to:

- Maintain groundwater quality suitable for all existing and potential beneficial uses;
- Prevent degradation of groundwater quality;
- Assist regulatory agencies in identifying the sources of contamination to assure cleanup by the responsible parties;
- Maintain or increase the basin's usable storage capacity; and
- Inform the general public, regulatory agencies and Producers of the condition of the groundwater basin and of water quality problems as they are discovered.

Eight specific programs established to achieve these objectives are:

- Water quality monitoring of surface and groundwater;
- Identification, interim containment, and cleanup of contamination;
- Coordinated operation with regulatory agencies;
- Control of toxic residuals;

- Hazardous waste management planning;
- Dissemination of technical information;
- Public disclosure; and
- Groundwater protection evaluation.

A key component of the policy describes circumstances under which the District will undertake contamination cleanup activities at District expense. This becomes necessary when contamination poses a significant threat and the party responsible for the contamination cannot be identified, is unable to cleanup the contamination, or is unwilling to cleanup the contamination. When appropriate to protect water quality in the basin, OCWD provides financial incentives for Producers to pump and treat groundwater that does not meet drinking water quality standards. These so-called "Basin Equity Assessment (BEA) Exemptions" are explained in Section 5.9.

5.1.2 WATER QUALITY TREATMENT GOALS FOR GROUNDWATER PROGRAMS

OCWD encourages clean up of groundwater to maximize beneficial use of contaminated water in areas with high concentrations of TDS, nitrates, selenium, color, organic compounds, and other constituents exceeding drinking water standards. Treatment goals include:

- State primary and secondary drinking water standards must be met when water is used for potable supplies.
- Treatment for irrigation water shall meet criteria necessary for the intended beneficial use.
- The District shall pursue payment or reimbursement of cleanup costs from the responsible party when contamination originates from a known source.

5.1.3 REGULATION AND MANAGEMENT OF CONTAMINANTS

A variety of federal, state, county and local agencies have jurisdiction over the regulation and management of hazardous substances and the remediation of contamination of groundwater and drinking water supplies. For example, the County of Orange Health Care Agency (OCHCA) regulates leaking underground fuel tanks except in cases where the city is the lead agency.

OCWD does not have regulatory authority to require responsible parties or potential responsible parties to clean up pollutants that have contaminated groundwater. In some cases, the District has pursued legal action against entities that have contaminated the groundwater basin to recover the District's remediation costs. In other cases, the District coordinates and cooperates with regulatory oversight agencies that investigate sources of contamination and assess the potential threat that the contamination poses to public health and the environment in the Santa Ana River watershed and within the County of Orange. Some of these efforts include:

- Reviewing on-going groundwater cleanup site investigations and commenting on the findings, conclusions, and technical merits of progress reports.
- Providing knowledge and expertise to assess contaminated sites and evaluating the merits of proposed remedial activities.

- Conducting third party groundwater split samples at contaminated sites to assist regulatory agencies in evaluating progress of groundwater cleanup and/or providing confirmation data of the areal extent of contamination.

5.1.4 LAND USE AND DEVELOPMENT

Protecting groundwater from contamination protects public health and prevents loss of valuable groundwater resources. Managing land use and planning for future development are key management activities essential for protecting water quality and reducing the risk of contamination.

OCWD monitors, reviews, and comments on environmental documents such as Environmental Impact Reports (EIR), Notices of Preparation, proposed zoning changes, and land development projects. District staff also review draft National Pollution Discharge Elimination System (NPDES) and waste discharge permits issued by the Santa Ana Regional Water Quality Control Board (RWQCB). The proposed projects and programs may have elements that could cause short or long term water quality impacts to source water used for groundwater replenishment or have the potential to degrade groundwater resources. Monitoring and reviewing waste discharge permits provides the District with insight on activities in the watershed that could affect water quality.

The majority of the basin's land area is located in a highly urbanized setting and requires tailored water supply protection strategies. Reviewing and commenting on stormwater permits adopted by the RWQCB for the portions of Orange, Riverside, and San Bernardino Counties that are within the Santa Ana River watershed are important. These permits can affect the quality of water in the Santa Ana River and other water bodies, thereby impacting groundwater quality in the basin.

OCWD works with local agencies having oversight responsibilities on the handling, use, and storage of hazardous materials; underground tank permitting; well abandonment programs; septic tank upgrades; and drainage issues. Participating in basin planning activities of the RWQCB and serving on technical advisory committees and task forces related to water quality are also valuable activities to protect water quality.

5.1.5 DRINKING WATER SOURCE ASSESSMENT AND PROTECTION PROGRAM

To comply with federal Safe Drinking Water Act requirements regarding the protection of drinking water sources, the California Department of Public Health (CDPH) created the Drinking Water Source Assessment and Protection (DWSAP) program. Water suppliers must submit a DWSAP report as part of the drinking water well permitting process and have it approved before providing a new source of water from a new well. OCWD provides technical support to Producers in the preparation of these reports.

This program requires all well owners to prepare a drinking water source assessment and establish a source water protection program for all new wells. The source water program must include: (1) a delineation of the land area to be protected, (2) the identification of all potential sources of contamination to the well, and (3) a description of management strategies aimed at preventing groundwater contamination. Managing land use and planning for future development are key management activities essential

for protecting, preventing, and reducing contaminant risks to future drinking water supplies.

Developing management strategies to prevent, reduce, or eliminate risks of groundwater contamination is one component of the multiple barrier protection of source water. Contingency planning is an essential component of a complete DWSAP and includes developing alternate water supplies for unexpected loss of each drinking water source, by man-made or catastrophic events.

5.1.6 WELL CONSTRUCTION POLICIES

Wells constructed by the District are built to prevent the migration of surface contamination into the subsurface. This is achieved through the placement of annular well seals and surface seals during construction. Also, seals are placed within the borehole annulus between aquifers to minimize the potential for flow between aquifers.

Well construction ordinances adopted and implemented by the OCHCA and municipalities follow state well construction standards established to protect water quality under California Water Code Section 231. To provide guidance and policy recommendations on these ordinances, the County of Orange established the Well Standards Advisory Board in the early 1970s. The five-member appointed Board includes the District's Hydrogeologist. Recommendations of the Board are used by the OCHCA and municipalities to enforce well construction ordinances within their jurisdictions.

5.1.7 WELL CLOSURE PROGRAM FOR ABANDONED WELLS

A well is considered abandoned when either the owner has permanently discontinued its use or it is in such a condition that it can no longer be used for its intended purpose. This often occurs when wells have been forgotten by the owner, were not disclosed to a new property owner, or when the owner is unknown. Past research conducted by OCWD identified approximately 1,400 abandoned wells which were not properly closed. Many of these wells may not be able to be properly closed due to overlying structures, landscaping, or pavement. Some of them may pose a threat to water quality because they can be conduits for contaminant movement as well as physical hazards to humans and/or animals.

OCWD supports and encourages efforts to properly close abandoned wells. As part of routine monitoring of the groundwater basin, OCWD will investigate on a case-by-case basis any location where data suggests that an abandoned well may be present and may be threatening water quality. When an abandoned well is found to be a significant threat to the quality of groundwater, OCWD will work with the well owner to properly close the well.

The City of Anaheim has a well destruction policy and has an annual budget to destroy one or two wells per year. The funds are used when an abandoned well is determined to be a public nuisance or needs to be destroyed to allow development of the site. The city's well permit program requires all well owners to destroy their wells when they are no longer needed. When grant funding becomes available, the city uses the funds to

destroy wells where a responsible party has not been determined and where the well was previously owned by a defunct water consortium.

5.2 Salinity Management

Increasing salinity is a significant water quality problem in many parts of the southwestern United States and Southern California, including Orange County. Elevated salinity levels can contaminate groundwater supplies, constrain implementation of water recycling projects and cause other negative economic impacts such as the need for increased water treatment by residential, industrial, commercial users, and water utilities. Often a component of salinity, elevated levels of nitrates pose a risk to human health.

5.2.1 SOURCES OF SALINITY

Salinity is a measure of the dissolved minerals in water. Also referred to as salts or TDS, salinity is measured in the laboratory by evaporating a known volume of water to dryness and measuring the remaining salts.

Dissolved minerals are composed of positively charged cations and negatively charged anions. Principal cations include sodium, calcium, potassium, and magnesium. Key anions are chloride, sulfate, carbonate, and bicarbonate. Water's hardness, related to TDS, refers to the measure of divalent metallic cations, principally calcium and magnesium.

High salinity and hardness limit the beneficial uses of water for domestic, industrial, and agricultural applications. Hard water causes scale formation in boilers, pipes, and heat-exchange equipment as well as soap scum and an increase in detergent use. This can result in the need to replace plumbing and appliances and require increased water treatment. Some industrial processes, such as computer microchip manufacturers, must have low TDS in the process water and often must treat the municipal supply prior to use. High salinity water may reduce plant growth and crop yield, and clog drip irrigation lines.

In coastal areas, seawater intrusion can be a major source of increased salinity in groundwater. Other identified sources of coastal groundwater salinity include connate water (water trapped in the pores of the sediment at the time the sediments were deposited) and brines disposed from past oil production.

5.2.2 REGULATION OF SALINITY

TDS is regulated by the EPA and the CDPH as a constituent that affects the aesthetic quality of water – notably, taste. The recommended secondary MCLs for key constituents comprising TDS are listed in Table 5-1.

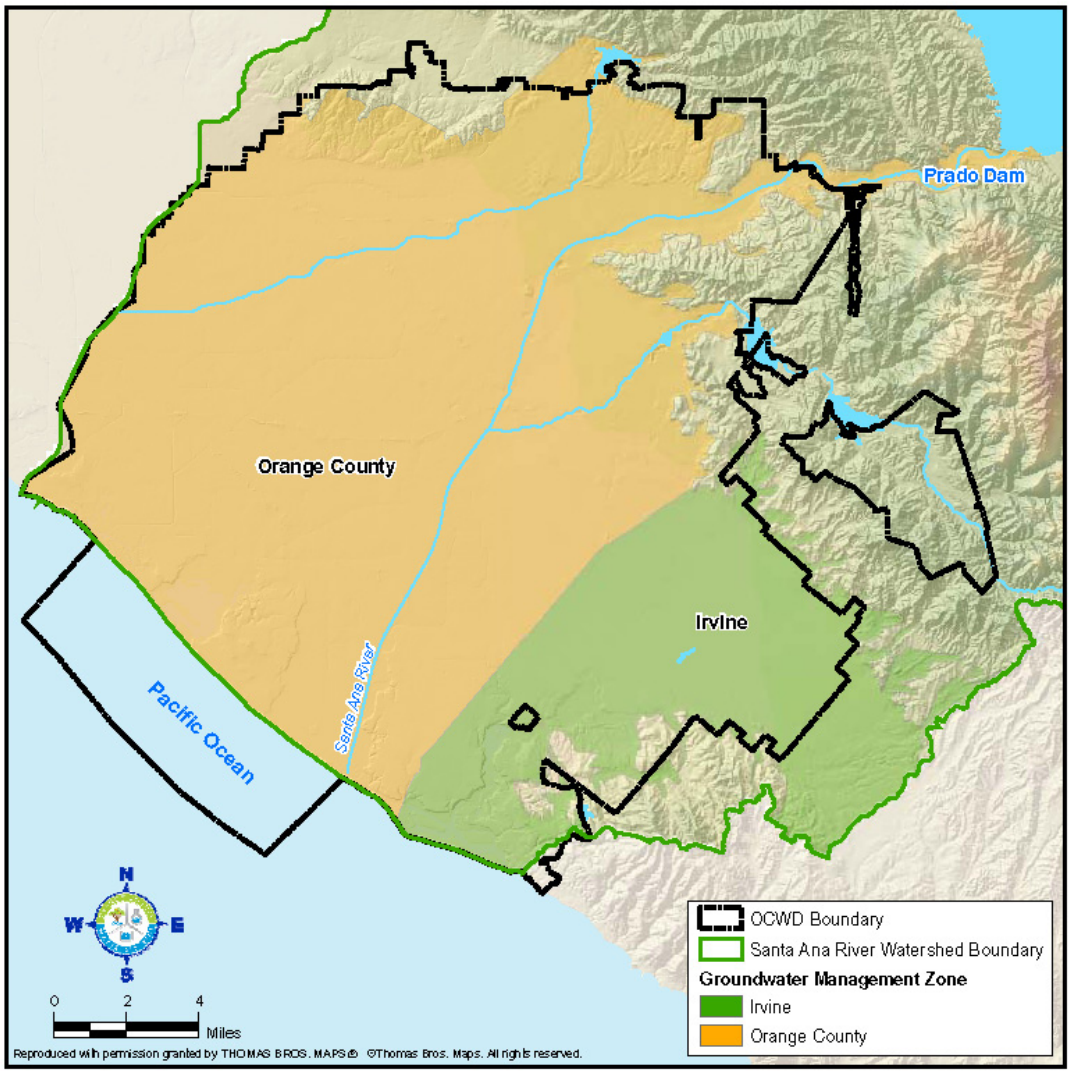
At the state level, TDS levels in groundwater are managed by the SWRCB which delegates this authority to the regional boards. The Santa Ana RWQCB salinity management program was developed with extensive stakeholder input. The Santa Ana Watershed is divided into management zones and allowable TDS levels are determined

for each of those zones. The Orange County groundwater basin is divided into two management zones as shown in Figure 5-1.

TABLE 5-1
SECONDARY DRINKING WATER STANDARDS FOR SELECTED CONSTITUENTS

Constituent	Recommended Secondary MCL, mg/L
Total Dissolved Solids (salts)	500
Chloride	250
Sulfate	250

FIGURE 5-1
Groundwater Management Zones



To set the allowable levels of TDS for each management zone, historical ambient or baseline conditions were determined. These were used by the RWQCB to set 'Water Quality Objectives" for each management zone, which were officially adopted as part of the Water Quality Control Plan for the Santa Ana River Basin, also referred to as "the Basin Plan." The levels of TDS in each groundwater management zone are measured periodically and compared to the adopted objectives.

When a newly determined ambient level is equal to or greater than the established objective, that management zone does not have an "assimilative capacity." This means that the quality of the groundwater in that zone is determined to be incapable of successfully assimilating increased loads of TDS without degrading the water quality. Conversely, when an updated ambient level is lower than the established objective, that management zone has an assimilative capacity and is determined to be capable of receiving modest inputs of TDS without exceeding the Water Quality Objective.

The Water Quality Objectives and ambient quality levels for the two Orange County management zones are shown in Table 5-2. Comparing the ambient water quality to the TDS objectives indicates that neither one of these zones have assimilative capacity for TDS.

TABLE 5-2
TDS WATER QUALITY OBJECTIVES FOR LOWER SANTA ANA RIVER BASIN MANAGEMENT ZONES

Management Zone	Water Quality Objective (mg/L)	Ambient Quality (mg/L)
Orange County	580	590
Irvine	910	920

(Wildermuth, 2008)

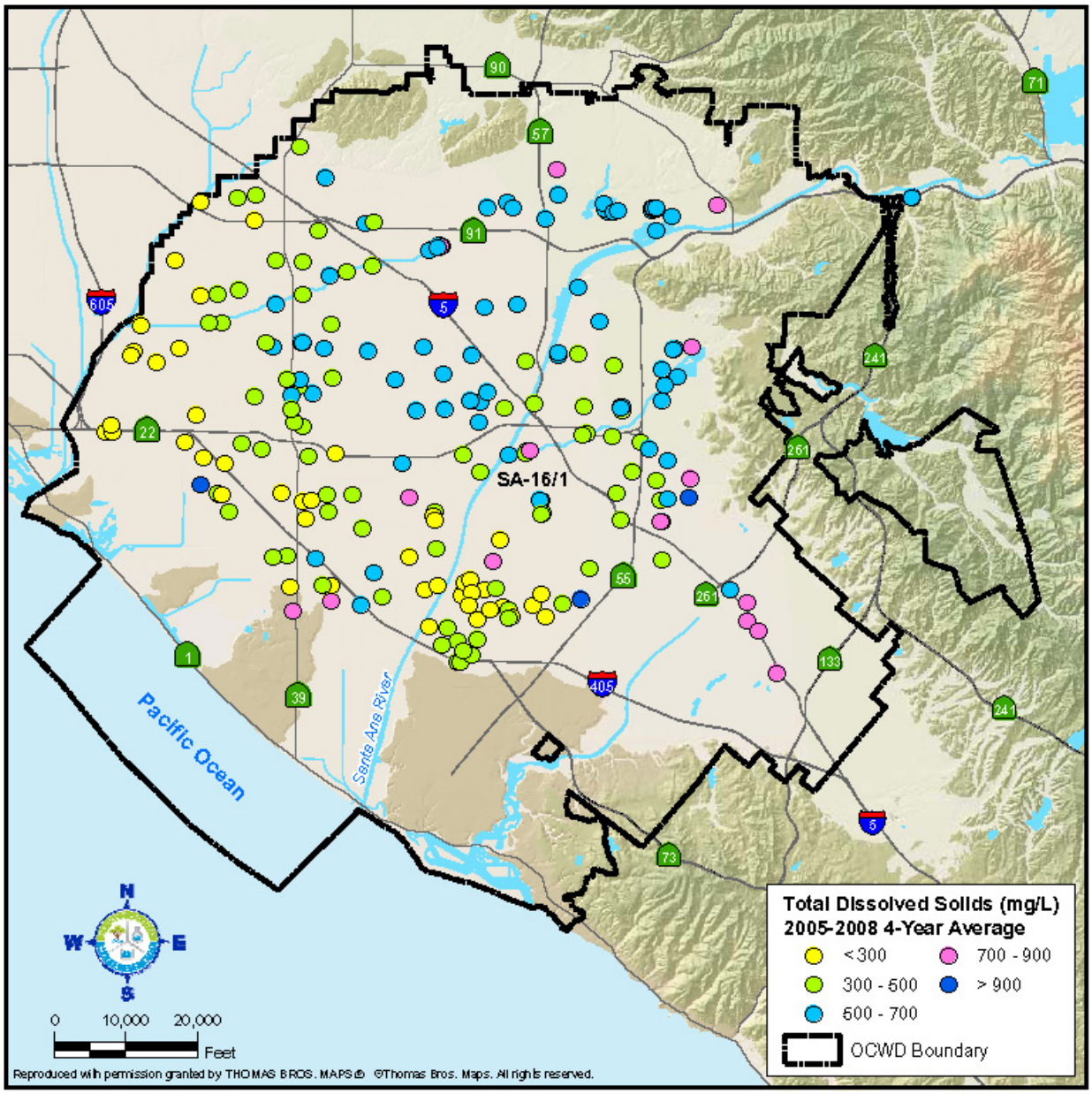
5.2.3 SALINITY IN THE GROUNDWATER BASIN

As explained in Section 3, OCWD monitors the levels of TDS in wells throughout the groundwater basin. Figure 5-2 shows the average TDS at production wells in the basin for the period of 2004 to 2008. In general, the portions of the basin with the highest TDS levels are located in areas of Irvine, Tustin, Yorba Linda, Anaheim and Fullerton. In addition, there is a broad area in the middle portion of the basin where the TDS generally ranges from 500 to 700 mg/L. Localized areas near the coast, where water production does not occur, contain relatively higher TDS concentrations.

Managing salinity levels in the basin and in recharge water is an important objective for the District. As explained in Section 4, water that recharges the Orange County groundwater basin includes:

- Santa Ana River baseflow and stormflow,
- Groundwater Replenishment System water, and
- Incidental recharge, including precipitation and irrigation return flows.

FIGURE 5-2
TDS IN GROUNDWATER PRODUCTION WELLS



Understanding the sources of salt and measuring the concentrations of TDS in each of the recharge sources is an important aspect in managing salinity. Table 5-3 presents the estimated salt inflows for the basin using average recharge volumes.

The inflows used here are the same as those used in calculating the basin water budget as explained in Section 2.3 and displayed in Table 2-2. TDS concentrations for the inflows were based on flow and water quality data collected by the District and the USGS. The Talbert injection barrier was calculated with the assumption that barrier water is from the GWR System and the Alamitos injection barrier was calculated using

the assumption that injection water is a 50:50 blend of recycled water and imported water.

The flow-weighted TDS of local incidental recharge of 1,100 mg/L was calculated using estimates of the TDS concentration of each component listed in Table 2-2. For subsurface inflow and recharge from the foothills, the TDS concentration was estimated using data from the closest nearby wells.

As shown in Table 5-3, the District estimates that the flow-weighted average inflow TDS concentration is 536 mg/L. It is important to note that the TDS concentration of GWR System water is 60 mg/L. OCWD anticipates that over time the use of GWR System water for Talbert Barrier operations and groundwater recharge will have a positive impact on the salt balance of the groundwater basin.

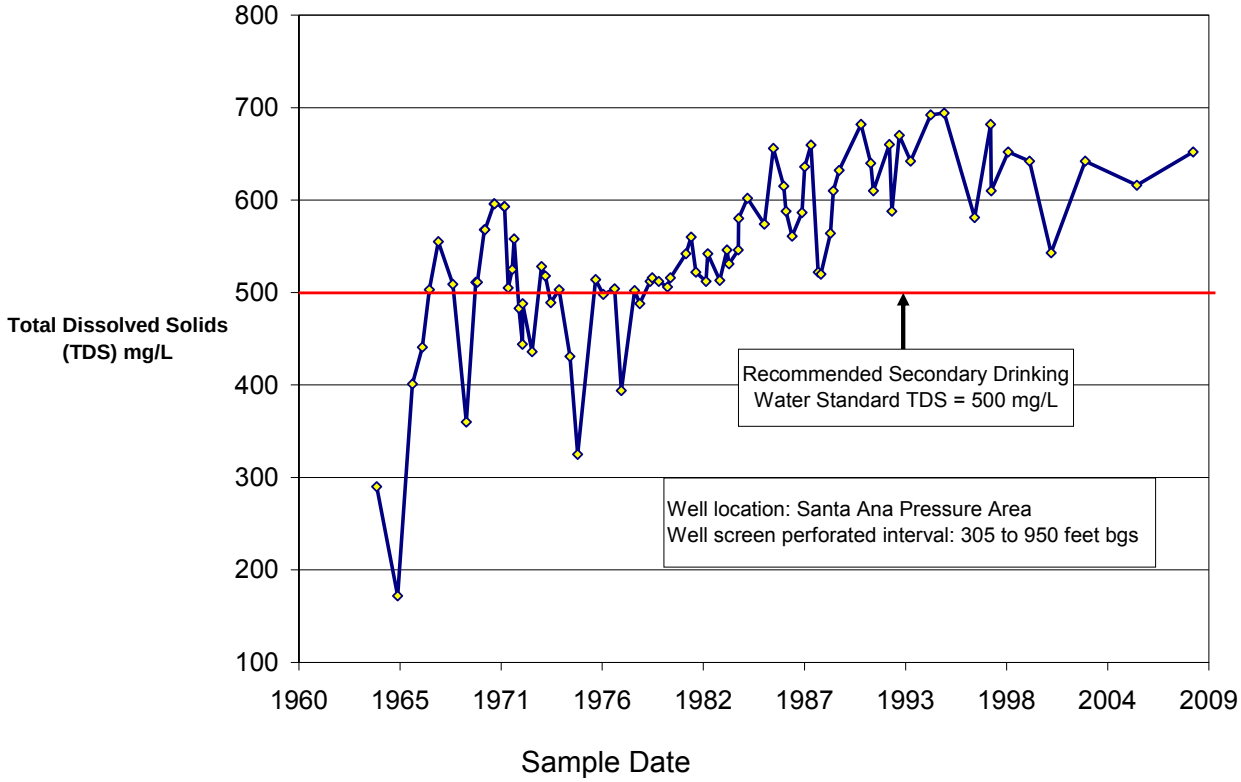
TABLE 5-3
SALT INFLOWS FOR ORANGE COUNTY AND IRVINE MANAGEMENT ZONES

	Inflow (afy)	TDS (mg/L)	Salt (tons/yr)
Recharged SAR Baseflow	148,000	620	125,000
Recharged SAR Stormflow	50,000	200	14,000
GWR System water recharge in Anaheim	37,000	60	3,000
Unmeasured Recharge (Incidental)	69,000	1,100	104,000
Injection Barriers			
Talbert	35,000	60	2,900
Alamitos	2,500	350	1,200
Total:	341,500	536*	250,100

* Flow weighted

Figure 5-3 illustrates TDS concentrations through time at a well in Santa Ana. The location of well SA-16 is shown on Figure 5-2. The TDS concentration at well SA-16 increased from approximately 200 to 300 mg/L in the mid-1960s to approximately 600 mg/L by the mid-1980s. From the mid-1980s to 2008, the TDS concentration varied between 500 to 700 mg/L.

FIGURE 5-3
TDS IN A POTABLE SUPPLY WELL (SA-16/1)



5.2.4 ECONOMIC IMPACTS OF INCREASING SALINITY

Increasing salinity of water supplies directly impacts consumer costs. A technical investigation of salinity impacts on water supplies of Southern California was published in 1999 by the United States Department of Interior, U.S. Bureau of Reclamation and the Metropolitan Water District of Southern California. The *Salinity Management Study* assessed economic impacts of salinity increases in Colorado River water and State Water Project water. The model was developed to account for regional differences in water deliveries, demographics, TDS concentrations, and average water use per household or by agriculture or industry.

The study estimated a regional economic benefit of $95 million per year (calculated in 1998 dollars) for a 100 mg/L decrease in imported water supply TDS in the Metropolitan region. Conversely, a 100 mg/L increase in TDS would increase consumer costs by $95 million annually as shown in Figure 5-4. Approximately $18 million annually would be realized in cost savings for groundwater supplies. Residential cost savings were estimated at $35 million per year. Figure 5-5 shows $64 million of benefits if most local groundwater (about 90 percent) and wastewater (about 80 percent) were to experience a 100 mg/L decrease in salinity.

FIGURE 5-4
ANNUAL ECONOMIC BENEFITS OF 100 MG/L SALINITY DECREASE IMPORTED WATER SUPPLIES
Source: MWD and Bureau of Reclamation Salinity Management Study (1999)

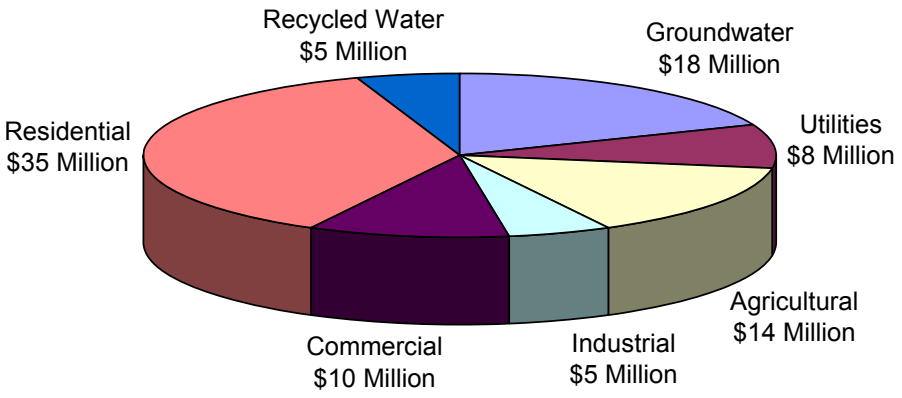
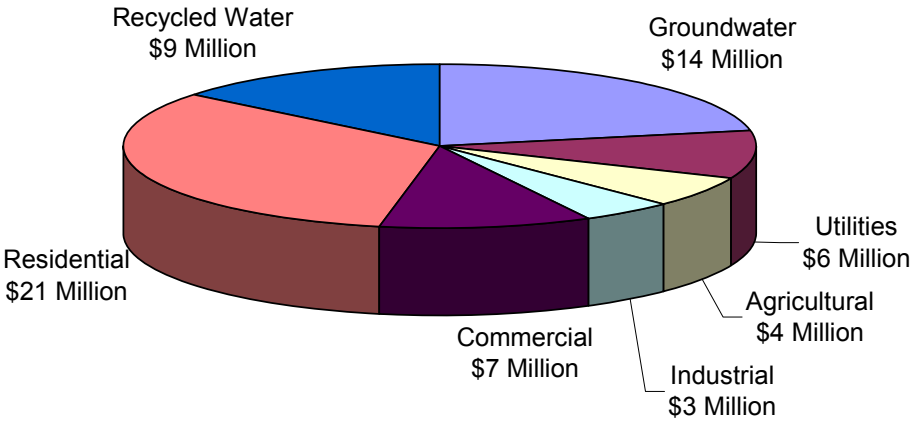


FIGURE 5-5
ANNUAL ECONOMIC BENEFITS OF 100 MG/L SALINITY DECREASE GROUNDWATER AND WASTEWATER



Source: MWD and Bureau of Reclamation Salinity Management Study (1999)

Table 5-4 summarizes the economic benefits to water users from salinity reduction. Cost savings include reduced need to construct desalting facilities and greater compliance of wastewater discharges with permit requirements. Residential consumer cost savings would be realized in longer lifespan for appliances and plumbing as well as the reduced need for water softening devices.

TABLE 5-4
SUMMARY OF ECONOMIC BENEFITS OF REDUCED SALINITY

User	Economic Benefit
Residential	Increased life of plumbing system and appliances
	Reduced use of bottled water and water softeners
Commercial	Decreased cost of water softening
	Decreased use of water for cooling
	Increased equipment service life
Industrial	Decreased cost of water treatment
	Decreased water usage
	Decreased sewer fees
Agricultural	Increased crop yield
	Decreased water usage for leaching purposes
Utilities	Increased life of treatment facilities and pipelines
Groundwater	Improved wastewater discharge requirements for permit compliance
	Decreased desalination and brine disposal costs
Recycled Water	Decreased use of imported water for salt management
	Decreased desalination and brine disposal costs

MWD/USBR 1999 Salinity Management Study

5.2.5 SALINITY MANAGEMENT PROJECTS IN THE UPPER WATERSHED

The District has a long-standing commitment to management of salinity in groundwater supplies, avoiding the loss of water supplies due to increased salinity, and developing projects to reduce salinity are District priorities. Since the Santa Ana River is the primary source of recharge water for the basin, salt management programs in the upper watershed are vital to protect the water quality in Orange County; success in this regard requires participation and cooperation of upper Santa Ana watershed stakeholders.

Several desalters, which are water treatment plants designed to remove salts, have been built in Riverside and San Bernardino Counties. These plants are effectively reducing the amount of salt buildup in the watershed. The Santa Ana Regional Interceptor (SARI), built by the Santa Ana Watershed Project Authority (SAWPA), began operation in 1975 to remove salt from the watershed by transporting industrial wastewater and brine produced by desalter operations directly to the OCSD for treatment. Approximately 75,000 tons of salt were removed by the SARI line in FY 2006-07.

The other "brine line" in the upper watershed, the Non-reclaimable Waste Line in the Chino Basin operated by the Inland Empire Utilities Agency (IEUA), segregates high TDS industrial wastewater.

5.2.6 OCWD SALINITY MANAGEMENT AND REMEDIATION PROGRAMS

Within Orange County, operations of the GWR System and several local and regional groundwater desalters are working to reduce salt levels.

The GWR System, described in Section 4.2, purifies wastewater that is used for groundwater recharge and for injection into the Talbert Barrier to prevent seawater intrusion. The GWR System provides a dependable supply of low salinity water, whose quantity and quality will not be impacted by future drought conditions. The GWR System is expected to reduce the basin salt load by approximately 48,000 tons/year, based on the difference between recharging 72,000 afy of GWR System water at 60 mg/L and an equal amount of imported blended Colorado River and SPW water at 550 mg/L.

High salinity groundwater areas located in Tustin and Irvine are being treated through the operation of desalter plants; these projects are described in Section 5.8.

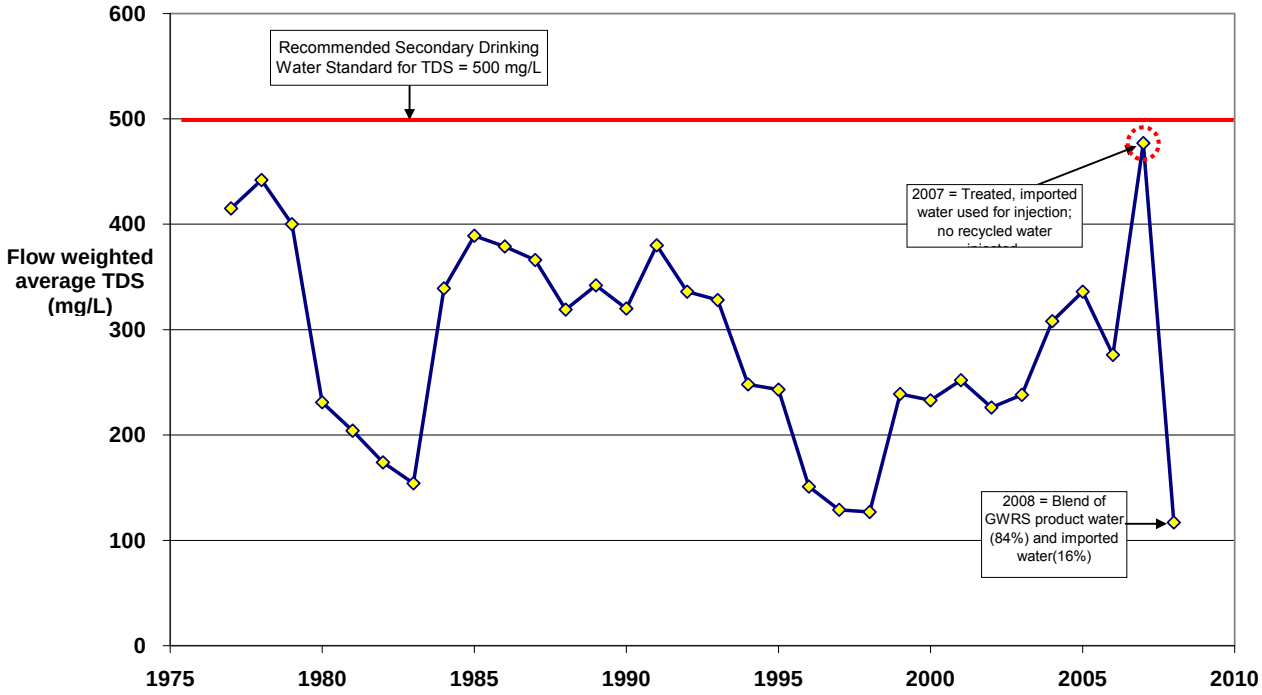
5.2.7 SEAWATER INTRUSION BARRIERS

OCWD's Talbert Barrier is composed of a series of injection wells that span the 2.5-mile-wide Talbert Gap between the Newport and Huntington mesas (see Figure 3-9). From 1975 until 2004, a blend of purified water from OCWD's WF-21, deep aquifer water, and imported potable water was injected into the barrier. The Talbert Barrier wells were used to inject an average of 12 mgd of water into four aquifer zones to form a hydraulic barrier to seawater that would otherwise migrate inland toward areas of groundwater production.

The GWR System began operations in January 2008 to better control seawater intrusion as well as to recharge the coastal aquifers. Twelve new wells enable injection of up to 35 mgd of purified water into the expanded injection barrier.

Figure 5-6 shows the total flow-weighted average of TDS levels of the Talbert Barrier Injection Water. Prior to 2004, injection water was a blend of imported water, WF-21 purified water, and deep aquifer water. During the time that WF-21 was decommissioned and the GWR System was in construction, a blend of imported water, potable water, and deep aquifer water was injected into the barrier. In 2007, only treated, imported water was used resulting in a flow weighted average TDS of Talbert Barrier injection water of 477 mg/L. With 84 percent of injection water supplied by the GWR System, the flow weighted average for 2008 dropped to 117 mg/L.

FIGURE 5-6
TALBERT BARRIER INJECTION WATER - TOTAL DISSOLVED SOLIDS (TDS)
Total Flow Weighted Average TDS of All Source Waters



The Alamitos seawater intrusion barrier is composed of a series of injection wells that span the Los Angeles/Orange County line in the Seal Beach-Long Beach area. It is operated by the LACDPW in cooperation with OCWD and the WRD**.** The source of this water is a blend of purified water from WRD and potable supplies from Metropolitan.

5.3 Nitrate Management

Nitrate is one of the most common and widespread contaminants in groundwater supplies. OCWD conducts an extensive program to protect the basin from nitrate contamination. The District regularly monitors nitrate levels in groundwater, operates 465 acres of wetlands in the Prado Basin to remove nitrates in Santa Ana River water, and works with Producers to treat individual wells when nitrate levels exceed safe levels.

5.3.1 SOURCES OF NITRATES

Nitrogen is an element essential for plant growth; in the environment it naturally converts to nitrate. Nitrate is a nitrogen-oxygen ion (NO_3^-) that is very soluble and mobile in water. Elevated levels of nitrate in soil and water supplies originate from fertilizer use, animal feedlots, wastewater disposal systems, and other sources. Plants and bacteria break down nitrate but excess amounts can leach into groundwater; once in the groundwater, nitrate can remain relatively stable for years.

The primary concern for human health is not nitrate but its conversion to nitrite (NO_2^-) in the body. Nitrite oxidizes iron in the hemoglobin of red blood cells to form methemoglobin, depriving the blood of oxygen. This is hazardous to infants as they do not yet have enzymes in their blood to counteract this process. They can suffer oxygen deficiency called methemoglobinemia, commonly known as "blue baby syndrome" named for its most noticeable symptom of bluish skin coloring.

5.3.2 REGULATION OF NITRATE

Both federal and state agencies regulate nitrate levels in water. The EPA and CDPH set the MCL in drinking water at 10 mg/L for nitrate-nitrogen. The Santa Ana Watershed is divided into management zones with nitrate-nitrogen water quality objectives set for each of those zones. These levels are determined after considering historical ambient or baseline conditions. Water quality objectives and ambient quality levels for Orange County's management zones are shown in Table 5-5. The main Orange County basin has a minor amount of assimilative capacity but the Irvine subbasin has none. Efforts to reduce nitrate levels in the Irvine subbasin are described in Section 5.8.

TABLE 5-5
NITRATE-NITROGEN WATER QUALITY OBJECTIVE FOR LOWER SANTA ANA RIVER BASIN MANAGEMENT ZONES

Management Zone	Water Quality Objective	Ambient Quality
Orange County	3.4 mg/L	3.0 mg/L
Irvine	5.9 mg/L	6.5 mg/L

Source: Recomputation of Ambient Water Quality for the Period 1987 to 2006 prepared by Wildermuth Environmental, August 2008.

5.3.3 OCWD NITRATE MANAGEMENT AND REMEDIATION PROGRAMS

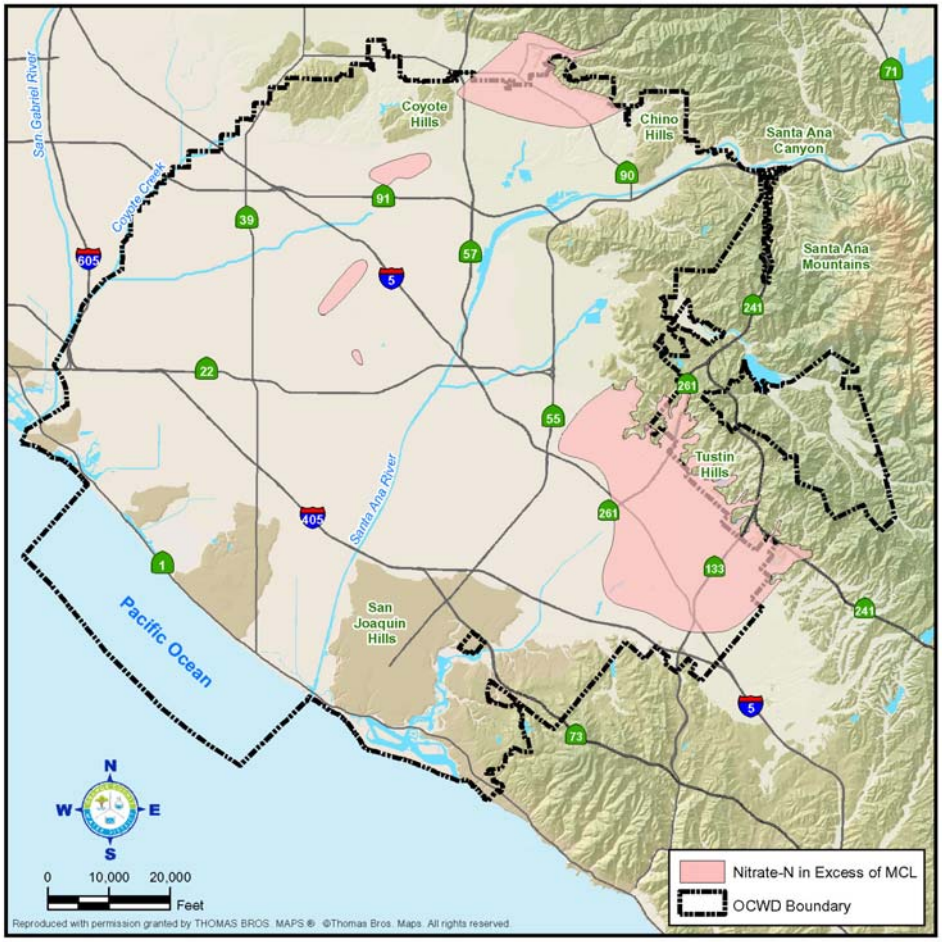
One of the District's programs to reduce nitrate levels in the groundwater basin is managing the nitrate concentration of water recharged by the District's facilities. This includes managing the quality of surface water flowing to Orange County through Prado Dam. As explained in Section 4, the primary source of recharge water for the groundwater basin is the Santa Ana River. To reduce the level of nitrate entering Orange County from the Santa Ana River, OCWD operates an extensive system of wetlands in the Prado Basin as shown in Figure 4-3.

OCWD diverts river flows through a 465-acre system of constructed wetlands, shown in Figure 5-7, where nitrates are naturally removed from the water. The wetlands provide a natural treatment system that removes approximately 15 to 40 tons of nitrates a month depending on the season. The wetlands are more effective from May through October when the water temperatures are warmer. During summer months the wetlands reduce nitrate from nearly 10 mg/L to 1 to 2 mg/L. In 2004-05, the wetlands were damaged by flooding. The wetlands were reconstructed and placed back in service in 2008.

All production wells are tested annually for nitrate; wells with concentrations equal to or greater than 50 percent of the MCL are monitored on a quarterly basis. Areas where nitrate concentrations exceed the MCL are shown in Figure 5-8.

FIGURE 5-7
PRADO WETLANDS

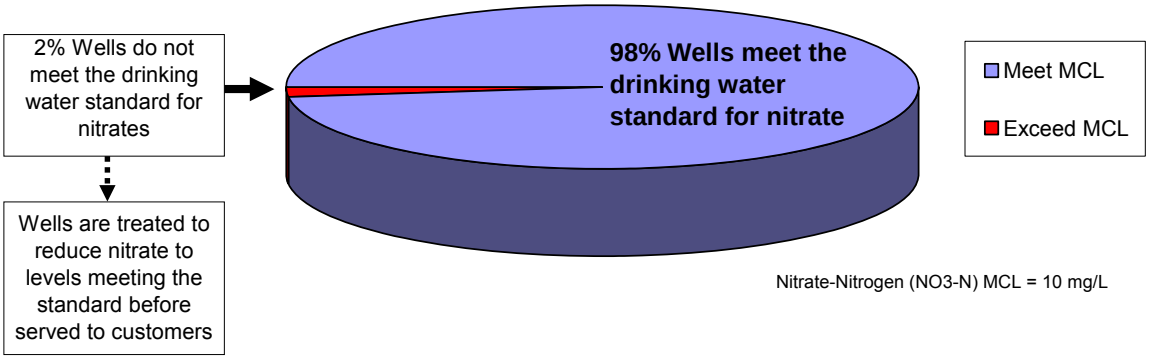
FIGURE 5-8
AREAS WITH ELEVATED NITRATE LEVELS



Within Orange County, nitrate-nitrogen levels in groundwater generally range from 4 to 7 mg/L in the Forebay area and from 1 to 4 mg/L in the Pressure area. Ninety-eight percent of the drinking water wells meet drinking water standards for nitrate-nitrogen as shown in Figure 5-9. The two percent above MCL are treated to reduce nitrate levels prior to being served to customers. Areas in the basin where nitrate levels exceed the MCL are suspected to be impacted by historical fertilizer use.

OCWD works with the Producers to address areas of high nitrate levels. The Tustin Main Street Treatment Plant, described in Section 5.8, is an example of such an effort.

FIGURE 5-9
PERCENT OF WELLS MEETING THE DRINKING WATER STANDARD (MCL)
2007 AVERAGE NITRATE DATA



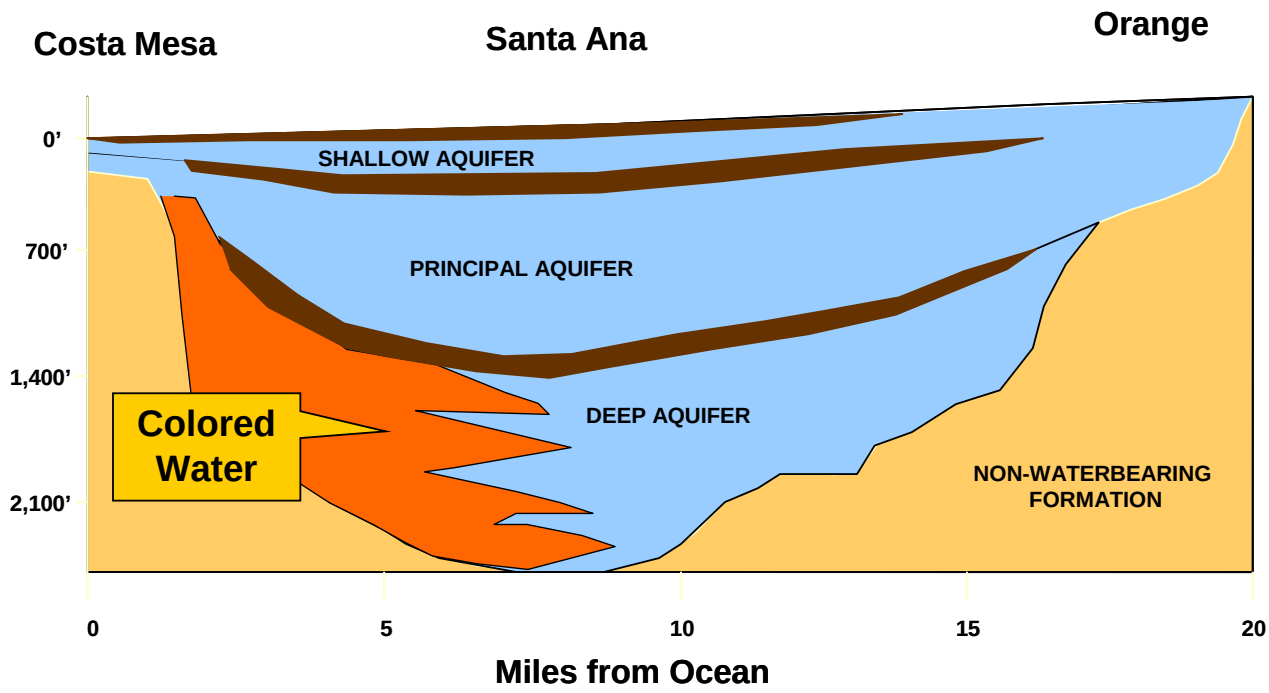
5.4 Colored Groundwater Management

This section discusses the occurrence of colored groundwater, the challenges of developing colored water sources, and production processes used to treat colored water.

5.4.1 OCCURRENCE OF COLORED WATER IN THE BASIN

Colored water is found in deep aquifers (600-2000 feet) over a broad region in the Lower Main aquifer, as shown in Figures 5-10 and 5-11. Natural organic material from ancient redwood forests and peat bogs gives the water an amber tint and a sulfur odor. Although colored water is of very high quality, negative aesthetic qualities, its color and odor, require treatment before use as drinking water.

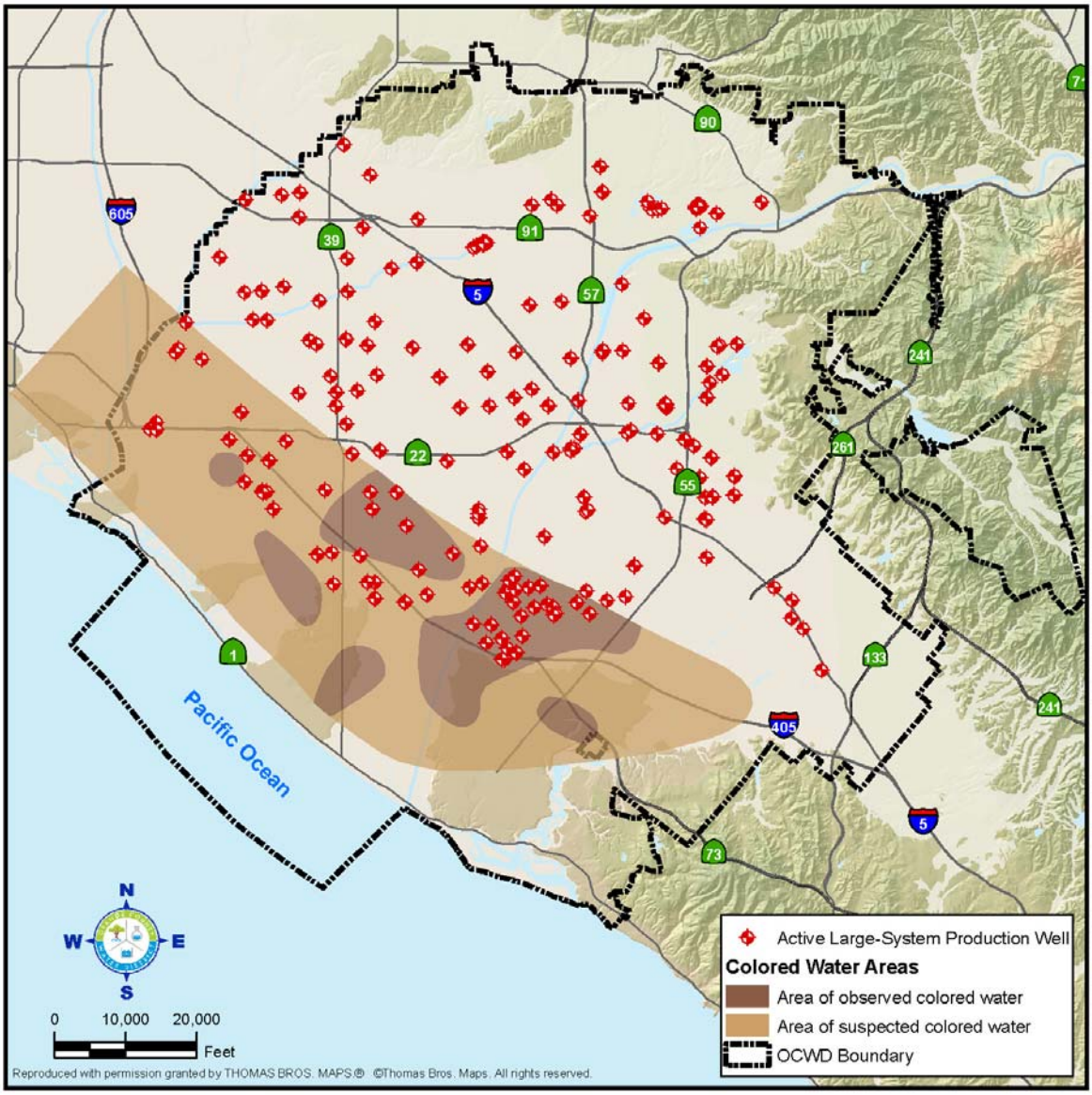
FIGURE 5-10
CROSS-SECTION OF AQUIFERS SHOWING COLORED WATER AREAS



The total amount of colored groundwater is estimated to be over one million acre feet, perhaps as much as several million acre feet. Economic constraints pose challenges to developing colored water supplies as the water needs to be treated to remove the color and odor. Costs depend on the water quality (color and other parameters) and the type and extent of required treatment.

An additional factor that must be considered is the impact of water levels in the clear zone compared to water levels in the deeper aquifers with colored water. Monitoring wells reveal a correlation of clear/colored zone water level fluctuations, indicating a fairly strong hydrologic connection between the two zones in some areas of the basin. Three facilities currently treat colored groundwater in Orange County. Mesa Consolidated Water District (MCWD) has operated an ozone oxidation treatment facility since 1985 at its Well No. 4 site. In 2001, MCWD opened its Colored Water Treatment Facility (CWTF) using ozone treatment to produce 4,000 gallons per minute. The third facility is the Deep Aquifer Treatment System (DATS), a treatment facility using nano-filtration membranes operated by IRWD since 2002. This facility purifies 7.4 mgd of colored water.

FIGURE 5-11
EXTENT OF COLORED WATER



5.5 Synthetic Organic Contaminants

Ninety-five percent of the basin's groundwater used for drinking water supplies is pumped from the main aquifer. Water from this aquifer continues to be of high quality. This section describes areas of the basin that are experiencing contamination threats, most of which occur in the shallow aquifer.

5.5.1 METHYL TERTIARY BUTYL ETHER (MTBE)

During the 1980s, gasoline hydrocarbons of greatest risk to drinking water were benzene, toluene, ethylbenzene, and xylenes, collectively known as BTEX chemicals.

Although leaking underground fuel tanks were identified throughout the basin, these chemicals typically were degraded by naturally-occurring microbes that allowed clean up by natural attenuation or passive bioremediation.

Unfortunately, a new additive to gasoline aimed at reducing air pollution has become a widespread contaminant in groundwater supplies. Methyl tertiary butyl ether (MTBE) is a synthetic, organic chemical that was added to gasoline to increase octane ratings during the phase-out of leaded gasoline. In the mid-1990s, the percentage of MTBE added to gasoline increased significantly to reduce air emissions. MTBE is a serious threat to groundwater quality; it sorbs weakly to soil and does not readily biodegrade. The greatest source of contamination comes from releases from underground fuel tanks.

The State of California banned the use of the additive in 2004 in response to its widespread detection in groundwater throughout the state. The CDPH set the primary MCL for MTBE in drinking water at 13 µg/L. The secondary MCL for MTBE is 5 µg/L.

Drinking water wells in the basin are tested annually for VOC analytes including MTBE. The District continues to work with local water agencies to monitor for MTBE and other fuel-related contaminants to identify areas that may have potential underground storage tank problems and releases resulting in groundwater contamination.

5.5.2 VOLATILE ORGANIC COMPOUNDS

VOCs in groundwater come from a number of sources. From the late 1950s through early 1980s, VOCs were used for industrial degreasing in metals and electronics manufacturing. Other common sources include paint thinners and dry cleaning solvents.

VOC contamination is found in several locations in the basin. In 1985, a contamination site was discovered beneath the former El Toro MCAS. Monitoring wells at the El Toro site installed by the U.S. Navy and OCWD delineated a one-mile wide by three-mile long VOC plume, comprised primarily of trichloroethylene (TCE). Beneath the former Air Station, VOC contamination was primarily found in the shallow groundwater up to 150 feet below the ground surface. Off-base, to the west, the VOC plume is in deeper aquifers from 200 to 600 feet deep.

Another VOC contamination site was found in portions of the shallow aquifer in the northern portion of the Orange County in the cities of Fullerton and Anaheim. Although not directly used for drinking water supplies, groundwater in the shallow aquifer eventually flows into the deeper principal aquifer, which is used for potable water supplies. To date, two city of Fullerton production wells have been removed from service and destroyed due to VOC contamination in that area. Currently, there are no production wells in that area that extract water from the shallow aquifer. The North Basin Groundwater Protection Project, described in Section 5.8, was initiated in 2005 to clean up the groundwater in this portion of the basin.

Elevated concentrations of perchloroethylene (PCE), TCE, and perchlorate were detected in IRWD's well No. 3, located in Santa Ana. OCWD is currently working with the Regional Board and the California Department of Toxic Substances Control to require aggressive cleanup actions at nearby sites that are potential sources of the

contamination. OCWD has initiated the South Basin Groundwater Protection Project described in Section 5.8 to address this contamination.

5.5.3 N-NITROSODIMETHYLAMINE (NDMA)

NDMA is a low molecular weight compound that can form in influent water entering wastewater treatment plants and after chlorine disinfection of wastewater. It is also found in food products such as cured meat, fish, beer, milk, and tobacco smoke. OCWD is monitoring NDMA levels in the groundwater basin. The California Notification Level for NDMA is 10 nanograms per liter (ng/L). The concentration of NDMA is typically less than 2 ng/L in the Santa Ana River at Imperial Highway. At OCWD's GWR System in Fountain Valley, NDMA concentrations are maintained below California's Notification Level through a combination of source control measures, reverse osmosis treatment, and advanced oxidation treatment using ultraviolet light and hydrogen peroxide.

5.5.4 1,4-DIOXANE

A suspected human carcinogen, 1,4-dioxane, is used as a solvent in various industrial processes such as the manufacture of adhesive products and membranes and may occur in consumer products such as detergents, cosmetics, pharmaceuticals, and food products.

In 2002, OCWD detected elevated levels of 1,4-dioxane in nine production wells exceeding the California Action Level. These wells were temporarily shutdown with a loss of 34 mgd of water supply. Further investigation traced the contaminant to one industrial discharger that was discharging 1,4-dioxane into wastewater collected by OCSD. This discharge was affecting water that was treated by WF-21 and injected into the Talbert Seawater Barrier. The discharger voluntarily ceased discharge of 1,4-dioxane and concentrations declined. Additional monitoring data showed low concentrations, the CDPH determined that the water was not a significant risk to health, and the wells were returned to service.

5.6 Perchlorate

Perchlorate has been detected at wells distributed over a large area of the groundwater basin. Based on data from 217 active production wells over the last three years and a detection limit of 2.5 micrograms per liter, perchlorate was not detected at 83 percent of the wells. Seventeen percent of the wells had detectable concentrations of perchlorate. For those wells with detectable amounts of perchlorate, 89 percent of the wells have detected perchlorate concentrations below the California primary drinking water standard of 6 micrograms per liter. Four of the 217 active production wells had perchlorate concentrations greater than 6 micrograms per liter. It is important to note that water delivered for municipal purposes meets the primary drinking water standard. Groundwater from production wells that have perchlorate concentrations over the primary drinking water standard is treated to reduce the perchlorate concentration below the primary drinking water standard prior to delivery for municipal usage.

Sources of perchlorate in the groundwater basin may include:

- Fertilizer application;

- Water imported from the Colorado River (through the use of Colorado River water for groundwater recharge, irrigation, or water supplies that impact the groundwater basin through onsite wastewater disposal systems);
- Industrial or military sites that used, disposed of, or stored perchlorate. Perchlorate has historically been used as an ingredient in rocket propellant, explosives, fireworks, and road flares; and
- Naturally occurring perchlorate (e.g., perchlorate in rainfall).

The occurrence of perchlorate in Chilean fertilizer applied for agricultural purposes has been documented in various studies (see for example, the discussion in the December 1, 2006 publication of the journal Analytical Chemistry (Foubister, 2006); see also Urbansky et al (2001)).

The occurrence of perchlorate in historic supplies of Colorado River water has been documented in published studies (see for example, the report published by the National Research Council in 2005 titled "Health Implications of Perchlorate Ingestion" (National Research Council, 2006); see also Urbansky et al (2001)). Due to source remediation efforts near Henderson, Nevada, the concentration of perchlorate in Colorado River water has decreased (Nevada Division of Environmental Protection, 2009).

Perchlorate has been detected in groundwater at various sites in California in association with industrial or military sites (Interstate Technology & Regulatory Council, 2005). Perchlorate has been detected in rainfall (see for example, the report published by the Interstate Technology & Regulatory Council, 2005 and Dasgupta et al (2005)).

The District's ongoing monitoring program is continuing to assess the distribution of perchlorate in the groundwater basin and how concentrations change through time. The District regularly reviews this information and will continue to work with the stakeholders to address this issue.

5.7 Constituents of Emerging Concern

Constituents of emerging concern are synthetic or naturally occurring substances (chemicals and microorganisms) that are not regulated but may have negative impacts on the environment and/or human health. The newest group of constituents of emerging concern includes pharmaceuticals, personal care products, and endocrine disruptors.

Pharmaceuticals and personal care products (PPCPs) include thousands of chemicals contained in consumer and health related products such as drugs (prescription and over-the-counter), food supplements, fragrances, sun-screen agents, deodorants, flavoring agents, insect repellants, and inert ingredients. Important classes of high use prescription drugs include antibiotics, hormones, beta-blockers (blood pressure medicine), analgesics (pain-killers), steroids, antiepileptic, sedatives, and lipid regulators.

Endocrine Disrupting Compounds (EDCs) are compounds that can disrupt the endocrine system. They can occur in a wide variety of products such as pesticides and pharmaceuticals. Research investigations have documented that EDCs can interfere with the normal function of hormones that affect growth and reproduction in animals and

humans. Findings of secondary sex changes, poor hatching, decreased fertility, and altered behavior have been observed in fish following exposure to EDCs.

In general, these substances have been identified as a pollution threat or were previously detected in the environment. As new laboratory methods are developed, substances can be detected at much lower concentrations. When such detection occurs before regulatory limits are established and potential human health effects are still unknown, water suppliers and health officials face new challenges. In some cases, public awareness and concern is high because the compounds are detected but scientific-based information on potential health impacts of such low concentrations is not available.

Water quality concerns arise from the widespread use of PPCPs and EDCs. In most cases, the impacts on human health from exposure to low concentrations of these substances are not known. European studies in the 1990s confirmed the presence of some of these chemicals in the less than one microgram per liter range (ppb) in surface waters and groundwater and at low concentrations in wastewater treatment plant effluents.

A USGS report found detectable concentrations of hormones and PPCPs in many vulnerable waterways throughout the United States (Kolpin 2002). Due to the potential impact of EDCs on future water reclamation projects, the District prioritizes monitoring of these chemicals.

OCWD's state-certified laboratory is one of a few in the state that has a program to continuously develop capabilities to analyze for new compounds. Recognizing that the state CDPH has limited resources to focus on methods development, OCWD works on developing low detection levels for chemicals likely to be targeted for future regulation or monitoring.

OCWD advocates the following general principles as water suppliers and regulators develop programs to protect public health and the environmental from adverse effects of these emerging contaminants:

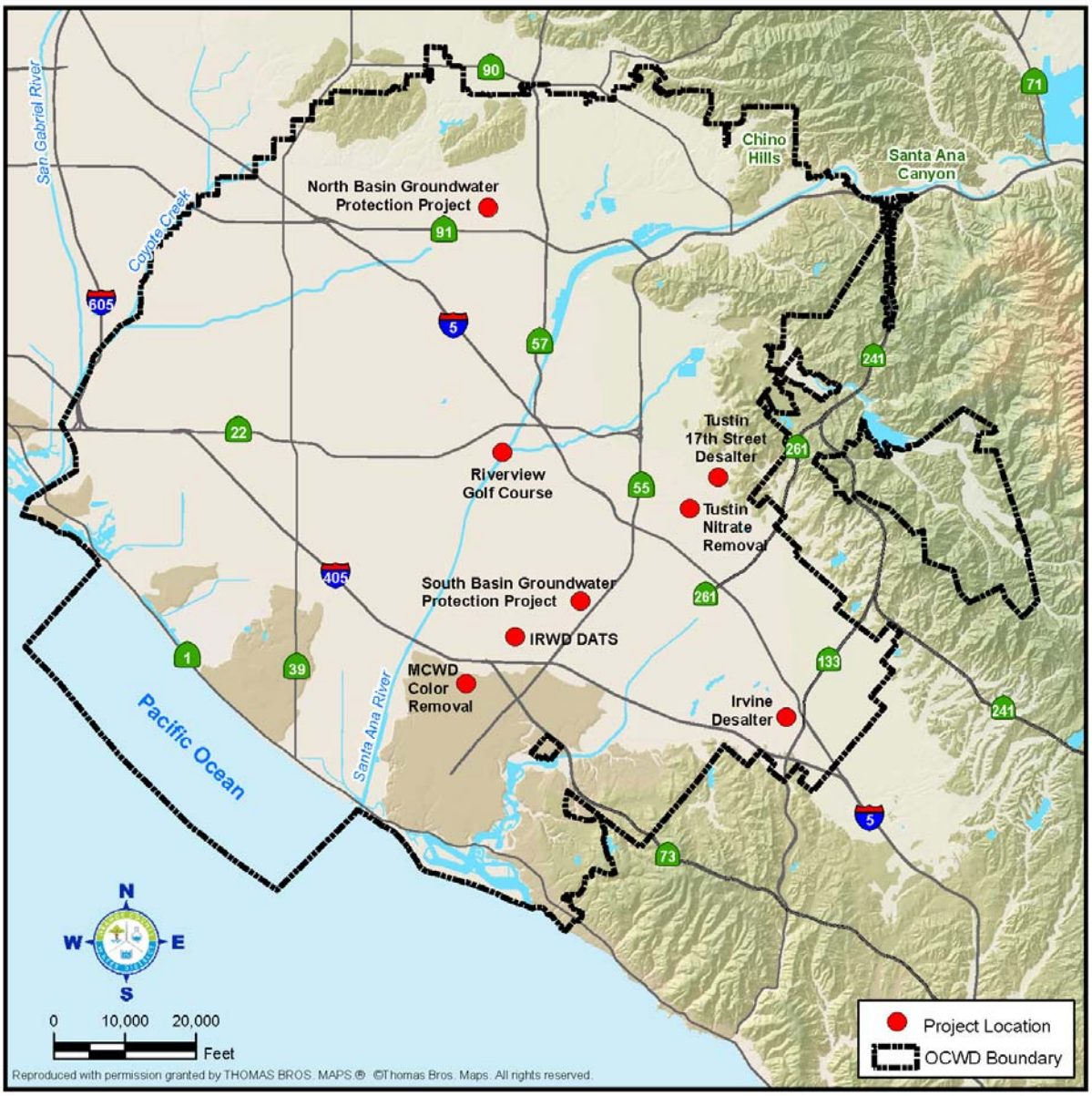
- Monitoring should focus on constituents that pose the greatest risk.
- Constituents that are prevalent, persistent in the environment, and may occur in unsafe concentrations should be prioritized.
- Analytical methods to detect these constituents should be approved by the state or federal government.
- Studies to evaluate the potential risk to human health and the environment should be funded by the state or federal government.
- The state and federal government should encourage programs to educate the public on waste minimization and proper disposal of unused pharmaceuticals.

OCWD is committed to (1) track new compounds of concern; (2) research chemical occurrence and treatment; (3) communicate closely with CDPH on prioritizing investigation and guidance; (4) coordinate with OCSD, upper watershed wastewater dischargers, and regulatory agencies to identify sources and reduce contaminant releases; and (5) inform the Producers on emerging issues.

5.8 Groundwater Quality Improvement Projects

This section describes specific projects that improve groundwater quality by removing TDS, nitrate, VOCs and other constituents as shown in Figure 5-12. Two water quality improvement projects discussed in the 2004 *Groundwater Management Plan* are no longer in operation. The Fullerton Iron and Manganese Removal Project was determined to be ineffective due to well capacity limitations. The Orange TCE project operated only on a temporary basis and has been permanently shut down.

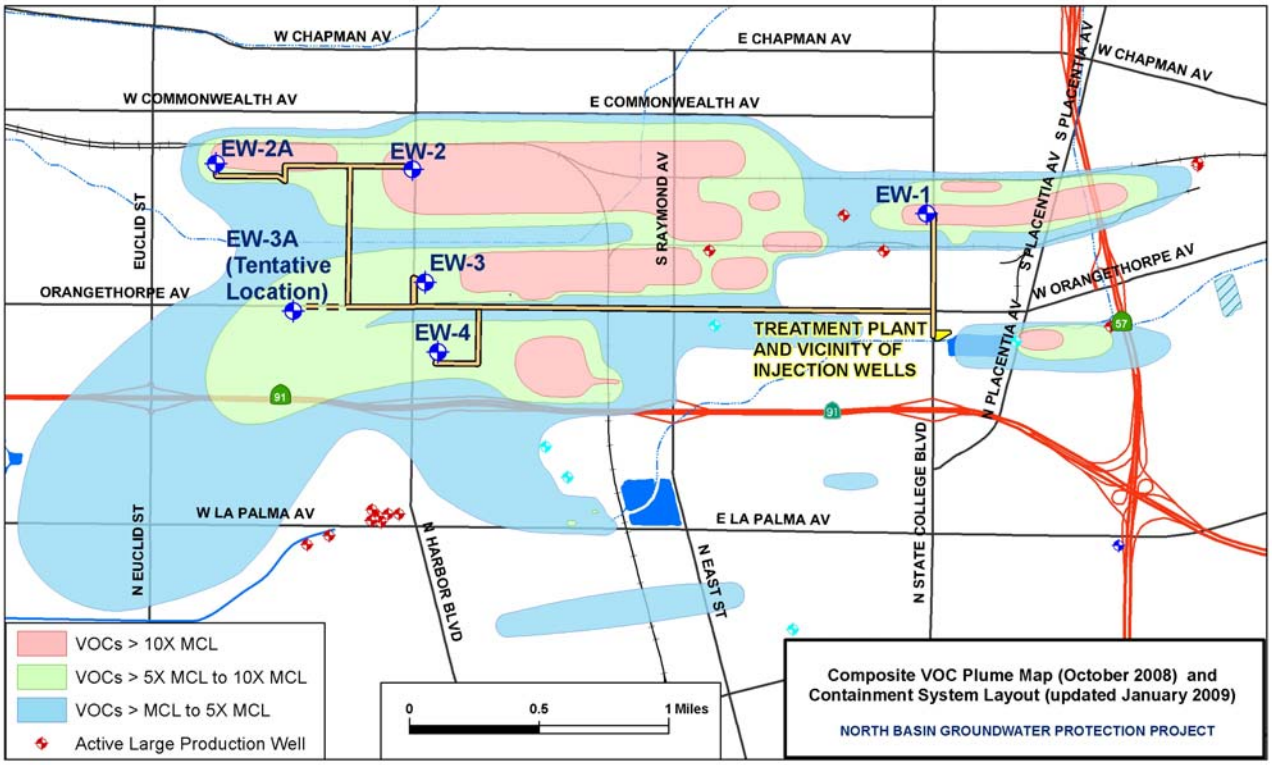
FIGURE 5-12
WATER QUALITY IMPROVEMENT PROJECTS



5.8.1 NORTH BASIN GROUNDWATER PROTECTION PROJECT (NBGPP)

In accordance with OCWD's groundwater cleanup policy, the District is implementing the NBGPP to protect drinking water supplies and the beneficial use of groundwater. OCWD has constructed five wells specifically to remove and contain contaminated groundwater in the shallow aquifer. Additional extraction wells may be needed. OCWD will also construct pipelines to bring the contaminated groundwater to a centralized treatment plant where the contaminants will be removed. The purified water will then be re-injected back into the shallow aquifer. An overview of the VOC plumes and the NBGPP is shown in Figure 5-13. OCWD has initiated legal action against the parties responsible for contamination to seek cost recovery so that the public does not have to pay for this project.

FIGURE 5-13
NORTH BASIN GROUNDWATER PROTECTION PROJECT

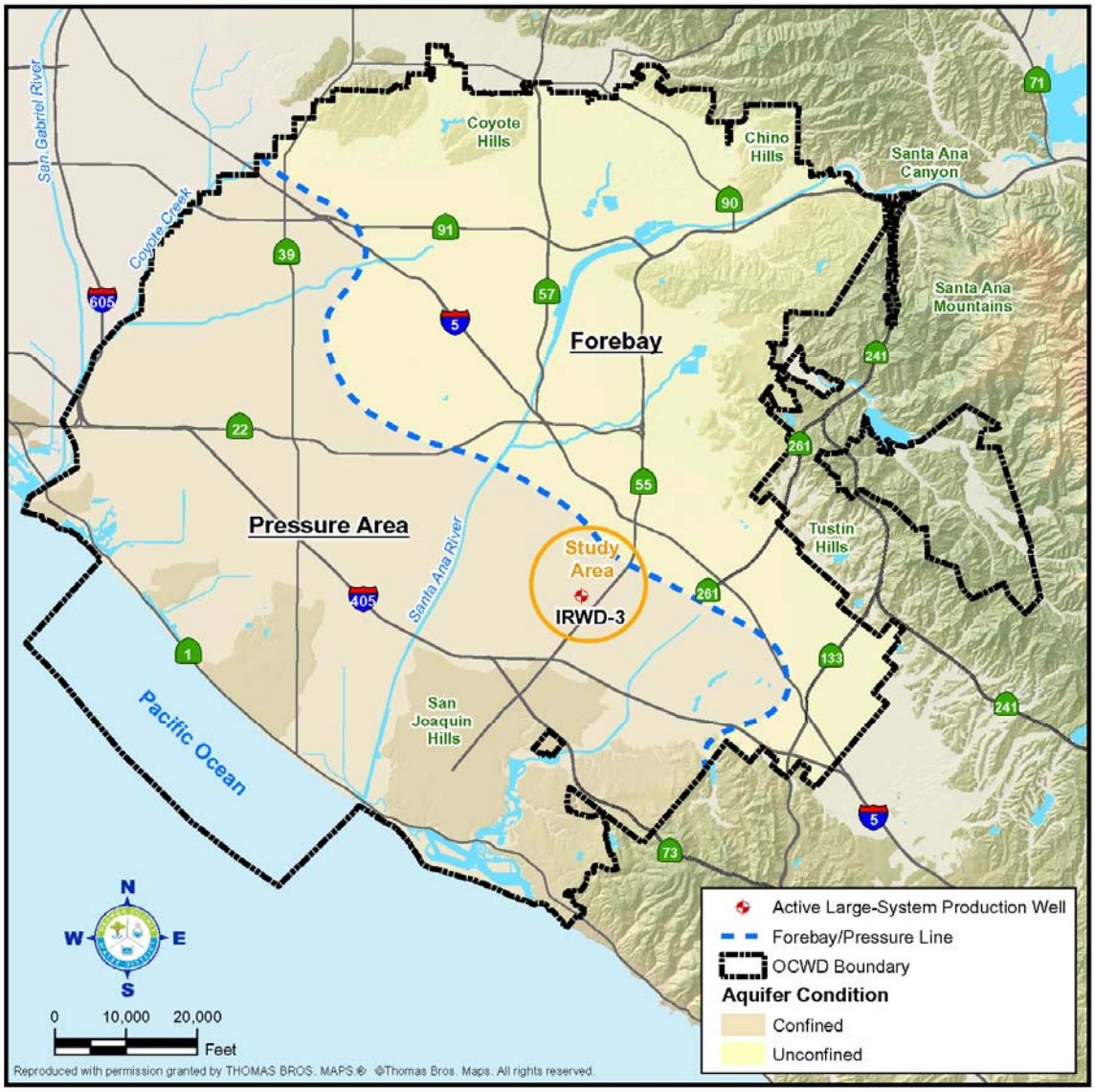


5.8.2 SOUTH BASIN GROUNDWATER PROTECTION PROJECT (SBGPP)

The District has initiated the SBGPP, a project similar to the NBGPP, to protect drinking water supplies in the south part of the Orange County groundwater basin. OCWD constructed six tri-nested monitoring wells to investigate the extent of VOC-contaminated groundwater in the Shallow Aquifer. Delineation of the contaminated groundwater will likely involve more than one phase of investigation. If "hot spots" or contaminated plumes are identified, the SBGPP may include comprehensive remediation systems to contain and remove the contamination similar to the NBGPP or

localized interim remedial measures. The study area for the SBGPP is shown in Figure 5-14.

FIGURE 5-14
SOUTH BASIN GROUNDWATER PROTECTION PROJECT



5.8.3 MTBE REMEDIATION

In 2003, OCWD filed suit against numerous oil and petroleum-related companies that produce, refine, distribute, market, and sell MTBE and other oxygenates. The suit seeks funding from these responsible parties to pay for the investigation, monitoring, and removal of oxygenates from the basin.

Treatment technologies used to remove MTBE from groundwater include granular activated carbon (GAC) or advanced oxidation. Depending upon site-specific requirements, a treatment train of two or more technologies in series may be

appropriate (i.e., use one technology to remove the bulk of MTBE and a follow-up technology to polish the effluent water stream). If other contaminants (e.g., excessive nitrates or TDS) are also found in groundwater with MTBE, additional treatment processes (ion exchange membranes) would also need to be included in the process train.

5.8.4 IRVINE DESALTER

The Irvine Desalter was built in response to the discovery in 1985 of VOCs beneath the former El Toro MCAS and the central area of Irvine. The plume of improperly disposed cleaning solvents migrated off base and threatened the main basin. IRWD and OCWD cooperated in building production wells, pipelines, and two treatment plants, both of which are now owned and managed by IRWD. One plant removes VOCs by air-stripping and vapor-phase carbon adsorption with the treated water used for irrigation and recycled water purposes. A second plant treats groundwater outside the plume to remove excess nitrate and TDS concentrations using RO membranes for drinking water purposes. Combined production of the Irvine Desalter wells is approximately 8,000 afy.

5.8.5 TUSTIN DESALTERS

Tustin's Main Street Treatment Plant has operated since 1989 to reduce nitrate levels from the groundwater produced by Tustin's Main Street Wells Nos. 3 and 4. The untreated groundwater can undergo either RO or ion exchange treatment. The RO membranes and ion exchange unit operate in a parallel treatment train. Approximately 1 mgd is bypassed and blended with the treatment plant product water to produce up to 2 mgd or 2,000 afy. During fiscal year 2007-08, 55,700 pounds of nitrate were removed at this treatment plant.

The Tustin Seventeenth Street Desalter began operation in 1996 to reduce high nitrate and TDS concentrations from the groundwater pumped by Tustin's Seventeenth Street Wells Nos. 2 and 4 and Tustin's Newport well. The desalter utilizes two RO membrane trains to treat the groundwater. The treatment capacity of each RO train is 1 mgd. Approximately 1 mgd is bypassed and blended with the RO product water to produce up to 3 mgd or 3,000 afy. During fiscal year 2007-08, 154,800 pounds of nitrate were removed at this treatment facility.

5.8.6 GARDEN GROVE NITRATE REMOVAL

The Garden Grove Nitrate Removal Project was a blending project utilizing two wells in order to meet the MCL for nitrate. Garden Grove Well No. 28, containing high nitrate concentrations, was blended with water from Well No. 23. The blending project operated from 1990 to 2005. The city took the well off line and is considering construction of upgraded treatment facilities to expand the pumping of groundwater in this area.

5.8.7 RIVER VIEW GOLF COURSE

VOC contamination, originating from an upgradient source, was discovered in a well owned by River View Golf Course, located in the City of Santa Ana. The well was used

for drinking water but was converted into a supply for golf course irrigation due to the contamination. Continued operation of the well helps to remove VOC contamination from the basin.

5.8.8 COLORED WATER TREATMENT

The 5-mgd MCWD ozone oxidation treatment plant removes the color from groundwater pumped from Well No. 6 and Well No. 11. One of the ozone by-products is assimiable organic carbon (AOC), which increases the microbiological regrowth potential within the distribution system. Pressurized biologically-active filtration is employed immediately after ozone oxidation in order to remove AOC and produce microbiologically stable water. In order to meet the stringent disinfection by-products MCLs, chloramination (a combination of chlorine and ammonia) is used to disinfect the product water prior to delivery to distribution system.

IRWD's DATS removes color from deep aquifer groundwater. A total of 8 mgd of colored groundwater is pumped from two wells (IRWD C8 and C9) to the DATS plant. Nanofiltration (NF) membranes remove color and organics. Three NF trains each produce 2.44 mgd at a recovery rate of 92 percent. The high quality NF product water is degasified, disinfected, and pumped into the Dyer Road Wellfield pipeline for potable use resulting in 7.4 mgd added to the drinking water system. The highly colored NF concentrate is sent to disposal by OCSD.

The colored water treatment projects operated by MCWD and IRWD provide benefit beyond the production of water supply. The aquifers with colored water are generally deeper than the primary clear water production zones, and upward vertical migration of the colored water into the clear water aquifers has been observed. Upward migration can impair water quality in the clear water zones. A large groundwater level difference between the colored water aquifer and clear water aquifers exacerbates this situation. By pumping from the colored water aquifer, the MCWD and IRWD projects reduce the groundwater level in the colored water aquifer, thus reducing the vertical migration of colored water into the clear water aquifers.

5.9 BEA Exemption for Improvement Projects

In some cases, the District encourages the pumping of groundwater that does not meet drinking water standards in order to protect water quality. This is achieved by using a financial incentive called the BEA Exemption. The benefits to the basin include removing and beneficially using poor-quality groundwater and reducing or preventing the spread of poor-quality groundwater into non-degraded aquifer zones.

As explained in detail in Section 6, OCWD uses financial incentives to manage the level of pumping from the groundwater basin. Producers pay a Replenishment Assessment (RA) for water pumped from the basin. Each year the District sets an allowable amount of pumping and assesses an additional charge, called the BEA, on all water pumped above that limit.

A BEA Exemption is used to encourage pumping of groundwater that does not meet drinking water standards in order to clean up and contain the spread of poor quality

water. Section 38.1 of the District Act provides specific criteria for exemption of the BEA:

> *"If the board of directors finds and determines that the water produced from the facility or facilities or any of them has or will have a beneficial effect upon the quality of water supplies of the district, the board of directors may make an order that water produced from the water-producing facility or facilities shall be exempted from either or both of the following:*
>
> *(A) The payment of all or any portion of the basin equity assessment…*
>
> *(B) The production requirements and limitations as provided in this act."*

OCWD uses a partial or total exemption of the BEA to compensate a qualified participating agency or Producer for the costs of treating poor-quality groundwater. These costs typically include capital, interest, and operations and maintenance (O&M) costs for the treatment facilities.

Under this provision, the District has exempted all or a portion of the BEA for pumping and treating groundwater for removal of nitrates, TDS, VOCs, and other contaminants. Water quality improvement projects that have received a BEA exemption are listed in Table 5-6.

When the District authorizes a BEA exemption for a project, OCWD is obligated to provide the replenishment water for the production above the BPP and forgoes the BEA revenue that OCWD would otherwise receive from the producer.

TABLE 5-6
SUMMARY OF IMPROVEMENT PROJECTS AND REPLENISHMENT OBLIGATIONS

Project Name	Project Description	BEA Exemption Approval Date	Groundwater Production above BPP (afy)	OCWD Subsidy
Irvine Desalter	Removal of nitrates, TDS, and VOCs	2001	10,000	BEA Exemption
Tustin Desalter	Removal of nitrates and TDS	1998	3,500	BEA Exemption
Garden Grove Nitrate	Blending two Garden Grove wells to meet nitrate MCL	1998	4,000	BEA Exemption
Tustin Nitrate Removal	Removal of nitrates	1998	1,000	BEA Exemption
River View Golf Course	Removal of VOCs	1998	350	$50/af reduction in BEA
MCWD Colored Water Removal	Color removal	2000	8,700	BEA Exemption
IRWD DATS	Color removal	1999	8,000	BEA Exemption

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6 INTEGRATED MANAGEMENT OF PRODUCTION AND RECHARGE

The District operates the groundwater basin in order to protect and increase the basin's sustainable yield in a cost effective manner. Accomplishing this goal requires careful management of recharge and water production. This section describes the methods and programs utilized by OCWD to maintain the long-term sustainability of the basin's groundwater supplies.

6.1 General Management Approach

OCWD is internationally known for its unique, proactive, supply-side management approach. This is a major factor that has enabled the District to develop one of the most advanced and progressive groundwater management systems in the world. The District seeks to expand the basin's yield by maximizing the amount of water recharged into the basin, developing new sources of water to recharge the basin, and increasing the effectiveness of the District's recharge facilities.

OCWD provides access to basin supplies at a uniform cost to all entities within the District without regard to the length of time they have been producing from the basin. After initiating this policy in 1954 with the establishment of the Replenishment Assessment (RA), OCWD witnessed a substantial growth in municipal and industrial water usage. This growth has not occurred without its accompanying challenges to OCWD: the need to augment recharge water supplies, establish methods to effectively manage demands on the basin, and balance the amount of total recharge and total pumping to protect the basin from being overdrafted.

The District's participation in a wide range of cooperative efforts with other water and waste water agencies as well as stakeholder organizations plays an important part in the management of the groundwater basin.

6.2 Cooperative Efforts to Protect Water Supplies and Water Quality

OCWD participates in cooperative efforts with state and federal regulatory agencies and stakeholders within the District boundaries, in Orange County, and in the Santa Ana River Watershed.

6.2.1 SANTA ANA WATERSHED PROJECT AUTHORITY (SAWPA)

SAWPA is a Joint Powers Authority whose mission is to develop and maintain regional plans, programs, and projects that will protect the Santa Ana River basin water resources. OCWD, one of SAWPA's five member agencies, actively participates on a number of work groups that meet on a regular basis to discuss, plan, and make joint decisions on management of water resources in the Santa Ana Watershed. OCWD actively participates in the following SAWPA work groups:

SAWPA Commission:
The commission, composed of Board members from SAWPA's five member agencies including OCWD, meets on a monthly basis to set policy and oversee the management of SAWPA.

Storm Water Quality Standards Task Force:
The Task Force is evaluating water quality standards as they relate to stormwater and dry weather flows. Particular emphasis is being given to the water quality that is needed to protect recreational beneficial uses.

Basin Monitoring Program Task Force:
The Basin Monitoring Program Task Force was formed in 1995 to determine the extent of and evaluate the impact of increasing concentrations of Total Inorganic Nitrogen (TIN) and TDS in groundwater in the watershed. Formation of the Task Force was in response to concerns by the Regional Board that water quality objectives for nitrogen and TDS were being exceeded in some groundwater basins in the watershed.

The over 20 water and waste water agencies and local governments on the Task Force worked with RWQCB staff to develop an amendment to the Water Quality Control Plan for the Santa Ana River Basin (Basin Plan) that was adopted in 2004. This nearly ten-year effort involved collecting and analyzing data in twenty-five groundwater management zones in the watershed to recalculate nitrogen and TDS levels and to establish new Water Quality Objectives to protect Beneficial Uses.

An important component in this effort was the recognition by stakeholders that groundwater basins are interconnected and that water quality in one basin impacts other basins and the quality of the water in the Santa Ana River.

The Basin Plan amendment charges the Task Force with implementing a watershed-wide TDS/Nitrogen groundwater monitoring program. Task Force members agreed to fund and participate in a process to recalculate ambient water quality every three years in each of the twenty-five groundwater management zones and to compare water quality to the water quality objectives in order to measure compliance with the Basin Plan. The latest recalculation, the second since adoption of the amendment, was published in August 2008 (Wildermuth, 2008).

Salinity Management and Imported Water Recharge Plenary Workgroup:
This workgroup, in cooperation with the Regional Board, implements a Cooperative Agreement signed by water agencies that use imported water for groundwater recharge. The workgroup is analyzing water quality data and estimating future conditions to evaluate the impact of recharging imported water.

Emerging Constituents Workgroup:

This workgroup is developing a monitoring program for emerging constituents in water that is intentionally recharged to local aquifers. The group will develop a

water quality monitoring program aimed at protecting surface water quality and groundwater supplies.

Santa Ana Sucker Conservation Team:

Meeting monthly since 1998, a group of concerned public agencies from throughout the Santa Ana River watershed have been working to determine the reasons for the decline of the Santa Ana Sucker (Catostomus santaanae) and to devise strategies for recovering the species. The U.S. Fish & Wildlife Service (USFWS) and the California Department of Fish & Game (CDFG) are part of this effort.

One Water One Watershed Initiative:

A large and diverse group of interested citizens and organizations is participating in developing an updated Santa Ana Watershed Integrated Regional Water Management Plan.

6.2.2 WATER QUALITY AND NATURAL RESOURCE PROTECTION IN THE PRADO BASIN

The water quality of the Santa Ana River and its tributary creeks has a direct impact on the quality of water that flows into Orange County. The operation of the Prado Wetlands, as described in Section 5.3.3, improves water quality through the removal of nitrates and other pollutants before the water reaches OCWD's groundwater recharge basins.

The Prado Basin contains the single largest stand of forested riparian habitat remaining in coastal southern California. The basin provides a variety of fish and bird habitats including several rare and endangered species. OCWD manages a large portion of this property and has undertaken numerous habitat restoration and species recovery projects.

As part of a cooperative agreement with the ACOE and the USFWS, OCWD has created more than 800 acres of habitat for the endangered least Bell's vireo and southwestern willow flycatcher and has funded more than $3 million in mitigation and monitoring measures for the vireo program. Through these restoration activities, OCWD has made significant contributions towards the recovery of vireo. In the mid-eighties, the vireo population had dropped to less than 20 breeding pairs. A 2007 survey identified 420 vireo territories, 237 of which contained pairs. Plans are underway to create additional river edge habitat, the preferred habitat of the flycatcher, in order to increase the population of this endangered bird.

A significant amount of the Prado Basin is infested with exotic vegetation, including the Giant Reed (*Arundo donax*), shown in Figure 6-1. Arundo grows rapidly, obstructs flood flows, has no value for wildlife habitat, and consumes nearly three times the water of native vegetation. Arundo consumes an estimated 56,200 af of water annually from the Santa Ana River.

OCWD has invested over $3 million in Arundo removal efforts. These efforts are coordinated by the Santa Ana Watershed Association (SAWA). The SAWA, of which OCWD is a founding member, is dedicated to improving environmental quality and habitat within the watershed. Other members of SAWA include the CDFG, Riverside

County Flood Control District, Riverside County Parks and Recreation, San Bernardino County Flood Control District, SAWPA, the RWQCB, the ACOE, the USFWS, and the U.S. Forest Service.

Approximately 3,100 acres of river bottom lands formerly infested by Arundo and other invasive weeds are now under management. It is estimated that by 2025, an annual minimum of 36,000 af of additional water will be available in the Santa Ana River as a result of removing Arundo (based on a minimum of 3.6 af of additional water per acre of Arundo removed).

FIGURE 6-1
ARUNDO REMOVAL

Arundo Control Begins with Removal by Hand or Machine Followed by Treatment of Re-growth with a Systemic Herbicide

6.2.3 CHINO BASIN INTEGRATED PLANNING

Chino Creek and Mill Creek are major tributaries that flow into the Santa Ana River in the Prado Basin. OCWD staff attends monthly meetings of stakeholders from this region to discuss and act upon issues of common concern. In 2006, the group, led by the IEUA and OCWD produced the *Chino Creek Integrated Plan: Guidance for Working Together to Protect, Improve, and Enhance the Lower Chino Creek Watershed*.

6.2.4 COOPERATIVE EFFORTS IN ORANGE COUNTY

OCWD supports the watershed planning efforts of the County of Orange. The county created three watershed management areas in order to localize the development and implementation of integrated regional watershed plans. Two of the management areas are within the OCWD service area. The North Orange County Management Area covers the areas within the county that are located within the Santa Ana River Watershed and the coastal watersheds west of the Santa Ana River. The Central Orange County Management Area covers the Newport Bay Watershed and the Newport Coast area. OCWD participates in the development and implementation of the North Orange County and Central Orange County watershed plans.

6.2.5 COOPERATIVE EFFORTS IN OCWD SERVICE AREA

OCWD participates in a variety of cooperative efforts with water retailers and cities within the OCWD service area as well as wastewater and flood control agencies, as described below.

Groundwater Producers

The Producers, the retail water agencies that produce the majority of the groundwater from the basin, meet with OCWD staff on a monthly basis to discuss issues related to management of the groundwater basin.

Municipal Water District of Orange County (MWDOC)

MWDOC, a member agency of the Metropolitan Water District of Southern California, provides imported water to 28 retail water agencies and cities in Orange County. MWDOC also supplies untreated imported water to OCWD when it is available for use as a supplemental source of water to recharge the groundwater basin. OCWD and MWDOC meet on a monthly basis and jointly plan for the maximum flexibility in the overall water supply, including:

- Coordinating mutual water resources planning, supply availability, and water use efficiency (conservation) programs for the benefit of the basin area in Orange County.
- Conducting and developing an Orange County Water Reliability Program to improve the overall water and emergency supply to Orange County.
- Evaluating ocean water desalination, water recycling, and other means to increase the supply and system reliability for the basin area.
- Evaluating water transfers and exchanges that would make surplus supplies from other areas available to the District.

Water Advisory Committee of Orange County (WACO)

WACO is a group of elected officials and water managers who meet on a monthly basis to provide advice to OCWD and MWDOC on water supply issues.

Groundwater Replenishment System Steering Committee

The GWR System is a joint project of the OCWD and the Orange County Sanitation District. Directors of the two districts meet on a monthly basis to coordinate joint operations.

Orange County Flood Control District

Three of the recharge basins used by OCWD for groundwater recharge are owned by the Orange County Flood Control District. OCWD also owns a six-mile section of the Santa Ana River that is used for conveyance of flood water. Quarterly meetings are held to discuss joint operations and planning.

6.3 Supply Management Strategies

One of OCWD's management objectives is to maximize the amount of water recharged into the basin. This is achieved through maximizing the efficiency of and expanding the District's recharge facilities and increasing the supply of recharge water. The District constructed the GWR System to increase the supply of water available to recharge the basin. Additional District supply management programs include encouraging and using recycled water for irrigation and other non-potable uses, participating in water conservation efforts, participating in efforts to manage water and other natural resources in the upper watershed, and working with MWDOC in developing and conducting other supply augmentation projects and strategies.

6.3.1 USE OF RECYCLED WATER

OCWD's Green Acres Project is a non-potable water supply project that utilizes a dedicated set of pipelines to deliver irrigation and industrial water to users. Most of the recycled water is used on golf courses, greenbelts, cemeteries, and nurseries. The Green Acres Project, in operation since 1991, reduces demands on the basin by providing non-potable water for non-potable uses. Secondary wastewater effluent from the OCSD is filtered and disinfected with chlorine to produce approximately seven mgd of irrigation and industrial water.

6.3.2 WATER CONSERVATION PROGRAMS

Water conservation plays an important role in meeting future water demands. By implementing conservation programs, future water demand can be reduced, and less imported water will be necessary to meet the area's water requirements.

The District cooperated with MWDOC, OCSD, and other agencies in a low-flush toilet program that subsidized the replacement of old high-volume toilets with modern low-flow toilets. The District also supports MWDOC and Metropolitan in a Hotel/Motel Water Conservation Program to save water through minimizing water use at hotels. This program, active in over 30,000 hotel/motel rooms, offers free laminated towel rack hangers or bed cards that encourage guests to consider using their towels and bed linens more than once during their stay.

OCWD supports MWDOC and other local agencies in a similar program aimed at restaurant water conservation. Free laminated cards are provided for restaurants to place on their tables. The cards inform patrons that water will be served only upon request. This encourages environmental awareness and water and energy conservation.

6.3.3 CONJUNCTIVE USE AND WATER TRANSFERS

The existing Metropolitan storage program provides for Metropolitan to store 66,000 af of water in the basin in exchange for Metropolitan's contribution to improvements in basin management facilities. This water can be withdrawn over a three-year time period. The improvements contributed by Metropolitan included the construction of eight new extraction wells and new injection wells for the Talbert Barrier Expansion.

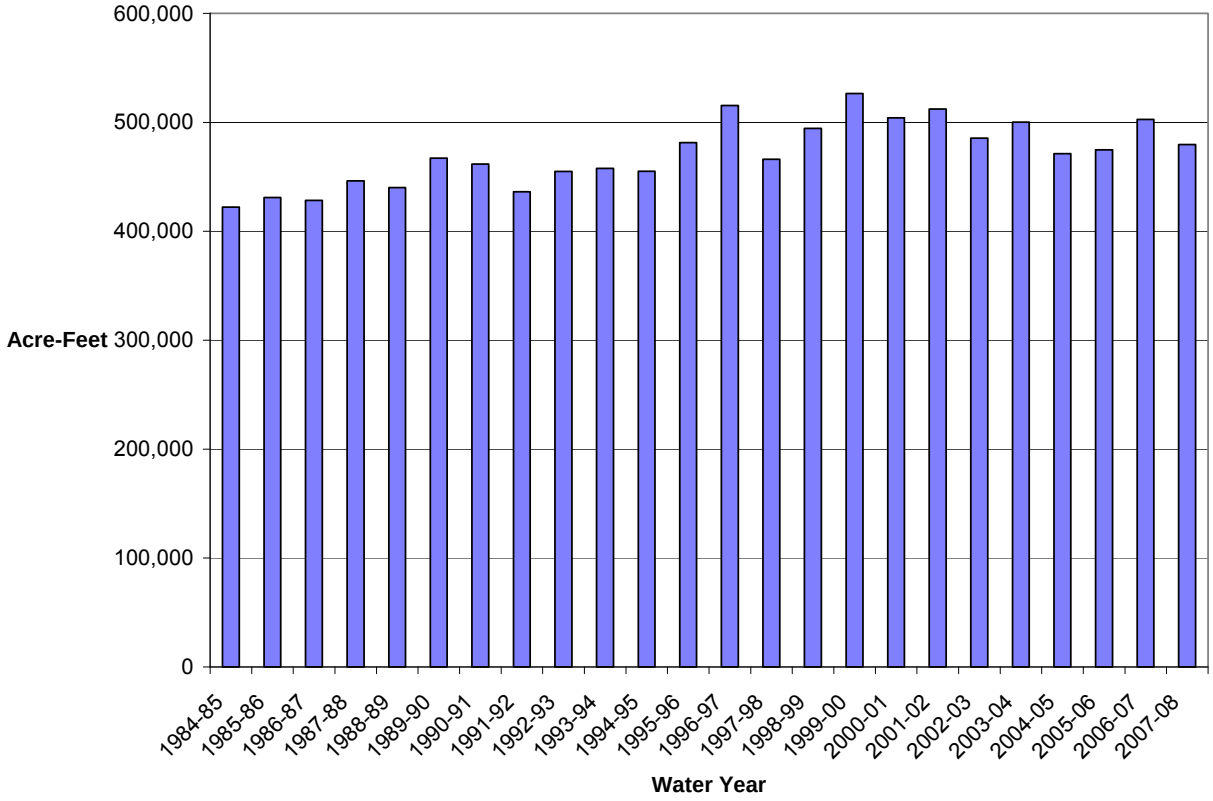
The District reviews opportunities for additional conjunctive use projects that would store water in the basin and could potentially store water in other groundwater basins. Additionally, the District reviews opportunities for water transfers that could provide additional sources of recharge water. Such projects are evaluated carefully with respect to their impact on available storage and their reliability and cost effectiveness.

6.4 Water Demands

Numerous factors influence water demands such as population growth, economic conditions, conservation programs, and hydrologic conditions. Estimates of future demands are therefore subject to some uncertainty and are updated on a periodic basis.

Total water demand within the District's boundary for water year 2007-08 (July 1-June 30) was 480,303 af. Total demand is met with a combination of groundwater, imported water, local surface water in Irvine Lake and Santiago Creek, and recycled water used for irrigation and industrial purposes. Figure 6-2 provides historical water demands in the District.

FIGURE 6-2
HISTORICAL TOTAL DISTRICT WATER DEMANDS



Demand estimates are based on a number of factors including projected population increases. Population within OCWD's service area is expected to increase from 2.5 million currently to 2.7 million by the year 2035 as shown in Table 6-1. This population growth is expected to increase water demands from the current approximately 480,000 afy to 558,000 afy in 2035 as shown in Table 6-2. Future annual water demands will fluctuate, primarily due to factors such as the effectiveness of future water conservations programs, economic conditions, and hydrologic conditions.

TABLE 6-1
ESTIMATED POPULATION WITHIN OCWD BOUNDARY

2010	2015	2020	2025	2030	2035
2,550,000	2,620,000	2,659,000	2,685,000	2,703,000	2,722,000

Source: MWDOC and Center for Demographics Research (2008)

TABLE 6-2
ESTIMATED FUTURE WATER DEMANDS IN OCWD BOUNDARY (AFY)

2009	2010	2015	2020	2025	2030	2035
490,000	500,000	519,000	538,000	548,000	553,000	558,000

Projections based on annual MWDOC survey completed by each Producer - Spring 2008

Expansion of the District's boundary through annexing additional land into the District has been a major factor in the growth of OCWD. From 1933 to now, the District's area has grown from 162,676 acres to over 229,000 acres (OCWD, 2006). Annexation requests by the City of Anaheim, Irvine Ranch Water District, and Yorba Linda Water District, if approved, could expand the District's boundary and increase water demands by approximately 48,000 afy.

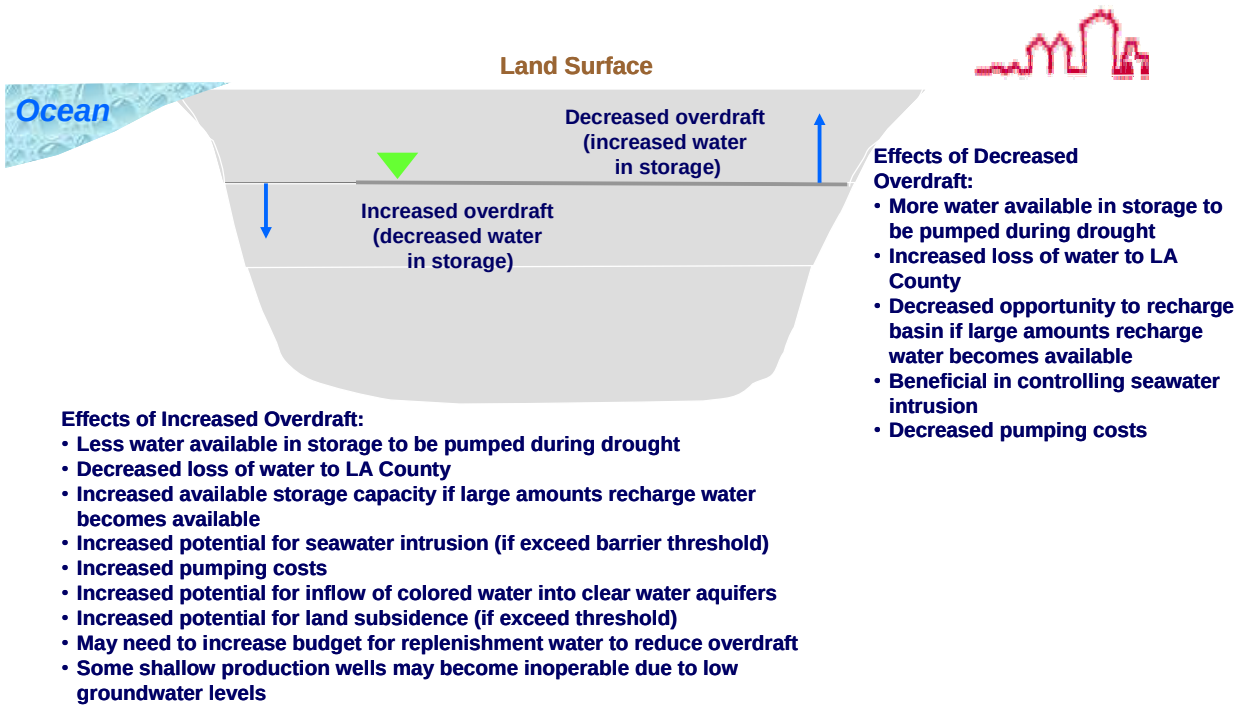
6.5 Basin Operating Range

OCWD does not regulate pumping from the groundwater basin. Instead, total pumping is managed by a process that uses financial incentives to encourage Producers to pump an aggregate amount of water that is sustainable over the long term. The process that determines a sustainable level of pumping considers the basin's safe operating range and the amount of recharge water available to the District.

The basin operating range refers to the upper and lower levels of groundwater storage in the basin that can be reached without causing negative or adverse impacts. The basin is in the upper (higher) end of the operating range when groundwater levels are high. Conversely, the basin is near the low end of the operating range when groundwater levels are lower. Figure 6-3 schematically illustrates the impacts of changing the amount of groundwater in storage.

The storage level is quantified based on a benchmark defined as the full basin condition. The groundwater basin rarely, if ever, reaches the full basin condition. The degree to which the storage is below the full basin condition is defined as "accumulated overdraft." Based on this definition of accumulated overdraft, it is anticipated that the accumulated overdraft would increase or decrease from year to year in response to hydrological variations. Provided that the accumulated overdraft is within the safe operating range, this approach is sustainable.

FIGURE 6-3
SCHEMATIC ILLUSTRATION OF IMPACTS OF CHANGING THE AMOUNT OF GROUNDWATER IN STORAGE



Each year the District determines the optimum level of storage for the following year. For example, at small amounts of overdraft (greater total amount of water in storage), the amount of energy required to pump groundwater is less and groundwater outflow to Los Angeles County is greater. On the other hand, larger amounts of overdraft increase the potential for seawater intrusion. Factors that are considered in determining the optimum level of storage are shown in Table 6-3.

The accumulated overdraft is calculated and published in the annual District's Engineer's Report. Since 2007, the determination of accumulated overdraft is based on a full basin benchmark defined for each of the three aquifer layers as described in Section 2.

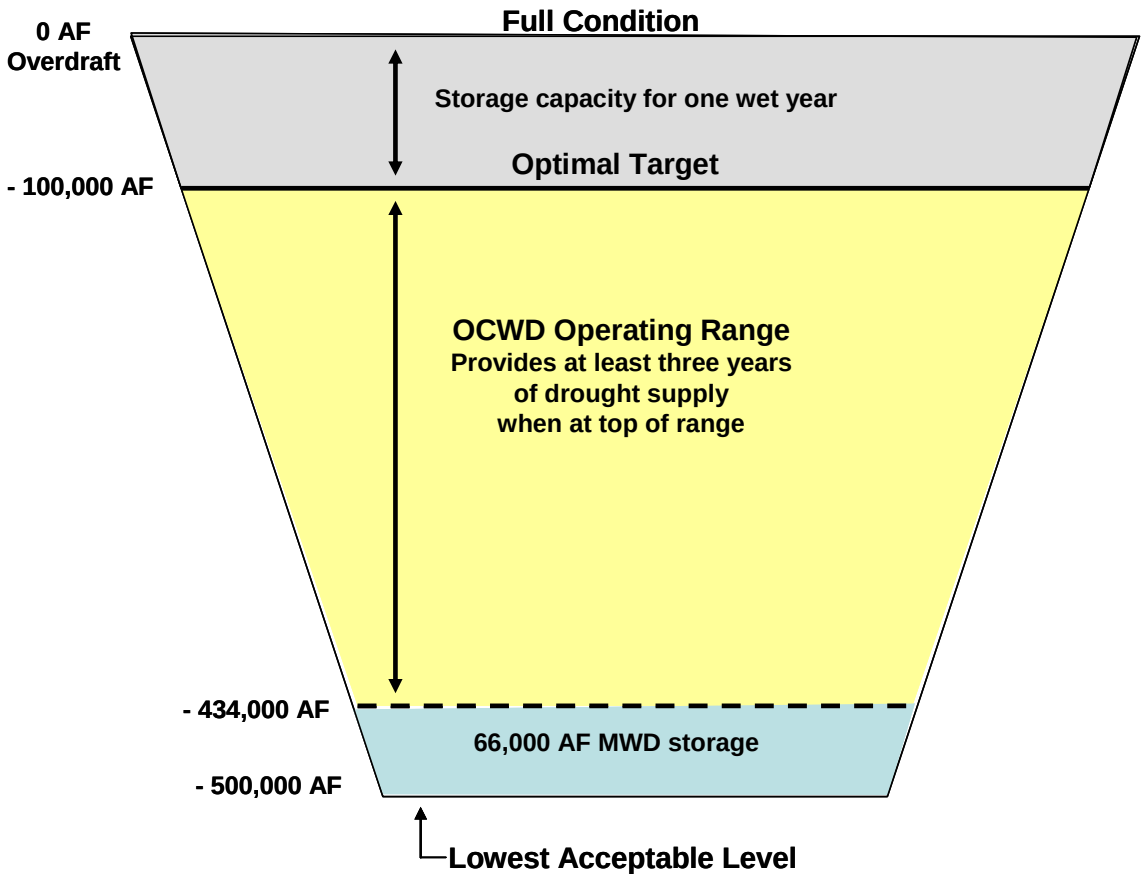
The shallow aquifer, the principal aquifer, and the aquitard between the shallow and principal aquifer stores approximately 66,000,000 af of water at the full condition. When the accumulated overdraft is 200,000 af, the Basin is approximately 99.7 percent full. When the overdraft increases from 200,000 to 400,000 af, the basin changes from 99.7 to 99.4 percent full. From a classical surface water reservoir perspective, the basin is

almost always nearly "full." In spite of the large amount of water stored in the basin, there is a narrow operating range within which the Basin can safely operate, as illustrated in Figure 6-4, which is largely dictated by water quality issues and the need to prevent land subsidence.

TABLE 6-3
BENEFITS AND DETRIMENTS OF DIFFERENT STORAGE LEVELS

ACCUMULATED OVERDRAFT (AF)	BENEFITS	DETRIMENTS
Less than 200,000	• Beneficial to controlling seawater intrusion • Lower pumping energy costs for producers • Easier to maintain stable BPP • Water available to be pumped from storage in shortage condition • Potential to temporarily increase BPP • Decreased potential for vertical migration of poor quality water • Opportunity to operate Basin to build reserves	• Increased loss of groundwater to Los Angeles County • Possible localized high groundwater levels if near full condition • Decreased opportunity to recharge Basin if large amount of low cost recharge water becomes available • Possible decrease in recharge capacity due to high groundwater levels (not observed at current recharge rates, but may be an issue with higher rates in future)
200,000 to 350,000	• Minimal to no problems with high groundwater levels • Increased available storage capacity if large amount of recharge water becomes available • Decreased groundwater outflow to Los Angeles County	• Limited amount of water in storage that can be pumped during drought or other shortage condition • Risk of seawater intrusion increases as overdraft increases from 200,000 to 350,000 af • Option for Metropolitan to call 20,000 afy from storage would further increase overdraft
350,000 to 500,000	• Minimal to no problems with high groundwater levels • Increased available storage capacity if large amount of recharge water becomes available • Further decrease in groundwater outflow to Los Angeles County	• Little to no water in storage that can be pumped during drought or other shortage condition • Increased pumping energy costs • Further increased risk of seawater intrusion • Coastal pumping reductions potentially needed • Option for Metropolitan to call 20,000 afy from storage further worsens overdraft • Increased number of production wells inoperable due to low groundwater levels below 400,000 af overdraft • Potential risk of increased land subsidence • Potential increased risk of vertical migration of poor quality water. • Need to increase budget for replenishment water to reduce overdraft • More difficult to maintain stable BPP

FIGURE 6-4
STRATEGIC BASIN OPERATING LEVELS AND OPTIMAL TARGET



Groundwater levels must be carefully managed to properly control seawater intrusion. With the water available for injection from the GWR System, seawater intrusion may be controlled in the Talbert Gap with a maximum overdraft of 500,000 af. Improvements to the Talbert Barrier may allow greater overdraft but the impact of greater withdrawals on the other gaps, Bolsa, Sunset and Alamitos, must also be evaluated.

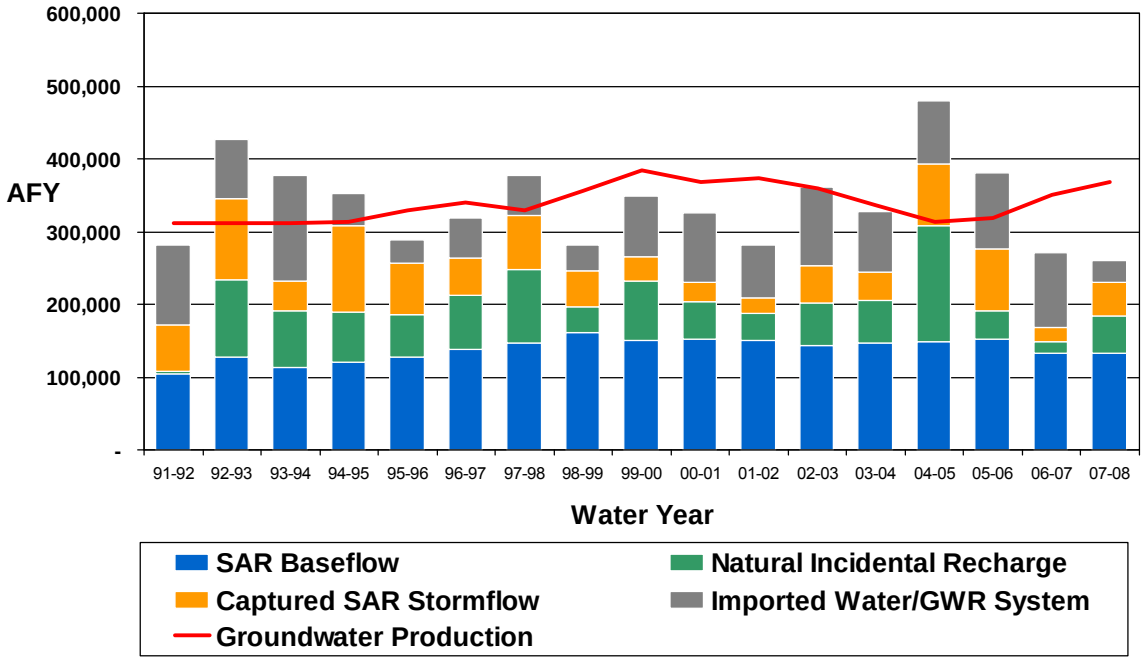
Additional issues that would need to be evaluated prior to increasing the amount of overdraft, assuming an effective seawater barrier was operating, would include the risk of land subsidence, inflow of colored water or poor quality groundwater into the principal aquifer from underlying or overlying aquifers, and the number of shallow production wells that would become inoperable due to lower groundwater levels.

6.6 Balancing Production and Recharge

Over the long term, the basin must be maintained in an approximate balance to ensure the long-term viability of basin water supplies. In one particular year, water withdrawals may exceed water recharged as long as over the course of a number of years this is

balanced by years where water recharged exceeds withdrawals. Levels of basin production and water recharged since water year 1991-92 are shown in Figure 6-5.

FIGURE 6-5
BASIN PRODUCTION AND RECHARGE SOURCES



Water Year	SAR Baseflow	Natural Incidental Recharge	Captured SAR Stormflow	Imported Water/ GWR System	Groundwater Production
91-92	105,000	2,000	65,000	109,000	311,000
92-93	127,000	107,000	111,000	82,000	312,000
93-94	114,000	78,000	41,000	144,000	312,000
94-95	120,000	70,000	117,000	44,000	314,000
95-96	128,000	58,000	70,000	32,000	329,000
96-97	138,000	74,000	51,000	56,000	339,000
97-98	146,000	101,000	74,000	55,000	329,000
98-99	161,000	36,000	50,000	35,000	356,000
99-00	150,000	82,000	33,000	84,000	384,000
00-01	153,000	50,000	27,000	95,000	369,000
01-02	150,000	38,000	21,000	73,000	374,000
02-03	143,000	58,000	52,000	109,000	359,000
03-04	146,000	59,000	39,000	84,000	337,000
04-05	149,000	159,000	85,000	87,000	314,000
05-06	153,000	39,000	84,000	104,000	318,000
06-07	133,000	15,000	19,000	103,000	350,000
07-08	132,000	52,000	46,000	30,000	368,000

6.7 Managing Basin Pumping

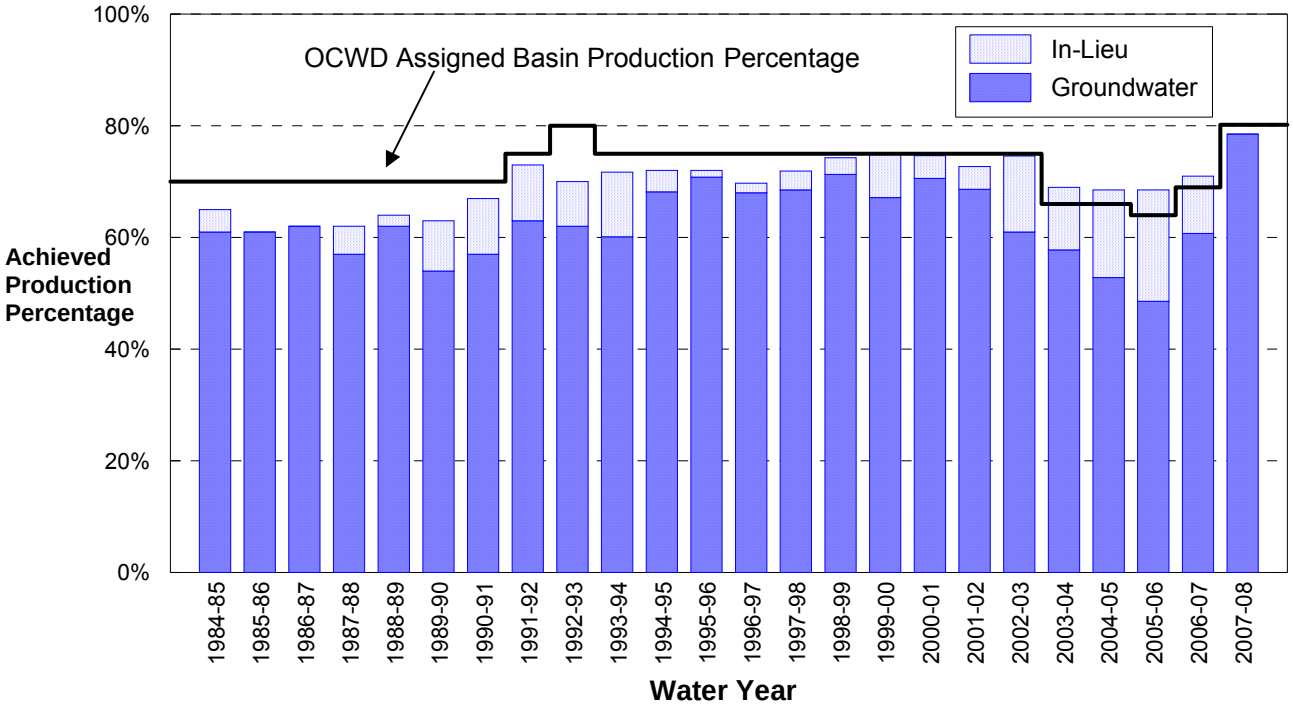
The primary mechanism used by OCWD to manage pumping is the Basin Production Percentage (BPP). Section 31.5 of the District Act empowers the Board to annually establish the BPP, defined as:

> "the ratio that all water to be produced from groundwater supplies with the district bears to all water to be produced by persons and operators within the District from supplemental sources as well as from groundwater within the District. "

In other words, the BPP is a percentage of each Producer's water supply that comes from groundwater pumped from the basin. The BPP is set uniformly for all Producers. Groundwater production at or below the BPP is assessed the RA. Any production above the BPP is charged the RA plus the BEA. The BEA is calculated so that the cost of groundwater production above the BPP is higher than purchasing imported potable supplies. This approach serves to discourage, but not eliminate, production above the BPP. The BEA can be increased as needed to discourage production above the BPP.

In simplified terms, the BPP is calculated by dividing groundwater production by total water demands. The BPP is set after evaluating groundwater conditions, availability of recharge water supplies, and basin management objectives. The BPP is also a major factor in determining the cost of groundwater production for that year. OCWD's goal is to set the BPP as high as possible to allow Producers to maximize pumping and reduce their overall water supply cost. Figure 6-6 shows the history of the BPP along with the actual BPP that was achieved by the Producers.

FIGURE 6-6
BASIN PRODUCTION PERCENTAGE HISTORY



Raising or lowering the BPP allows the District to manage the amount of pumping from the basin. The BPP is lowered when basin conditions necessitate a decrease in pumping. A lower BPP results in the need for Producers to purchase additional, more expensive imported water from Metropolitan.

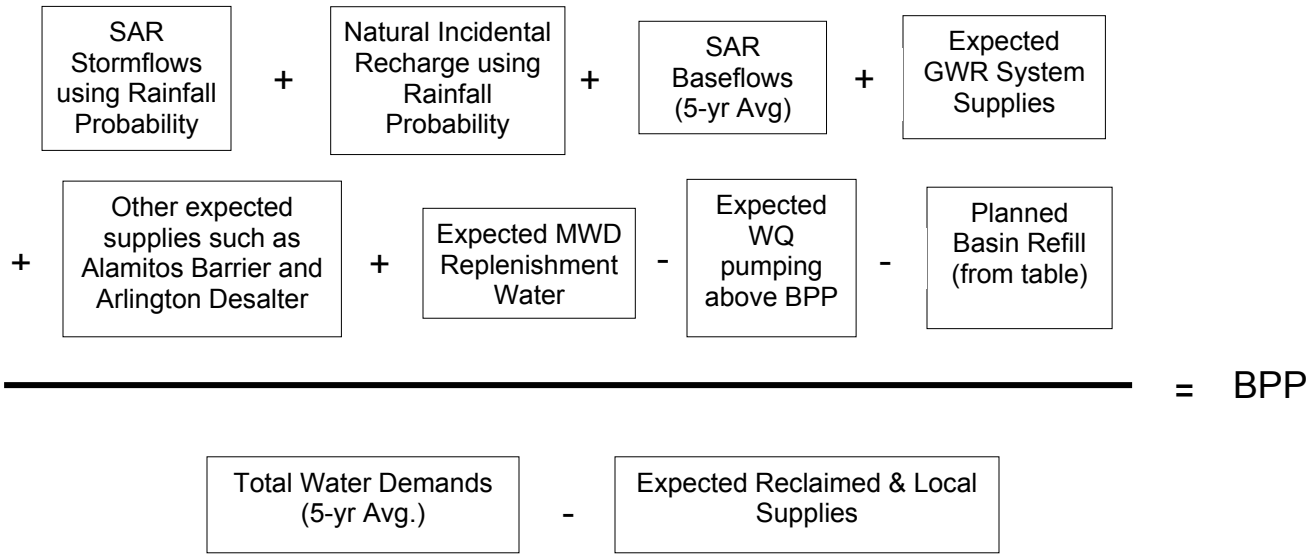
One example of a condition that could require a lowering of the BPP is to protect the basin from seawater intrusion. In this case, reduced pumping would allow groundwater levels to recover and seawater intrusion to be reduced. A change in the BPP affects the District's budget as less pumping reduces collected revenues.

6.7.1 METHODOLOGY FOR SETTING THE BASIN PRODUCTION PERCENTAGE

The formula used to estimate the BPP is shown in Figure 6-7. The formula is used as a guideline and the District's Board of Directors sets the BPP after considering the relevant information and input from the Producers and the public. To determine the BPP for a given year the amount of water available for basin recharge must be estimated. The supplies of recharge water that are estimated are:

- Santa Ana River stormflow
- Natural incidental recharge
- Santa Ana River baseflow
- GWR System supplies
- Other supplies such as Metropolitan and recycled water purchased for the Alamitos Barrier.

FIGURE 6-7
BPP CALCULATION



MWD = Metropolitan Water District of Southern California

Probability factors are used to estimate recharge into the groundwater basin from Santa Ana River stormflow and natural incidental recharge. The probability percentages are based on over 100 years of rainfall data and represent the probability that the upcoming year will not be drier than the predicted rainfall amount. As the accumulated overdraft increases, a higher level of certainty or probability is used in the BPP calculation to ensure that the basin recharge estimates are attained or exceeded.

For example, if the accumulated overdraft is 500,000 af, then a 90 percent rainfall probability would be used to conservatively estimate that the upcoming year's rainfall will only be nine inches even though there is a 90 percent chance that it will be greater. With this methodology, there is 90 percent likelihood that the upcoming year's estimate of rainfall will be exceeded.

When the basin is nearly full, the ten percent probability of expected rainfall would be used. In other words, it would be determined that there is only a ten percent chance of having an upcoming year that is wetter than assumed, or conversely, a 90 percent chance that the upcoming year will be drier. For the San Bernardino rainfall station, the ten percent rainfall exceedance probability is 27 inches of rainfall. Therefore, assuming 27 inches of rainfall for the upcoming year's BPP calculation would ensure with 90 percent likelihood that it would actually be *drier*, less water would be recharged into the basin, and the accumulated overdraft would be *increased* so as to prevent overfilling the basin and losing water to the ocean.

When the basin is within the optimal range of 100,000 to 150,000 af of accumulated overdraft, the 50 percent probability of rainfall is suggested to be used. In other words, there would be an equal chance (50/50) of having either a wetter or drier year than assumed. In this case, the 50 percent rainfall exceedance probability is very similar to assuming average hydrology for the upcoming year.

This methodology provides a guideline for the upcoming year's recommended amount of basin refill, dependent of the level of accumulated overdraft. For each increasing level of accumulated overdraft, an increasing amount of basin refill is suggested, ranging from approximately five to ten percent of the accumulated overdraft. For example, at an accumulated overdraft level of 400,000 af, the suggested amount of basin refill or overdraft reduction for the upcoming year would range from 20,000 to 40,000 af. Therefore, at this assumed basin refill rate, it would take approximately 10 to 20 years to completely fill the basin and eliminate the overdraft.

Table 6-4 shows the established amount or range for the planned basin refill water (reduction to the basin's accumulated overdraft) that is used in the formula based upon the basin's accumulated overdraft. The range is based upon provisions in the District Act which call for refilling the groundwater basin in not less than 10 years and not greater than 20 years. For example; if the accumulated overdraft is 400,000 af, refilling the basin over a 20-year period would yield a value of 20,000 afy while refilling the basin over a 10-year period yields a value of 40,000 afy.

TABLE 6-4
ACCUMULATED OVERDRAFT, BASIN REFILL, PROBABILITY FACTOR & RAINFALL AMOUNT

Accumulated Overdraft (af)	Planned Basin Refill Amount (af)	San Bernardino Rainfall Projection (inches)	Probability Factor
0	-20,000	27	10%
100,000	0	15	50%
200,000	10,000 to 20,000	14	60%
300,000	15,000 to 30,000	13	70%
400,000	20,000 to 40,000	11	80%
500,000	25,000 to 50,000	9	90%

For the 2008-09 water year, the estimated supply of recharge water is summarized in Table 6-5.

TABLE 6-5
RECHARGE WATER SUPPLIES ESTIMATED FOR 2008-09

Source	Amount (afy)
Santa Ana River Baseflows	146,300
Captured Santa Ana River Stormflows	50,000
Natural Net Incidental Recharge	60,000
Expected Groundwater Replenishment Supplies	61,000
Other Expected Supplies	11,000
Total	328,300

6.7.2 BASIN PRODUCTION LIMITATION

Another management tool that enables OCWD to sustainably manage the basin is the Basin Production Limitation. Section 31.5(g) (7) of the District Act authorizes limitations on production and the setting of surcharges when those limits are exceeded. This provision can be used when it is necessary to shift pumping from one area of the basin to another. An example of this was the Temporary Coastal Pumping Transfer Program, which shifted approximately 20,000 afy of pumping from the coastal area to inland to minimize seawater intrusion.

6.8 Drought Management

Drought is an extended period of below-average precipitation. There is no single, official definition of the time period associated with a drought. The magnitude of a drought depends on the extent of the deviation from average precipitation, the areal extent of the below-average precipitation, and other factors.

During a drought, flexibility to increase pumping from the basin becomes increasingly important. To the extent that the basin has water in storage that can be pumped out, the basin provides a valuable water supply asset during drought conditions. Ensuring that the basin can provide a buffer against drought conditions requires:

- Maintaining sufficient water in storage that can be pumped out in time of need;
- Operating the basin at the lower water storage in a safe manner; and
- Possessing a plan to refill the basin.

The San Bernardino precipitation station data, shown in Figure 4-11, is used to evaluate the extent of droughts in the Santa Ana River watershed. This station is selected because it is used in the Santa Ana River Watermaster reports (Santa Ana River Watermaster Report, 2008) and has a relatively long period of record.

During drought conditions, the District experiences a decline in the supply of recharge water. Replenishment water from Metropolitan is only available to OCWD when Metropolitan has excess supplies. In addition, the local supply of Santa Ana River recharge water and net incidental recharge water could decline up to 55,000 afy or more during drought years as shown in Table 6-6.

TABLE 6-6
IMPACT OF DROUGHTS ON RECHARGE WATER SUPPLIES

RECHARGE WATER SUPPLY	ESTIMATED DECREASE IN SUPPLY DUE TO DROUGHT (AF/YR)
Santa Ana River Baseflow	15,000
Santa Ana River Stormflow	20,000 or more
Net Incidental Recharge	20,000 or more
Total	55,000 or more

Note: does not include potential decline in Metropolitan replenishment supplies

6.8.1 MAINTAINING WATER IN STORAGE FOR DROUGHT CONDITIONS

For the basin to serve as a safe, reliable buffer, sufficient groundwater must be stored before a drought occurs. As an example, assume the basin has an accumulated overdraft of 150,000 af and can be drawn down to 500,000 af without irreparable seawater intrusion. The basin has 350,000 af of water in storage. In a hypothetical five-year drought, recharge water supplies can decrease 55,000 afy without jeopardizing the long-term health of the basin. Since recharge water supplies are likely to decline during drought years, the water stored at the beginning of the drought is critical. If water is stored in Metropolitan's conjunctive use storage program, this stored water must also be accounted for.

6.8.2 BASIN OPERATION DURING DROUGHT

When the basin overdraft is intentionally increased, the basin must be operated in a safe manner, considering the potential for land subsidence and seawater intrusion, the availability of sufficient excess recharge capacity to eventually refill the basin, the impact of low groundwater levels on shallow production wells, and a potential for

colored water to flow into clear water aquifers. Approaches for refilling the Basin are described in Table 6-7.

TABLE 6-7
APPROACHES TO REFILLING THE BASIN

APPROACH	DISCUSSION
Decrease Total Water Demands	• Increase water conservation measures (note this does not result in a 1:1 decrease in groundwater pumping because some of the increased conservation reduces Metropolitan demands); this decreases pumping from the basin if the BPP is held constant and all other factors remain the same.
Decrease BPP	• Allows groundwater levels to recover rapidly • Decreases revenue to the District • Increases water cost for producers • Does not require additional recharge facilities • Dependent upon other sources of water (e.g., water from Metropolitan) being available to substitute for reduced groundwater pumping
Increase Recharge	• Dependent on increased supply of recharge water • Water transfers and exchanges could be utilized to provide the increased supply of recharge water • Dependent on building and maintaining excess recharge capacity (which would be under-utilized in non-drought years)
Combination of the Above	• A combination of the approaches provides flexibility and a range of options for refilling the basin

7 FINANCIAL MANAGEMENT

OCWD strives to improve the efficiency of all aspects of its operations in its continuing efforts to increase the water quality and reliability of Orange County's local water resources at the lowest possible cost. The District manages its finances to provide long-term fiscal stability. To achieve this objective OCWD:

- **Manages finances to maintain high credit ratings.**
- **Manages District operations efficiently and effectively.**
- **Maintains reserves for purchase of supplemental water supplies when available.**
- **Recovers contamination clean up costs from responsible parties when possible.**
- **Sets the Basin Production Percentage to optimize sustainable use of groundwater.**

7.1 Background Financial Information

The District's fiscal year (FY) begins on July 1 and ends on June 30. The annual operating budget for 2008-09 was approximately $116.3 million; District revenues are expected to be approximately $116.3 million. A significant increase in the budget to fund the operation of the GWR System was approved by the Board in 2007.

7.2 Operating Expenses

The District's budgeted operating expenses for FY 2008-09 are summarized in Table 7-1 and described below.

TABLE 7-1
FY 2008-09 BUDGETED OPERATING EXPENSES

EXPENSES	AMOUNT (in millions)
General Fund	$57.2
Total Debt Service	28.3
Water Purchases	19.1
New Equipment/ Small Projects	2.2
Increase to Reserves	0.9
Refurbishment and Replacement Expenditures	8.6
Total	**$116.3**

7.2.1 GENERAL FUND

The District's general fund account primarily allows the District to operate the recharge facilities in the cities of Anaheim and Orange, GWR System, the Talbert and Alamitos Injection Barriers, the Green Acres Project, and the Prado Wetlands. In addition, the District's Water Quality Laboratory, groundwater monitoring programs, watershed management, planning, and other miscellaneous activities are funded by this account.

7.2.2 DEBT SERVICE

The debt service budget provides for repayment of the District's debt from issues of previous bonds. OCWD has a comprehensive long-range debt program, which provides for the funding of projects necessary to increase basin production and protect water quality, while providing predictable impacts to the RA. The annual project-related debt expense is approximately $28.3 million.

The District holds very high credit ratings of AAA credit from Standard & Poor's, AAA from Fitch, along with an Aa2 rating from Moody's. Because of these excellent credit ratings, OCWD is able to borrow money at a substantially reduced cost.

7.2.3 WATER PURCHASES

The District Act authorizes OCWD to purchase supplemental water for groundwater recharge to reduce overdraft of the basin. As described in Section 4, replenishment water is primarily purchased from Metropolitan, either as direct or in-lieu replenishment. This fund provides the flexibility to take advantage of surplus Metropolitan replenishment water or other surplus supplies when such supplies are available. During times of drought when replenishment water is unavailable for purchase, OCWD may budget funds for placement in reserve for future years. The District anticipates that surplus imported water will not be available for the next few years. A significant portion of the $19.1 million in the FY 2008-09 budget to purchase replenishment water will be placed in reserve. Funds in this account are also used to purchase treated full service supplies from MWDOC to blend with GWR System purified water for injection into the seawater barrier.

7.2.4 NEW CAPITAL EQUIPMENT

This category includes equipment items such as laboratory equipment, vehicles, fax machines, tools, computers, and software. These items are expensed and funded using current revenues.

7.2.5 REFURBISHMENT AND REPLACEMENT FUND

OCWD has over $700 million in existing plant and fixed assets. These facilities were constructed to provide a safe and reliable water supply. The Replacement and Refurbishment Fund was established to ensure that sufficient funds are available to repair and replace existing District infrastructure, such as pumps, heavy equipment, wells and water recycling facilities.

7.3 Operating Revenues

Expected operating revenues for FY 2008-09 are shown in Table 7-2 and described below.

Table 7-2
FY 2008-09 Operating Revenues

REVENUES	AMOUNT (in millions)
Replenishment Assessments	$84.5
Basin Equity Assessment	1.0
Property Taxes	18.1
Other Miscellaneous Revenue	12.7
Total	**$116.3**

7.3.1 REPLENISHMENT ASSESSMENTS

RAs are paid for all water pumped out of the basin. The District invoices Producers for their production in July and January. The amount of revenue generated by the RA is directly related to the amount of groundwater production. The RA is anticipated to generate $84.5 million in FY 2008-09 based on 341,058 af of total anticipated basin production. The BEA is assessed annually for all groundwater production above the BPP. The BEA rate is calculated for each agency and is currently approximately $381/af**.** Anticipated BEA revenues are budgeted at $1.0 million for FY 2008-09.

7.3.2 PROPERTY TAXES

The District receives a small percentage of the property taxes, also referred to as ad valorem taxes, collected in the service area. For 2008-09, the District expects to receive approximately $18.1 million from property taxes. The County of Orange assesses and collects the property taxes and transmits them to the District at various times during the year. This revenue source has been dedicated to the District's annual debt service expense.

7.3.3 OTHER MISCELLANEOUS REVENUE

Cash reserves generate interest revenues. The majority of cash reserves are invested in short-term securities. Yields on cash reserves are anticipated to be low and have been estimated at three percent for 2008-09, for anticipated revenue of $4.2 million.

Miscellaneous revenues are primarily comprised of water sales from the Green Acres Project and loan repayments. The loan repayments originate from the Conjunctive Use Well Program in which the District loaned Producers money at low interest rates for construction of new production wells and related facilities. In addition, numerous small items such as rents, subsidies, and minor fees are grouped in this account. Approximately $8.7 million is expected to be received in 2008-09.

7.4 Reserves

The District maintains cash reserves to ensure its financial integrity so that the basin can be successfully managed and protected. Cash reserves ensure that:

- OCWD has sufficient funds for cash flow purposes;
- Funds are available for unexpected events such as contamination issues;
- Funds are available to make necessary replacements and repairs to infrastructure;
- OCWD has access to debt programs with low interest cost;
- A financial hedge is available to manage variable rate debt; and
- Funds are available to purchase Metropolitan replenishment water when available.

7.4.1 RESERVE POLICIES

The District has reserve policies, which establish reserves in the following categories:

- Operating reserves
- The Replacement and Refurbishment Program
- The Toxic Cleanup Reserve
- Contingencies required by the District Act
- Bond reserve covenants

7.4.1.1 Operating Reserves

This reserve category helps the District maintain sufficient funds for cash flow purposes and helps sustain the District's excellent credit rating. Maintaining this reserve, which is set at 15 percent of the operating budget, is particularly important because the principal source of revenue, the RA, is only collected twice a year. Payments for significant activities, such as replenishment water purchases, are typically required on a monthly basis. The reserve provides the financial "bridge" to meet the District's financial obligations on a monthly basis.

7.4.1.2 Replacement and Refurbishment Program

The District maintains a Replacement and Refurbishment Fund to provide the financial resources for replacement and/or repair of the District capital assets. These assets include treatment facilities, monitoring and injection wells, and treatment facilities. The fund balance at the end of FY 2008-09 was projected to be approximately $41.2 million.

7.4.1.3 Toxic Cleanup Reserve

Funds are reserved in this account to be used in the event that a portion of the basin becomes threatened by contamination. Over two million residents in the District rely on the basin as their primary source of water. Approximately $7 million is projected to be available in this reserve fund at the end of FY 2008-09 to allow the District to respond immediately to contamination threats in the basin.

7.4.1.4 General Contingencies

Section 17.1 of the District Act requires the allocation of funds to cover annual expenditures that have not been provided for or that have been insufficiently provided for and for unappropriated requirements. This reserve amount is $3 million.

7.4.2 DEBT SERVICE ACCOUNT

Restricted funds in this account have been set aside by the bonding institutions as a requirement to ensure financial solvency and to help guarantee repayment of any debt issuances. These funds cannot be used for any other purpose. The requirement varies from year to year depending on the District's debt issuance and outstanding state loans. The account currently has approximately $5.5 million.

7.5 Capital Improvement Projects

The District prepares a Capital Improvements Project budget to support basin production by increasing recharge capacity and operational flexibility, protect the coastal portion of the basin, and provide water quality improvements. The FY 2008-09 budget includes $20.5 million for this account.

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8 RECOMMENDATIONS

This section provides recommendations for the District to consider as part of ongoing management of the basin.

The District's programs to protect and increase the basin's sustainable yield in a cost-effective manner continue to evolve due to increasing water demands and changes in the availability of recharge water supplies. The occurrence of wet and dry periods, the future availability and cost of imported water for groundwater recharge, and changing water management practices of agencies in the watershed will continue to affect the District's management of the basin. The District's programs to protect and enhance water quality will also continue to change due to new regulations and requirements.

Recommendations for the District to continue its proactive management of the basin are summarized in Table 8-1. The table organizes these recommendations by general program area and also links the recommendations to the three management objectives of protecting and enhancing water quality, protecting and increasing the basin's sustainable yield, and increasing the efficiency of OCWD's operations.

Specific projects that may be developed as a result of these recommendations would be reviewed and approved by the District's Board of Directors and processed for environmental review prior to project implementation.

TABLE 8-1
RECOMMENDATIONS

PROGRAM/ACTIVITY	PROTECT AND ENHANCE WATER QUALITY	PROTECT AND INCREASE SUSTAINABLE YIELD	INCREASE EFFICIENCY
REPORTING AND MONITORING			
Continue to monitor groundwater elevations and the amount of water in storage to provide information to manage pumping in the basin within safe and sustainable levels	✓	✓	
Continue to monitor groundwater quality and the quality of recharge water sources	✓		
Update the *Groundwater Management Plan* periodically	✓	✓	✓
Update the *Long Term Facilities Plan* periodically	✓	✓	✓

PROGRAM/ACTIVITY	PROTECT AND ENHANCE WATER QUALITY	PROTECT AND INCREASE SUSTAINABLE YIELD	INCREASE EFFICIENCY
Continue annual publication of the *Santa Ana River Water Quality Report*; the *Engineer's Report on the Groundwater Conditions, Water Supply and Basin Utilization;* the *Santa Ana River Watermaster Report;* and the *Groundwater Replenishment System Operations Annual Report*	✓	✓	✓
Begin in 2009 periodic publication of the *Report on Managed Aquifer Recharge in the Orange County Groundwater Basin*		✓	
RECHARGE WATER SUPPLY MANAGEMENT			
Increase storage of storm flows behind Prado Dam through cooperative efforts with the ACOE		✓	✓
Monitor water management and recycling plans in the watershed for their potential impact upon OCWD recharge operations	✓	✓	
Complete a feasibility study on reducing sediment loads in recharge water	✓		✓
Complete construction of the Initial Expansion of the GWR System	✓	✓	
Increase drought preparedness through utilization of the full capacity of the GWR System		✓	
Develop improved tools to evaluate the efficiency of potential new recharge basins and proposed changes to existing recharge operations		✓	✓
Evaluate new approaches to groundwater recharge and approaches to increasing the efficiency of the District's recharge facilities		✓	✓
Maintain and expand efforts to remove non-native vegetation and plant native vegetation in the watershed.	✓	✓	
Promote incidental recharge to the extent feasible without negatively impacting groundwater quality		✓	

PROGRAM/ACTIVITY	PROTECT AND ENHANCE WATER QUALITY	PROTECT AND INCREASE SUSTAINABLE YIELD	INCREASE EFFICIENCY
WATER QUALITY MANAGEMENT			
Manage recharge water supplies so that water recharged through District facilities meets or is better than Department of Public Health MCLs and Notification Levels	✓		
Continue operation of Prado Wetlands in order to reduce nitrogen loads in Santa Ana River water	✓		
Complete and publish, in cooperation with Metropolitan and the NWRI, a research study on emerging constituents.	✓		
Prevent future contamination through coordinated efforts with regulatory agencies and watershed stakeholders	✓		
Complete construction and begin operation of the North Basin Groundwater Protection Project	✓		
Complete remedial investigation and begin construction of the South Basin Groundwater Protection Project	✓		
Address MTBE contamination	✓		
Open and begin operations of a new water quality laboratory in Fountain Valley	✓		
Maintain control of seawater intrusion in the Talbert Gap	✓	✓	
Improve the performance of the Alamitos Seawater Barrier through evaluating need for additional injection wells and to construct necessary facilities	✓	✓	
INTEGRATED MANAGEMENT OF PRODUCTION AND RECHARGE			
Continue to participate in cooperative efforts with watershed stakeholders	✓	✓	
Operate the basin within a safe and sustainable operating range		✓	

PROGRAM/ACTIVITY	PROTECT AND ENHANCE WATER QUALITY	PROTECT AND INCREASE SUSTAINABLE YIELD	INCREASE EFFICIENCY
FINANCIAL MANAGEMENT			
Set the Basin Production Percentage to optimize sustainable use of the groundwater			✓
Manage finances to maintain high credit ratings			✓
Maintain reserves for purchase of supplemental water supplies when available			✓

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APPENDICES

APPENDIX A	DOCUMENTS REGARDING PUBLIC PARTICIPATION
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NOTICE OF EXEMPTION

CERTIFICATION OF BOARD ACTION APPROVING GROUNDWATER MANAGEMENT PLAN 2009 UPDATE

MINUTES
GROUNDWATER PRODUCERS MEETING
Sponsored by the
ORANGE COUNTY WATER DISTRICT
Field Headquarters, Anaheim

Wednesday, January 14, 2009, 10 AM

1. **MTBE Sampling Update**

   Roy Herndon informed the group that the latest round of sampling and low level testing had been completed with the lab hired by the District. And that low levels of MTBE had been detected in about 1/3 of the major production wells in the basin. The Producers were told to contact Roy if they wanted specific information on their individual wells.

2. **Long-Term Facilities Plan Report**

   The Producers were asked to get any comment letters they may have on the final draft report to OCWD by January 21, 2009. OCWD will then respond to those letters. The LTFP final review will occur at the next Producers meeting on February 11, 2009 and could then go to the OCWD Board on February 18, 2009. The recent Golden State Water Company letter on the LTFP was distributed.

3. **Groundwater Management Plan – 5 Year Update**

   Greg Woodside informed everyone of the need to update the GWMP to comply with state guidelines. The District is working to provide a draft of the updated document in late February and to take it to the OCWD Board in April. Greg reviewed potential basin management goals for the document.

4. **Santiago Pump Station Project**

   The same presentation on this project provided to the Water Issues Committee was given to the Producers. It was suggested that OCWD should show the financial savings and the additional recharge created by the project.

5. **FY09-10 Budget process update**

   John Kennedy provided an update on several budget related issues including:

   - OCWD is working to provide FY09-10 RA and BPP projections by January 21.
   - The District will also provide the draft FY09-10 Work Plans for each of the cost centers on January 21.

   OCWD Staff was also asked to provide a BEA estimate and an estimate of what the Accumulated Overdraft would be at the end of FY09-10

6. **Follow-up on Producer letter regarding modeling for the Talbert Barrier and Basin Storage**

   OCWD's response letter to the Producers regarding this issue was provided. Bob McVicker provided comments on the need to better understand color water upwelling in their part of the groundwater basin.

7. **Other**

AGENDA ITEM SUBMITTAL

Meeting Date: May 13, 2009

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: G. Woodside/C. Miller

Budgeted: N/A
Budgeted Amount: N/A
Cost Estimate: N/A
Funding Source: N/A
Program/Line Item No.: N/A

General Counsel Approval: N/A
Engineers/Feasibility Report: N/A
CEQA Compliance: Exemption to be filed upon Board receipt of final plan

Subject: REVIEW OF UPDATED GROUNDWATER MANAGEMENT PLAN

SUMMARY

Staff has prepared a draft updated Groundwater Management Plan (Plan). The Plan was last updated in 2004. Staff will distribute the draft updated Plan for review by the Board and Producers. The Plan will also be posted on the District's web site.

RECOMMENDATION

Informational

BACKGROUND/ANALYSIS

The District prepared its first Groundwater Management Plan in 1989. The Plan was last updated in 2004. The Plan needs to be updated to remain consistent with guidelines established by the California Department of Water Resources.

The California Water Code sets forth the process for adopting and updating a Groundwater Management Plan. The Water Code lists components that must be included and requires the completion of plans in order for the state to grant public funds for construction of certain groundwater projects.

The 2009 Draft Update proposes the District's overall goals in managing the basin as follows:

- To protect and enhance groundwater quality,
- To protect and increase the sustainable yield of the basin in a cost-effective manner, and
- To increase the efficiency of OCWD's operations.

The updated Plan will be made available for public review. Staff will respond to comments from the Board, Producers, and the public and will prepare a revised version that addresses the comments received. Staff will then recommend that the Plan be adopted by the Board. The proposed schedule is:

May 13, 2009	Post Draft Updated Plan on OCWD website
May 14, 2009	Post public notice in Orange County Register
June 10, 2009	Workshop at Water Issues Committee and Producers Meeting
June 17, 2009	Public Hearing at OCWD Board meeting
June 24, 2009	Deadline for public comment
July 15, 2009	Consideration of adoption by Board of Directors

According to the Department of Water Resources, plan updates should provide a historical record of progress, including projects completed and how those projects improved resource management. The 2009 Update explains how OCWD manages the groundwater basin in order to accomplish the stated management objectives.

Major accomplishments since the adoption of the 2004 plan are listed and completed projects are described, examples of which are listed below:

- Analysis of 14,000 water quality samples in 2008.
- Completion of the Groundwater Replenishment System in 2008.
- Development of the three-layer method of determining maximum accumulated overdraft and publication of the *Report on Evaluation of Orange County Groundwater Basin Storage and Operational Strategy* in 2007.
- Improvements to recharge operations such as completion of the La Jolla Recharge Basin, the Kraemer-Miller pipeline improvements, and the Santiago Creek Recharge Enhancement Project.
- Completion of water quality improvement projects such as the Irvine Desalter and the initiation of the North and South Basin Groundwater Protection Projects.

PRIOR RELEVANT BOARD ACTION(S)

None

Minutes

GROUNDWATER PRODUCERS MEETING

Sponsored by the

ORANGE COUNTY WATER DISTRICT

18700 Ward Street, Fountain Valley (714) 378-3200

Wednesday, May 13, 2009, 10 AM

1. **Groundwater Management Plan Update**

   Greg Woodside gave an overview of the updated GWMP and how it would be processed this summer. A draft report was distributed. Greg reviewed the report recommendations.

2. **Review FY09-10 BPP/BEA/Pumping Limitation and Surcharge**

   John Kennedy reviewed the new rates and charges for FY09-10

3. **Annexation Update**

   John Kennedy provided a summary of how the District plans to terminate the 2004 annexation MOU with IRWD and the City of Anaheim. After responses are provided on the draft January 2006 Program EIR the District will formally inform IRWD and Anaheim of the termination as allowed for in Section 7 of the MOU. Future annexations could still be considered but under a different process from what was provided for in the 2004 MOU. Other comments included that Producers interested in annexing may be required to submit new applications. Additionally if annexations are considered individually, there is still a need to review the cumulative potential annexations.

With the MOU terminated the District can receive and file the Long-Term Facilities Plan Report. The LTFP will be reviewed with the Producers in June and taken to the OCWD Board in July.

4. **GWR System Update**

   a. **Expansion**

      Mike Markus gave an update on the process to select a design consultant for the expansion and some of the issues that need to be resolved. It was mentioned that OCWD should reassess the projects viability at key milestones prior to 100% design.

   b. **Existing plant water supply unit cost for FY08-09**

      A handout was provided which shows the existing unit cost at $582/af after the first nine months of FY08-09

5. **Other**

   Bob McVicker asked that OCWD provide BPP projections for future years. Discussion on AB1100 also incurred regarding legislation that would allow OCWD to bottle a small amount of GWR System water.

Information: OCWD May 20, 2009 Board meeting moved to May 27th.

OCWD Public Notices

May 13, 2009 - June 24, 2009

The Orange County Water District Draft Groundwater Management Plan 2009 Update is available for public review at www.ocwd.com under "News & Publications." Written comments will be accepted until June 24, 2009 at:
Orange County Water District
Attn: Marsha Westropp
P.O. Box 8300
Fountain Valley, CA 92728-8300

Or via e-mail at mwestropp@ocwd.com

A copy of the draft plan may be obtained by submitting a written request to OCWD at the above post office or e-mail address.

The public is invited to comment on the plan at the public hearing to be held at the regularly scheduled meeting of the Board of Directors at 5 p.m., June 17, 2009 in the Boardroom at OCWD's office at 18700 Ward Street, Fountain Valley, CA 92708. The Groundwater Management Plan 2009 Update is scheduled to be considered for adoption at the regularly scheduled meeting of the Board of Directors at 5 p.m., July 15, 2009. Any change to the schedule for the Board of Directors to adopt the updated plan will be posted on www.ocwd.com under "Board Agendas."

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18700 Ward Street, Fountain Valley, California 92708 • Ph: (714) 378-3200 • Fx: (714) 378-3373 • info@ocwd.com

Orange County Water District
Orange County's Groundwater Authority

EMPLOYMENT • SITE MAP • CONTACT • SEARCH Keyword(s) GO

ABOUT BOARD & AGENDAS CONSERVATION & EDUCATION ENVIRONMENT PROGRAMS & PROJECTS GOVERNMENT AFFAIRS NEWS

Publications & Newsletters

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Get ADOBE® READER®

OCWD Draft Groundwater Management Plan 2009 Update (11.5 MB)

The Orange County Water District Draft Groundwater Management Plan 2009 Update is available for public review by downloading the linked document above. Written comments will be accepted until June 24, 2009 at OCWD, Attn: Marsha Westropp, P.O. Box 8300, Fountain Valley, CA 92728-8300, or via e-mail at mwestropp@ocwd.com. A copy of the draft plan may also be obtained by submitting a written request to OCWD at the above post office or email address.

The public is invited to comment on the plan at the public hearing held at the regularly scheduled meeting of the OCWD Board of Directors at 5 p.m., June 17, 2009. The Groundwater Management Plan 2009 Update is scheduled to be considered for adoption at the regularly scheduled meeting of the OCWD Board of Directors at 5 p.m., July 15, 2009. Any change to the schedule for the Board of Directors to adopt the updated plan will be posted on www.ocwd.com under "Board Agendas."

Notice of Basin Equity Assesment.July 1 2009 to June 30 2010

Notice of Levy of Replenishment Assesments.July 1 2009 to June 30 2010

Board Resolution to Adopt Ticket Distribution Policy

Board Resolution Authorizing Payment for Meals

Comprehensive Annual Financial Report FY Ended 6-30-2008

OCWD 2006-2007 Engineer's Report; Groundwater Conditions, Water Supply and Basin Utilization

OCWD 2005-2006 Engineer's Report; Groundwater Conditions, Water Supply and Basin Utilization (5.43 MB)

OCWD Budget Report for Fiscal Year 07-08 (3.47 MB)

2004 - Santa Ana River Water Quality and Health Study (25.6 MB)

2004 - Santa Ana River Quality Health Study Final Report Appendices (2.64 MB)

2006 - 07 Fiscal Year Final Budget Report (3.33 MB)

2004 Groundwater Management Plan (7.87 MB)

OCWD Fact Sheet -May 2008

The 1933 OCWD District Act (223 kb)

OCWD 75th Anniversary Supplement

Newsletters:

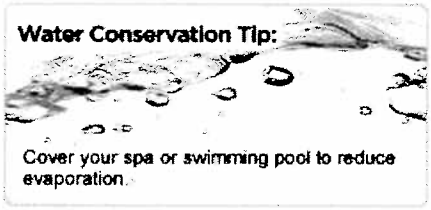
NEW-- Hydrospectives - Monthly E-Newsletter

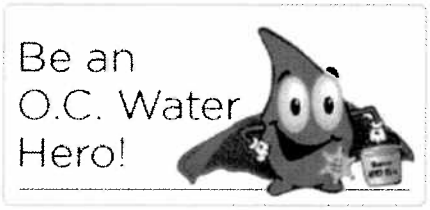
2008 Year In Review
November 2008 E-Hydrospectives
October 2008 E-Hydrospectives
September 2008 E-Hydrospectives
August 2008 E-Hydrospectives
July 2008 E-Hydrospectives
June 2008 E-Hydrospectives

Hydrospectives - Quarterly Groundwater News

- **Vol. V, Issue 2 - Fall 2007**
- **Vol. V, Issue 1 - Spring 2007**
- **Vol. IV, Issue 3 - Winter 2006**
- **Vol. IV, Issue 1 - Summer 2005**
- **Vol. III, Issue 3 - Fall 2004**

Directions + Map





AFFIDAVIT OF PUBLICATION

STATE OF CALIFORNIA,)
) ss.
County of Orange)

I am a citizen of the United States and a resident of the County aforesaid; I am over the age of eighteen years, and not a party to or interested in the above entitled matter. I am the principal clerk of **The Orange County Register**, a newspaper of general circulation, published in the city of Santa Ana, County of Orange, and which newspaper has been adjudged to be a newspaper of general circulation by the Superior Court of the County of Orange, State of California, under the date of 1/18/52, Case No. A-21046, that the notice, of which the annexed is a true printed copy, has been published in each regular and entire issue of said newspaper and not in any supplement thereof on the following dates, to wit:

May 19, 26, 2009

"I certify (or declare) under the penalty of perjury under the laws of the State of California that the foregoing is true and correct":

Executed at Santa Ana, Orange County, California, on

Date: May 26, 2009

Adolfo Mo
Signature

The Orange County Register
625 N. Grand Ave.
Santa Ana, CA 92701
(714) 796-7000 ext. 2209

PROOF OF PUBLICATION

Proof of Publication of

Notice of Public Hearing
For the Purpose of Updating the Orange County Water District
Groundwater Management Plan 2009

Notice is hereby given that the Orange County Water District ("District") will hold a public hearing on Wednesday, June 17, 2009 at 5 p.m., or as soon thereafter as the matter may heard, in the Boardroom at the office of said District, 18700 Ward Street, Fountain Valley, California 92708.

The hearing is for the purpose of notifying the public of the intention of the District to update the District's Groundwater Management Plan and for soliciting public comments on the draft Groundwater Management Plan 2009 Update prior to adoption of the plan.

The draft plan may be viewed on the District's website, www.ocwd.com. Copies may be obtained by submitting a written request to Orange County Water District, P.O. Box 8300, Fountain Valley, CA 92728-8300 Attn: Marsha Westropp. Copies will be available at the public hearing.

The public is invited to attend the public hearing and comment on the draft plan. Written comments must be submitted by June 24, 2009. Comments can be submitted to the above post office box address, Attn: Marsha Westropp or via email at mwestropp@ocwd.com . For additional information call 714-378-8248.

The Groundwater Management Plan 2009 Update is scheduled to be considered for adoption by the District's Board of Directors at the regularly scheduled meeting of the Board of Directors to be held on July 15, 2009 at 5 pm. Any change to the schedule for the Board of Directors to adopt the Groundwater Management Plan 2009 Update will be posted on the District's website, www.ocwd.com.

Publish: Orange County Register May 19, 26, 2009 R-915

AGENDA ITEM SUBMITTAL

Meeting Date: June 10, 2009

To: Water Issues Committee
Board of Directors

From: Mike Markus

Staff Contact: G. Woodside/C. Miller

Budgeted: N/A
Budgeted Amount: N/A
Cost Estimate: N/A
Funding Source: N/A
Program/Line Item No.: N/A

General Counsel Approval: N/A
Engineers/Feasibility Report: N/A
CEQA Compliance: Exemption to be filed upon Board adoption of updated plan

Subject: UPDATE: 2009 GROUNDWATER MANAGEMENT PLAN, PUBLIC COMMENT PERIOD AND PUBLIC HEARING

SUMMARY

Staff distributed draft copies of the updated Groundwater Management Plan (Plan) to the Board and Producers on May 13, 2009. Public notices were published in the Orange County Register and the draft plan was posted on the District's web site. A public hearing on the draft Plan will be held at the June 17 Board of Directors Meeting.

RECOMMENDATION

Informational

BACKGROUND/ANALYSIS

The District prepared its first Groundwater Management Plan in 1989. The Plan has been updated periodically to incorporate new information, and was last updated in 2004. The Plan needs to be periodically updated to remain consistent with guidelines established by the California Department of Water Resources.

The California Water Code lists components that must be included and requires the completion of plans in order for the state to grant public funds for construction of certain groundwater projects.

The 2009 Plan discusses the District's overall goals in managing the basin as follows:

- To protect and enhance groundwater quality,
- To protect and increase the sustainable yield of the basin in a cost-effective manner, and
- To increase the efficiency of OCWD's operations.

The comment period for the Plan is now open. Staff will respond to comments from the Board, Producers, and the public and will prepare a revised version that addresses comments received. The proposed schedule for adopting the plan is as follows:

June 10, 2009	Workshop at Water Issues Committee and Producers Meeting
June 17, 2009	Public Hearing at OCWD Board meeting
June 24, 2009	Deadline for public comment
July 15, 2009	Consideration of Plan adoption by Board of Directors

According to the Department of Water Resources, plan updates should provide a historical record of progress, including projects completed and how those projects improved resource management. The 2009 Update explains how OCWD manages the groundwater basin in order to accomplish the stated management objectives.

Major accomplishments since the adoption of the 2004 Plan are listed and completed projects are described, examples of which are listed below:

- Analysis of 14,000 water quality samples in 2008.
- Completion of the Groundwater Replenishment System in 2008.
- Development of the three-layer method of determining maximum accumulated overdraft and publication of the *Report on Evaluation of Orange County Groundwater Basin Storage and Operational Strategy* in 2007.
- Improvements to recharge operations such as completion of the La Jolla Recharge Basin, the Kraemer-Miller pipeline improvements, and the Santiago Creek Recharge Enhancement Project.
- Completion of water quality improvement projects such as the Irvine Desalter and the initiation of the North and South Basin Groundwater Protection Projects.

PRIOR RELEVANT BOARD ACTION(S)

None

Minutes

GROUNDWATER PRODUCERS MEETING

Sponsored by the

ORANGE COUNTY WATER DISTRICT

18700 Ward Street, Fountain Valley (714) 378-3200

Wednesday, June 10, 2009, 10 AM

1. **Water Quality Issues**

   None

2. **Review Groundwater Management Plan**

   Greg Woodside updated everyone on the processing of the GWMP. The Producers were provided a copy of the GWMP last month.

3. **Review Long-Term Facilities Plan**

   Greg Woodside reviewed the LTFP and the schedule for completing the document. The document will be mailed and emailed to everyone this week.

4. **Update on Warner Basin Hopkins Development Study**

   Mike Markus updated the group on the preliminary development work occurring with the Hopkins group and the District's likely plans to continuing exploring this idea for the next six months. Hopkins is looking at ideas to place retail development around Warner Basin but would need to compensate OCWD for any lost percolation.

5. **FY10-11 BPP Projections**

   John Kennedy distributed some preliminary FY10-11 BPP projections for planning purposes. OCWD was asked to provide an RA projection also at next months meeting.

6. **Potential loss of Ad Valorem property tax – Prop 1A**

   The District is closely monitoring the Sacramento budget discussions and the potential loss of a portion of our $19 million in property tax income. We are unsure if the state plans to take or borrow some of these revenues. Eleanor Torres informed everyone that the District may have

discussions with some local City Councils on this issue and would coordinate such with the Producers.

7. **OCWD Long-Term Variable Rate Debt Program**

   Mike Markus explained how the District's variable rate debt cost has increased due to a downgrading of the German Landesbank (who provides the letter of credit for the deal). OCWD may convert the debt to fixed rate debt.

8. **Garden Grove Well 28 & Laguna Beach potential program**

   The Producers were informed that the District, Garden Grove and Laguna Beach have met to discuss a possible option to pump and treat the GG Well 28 which has high nitrates. The potential deal would incorporate an agreement the District has with LB to pump 2,025 afy of ground water. When additional details are developed they will be brought back to a future Producers meeting.

9. **Select a Vice Chair for the Producers Group in FY09-10**

   Rick Shintaku of Anaheim was elected to be the Vice Chairman

10. **Other**

    Mike Markus updated everyone on the GWR System flows and the plans to hire a design consultant to expand the plant from 70 mgd to 100 mgd.

Agenda Item # 1

AGENDA ITEM SUBMITTAL

Meeting Date: June 17, 2009

To: Board of Directors

From: Mike Markus

Staff Contact: G. Woodside/C. Miller

Budgeted: N/A
Budgeted Amount: N/A
Cost Estimate: N/A
Funding Source: N/A
Program/Line Item No.: N/A

General Counsel Approval: N/A
Engineers/Feasibility Report:N/A
CEQA Compliance: N/A

Subject: PUBLIC HEARING TO CONSIDER DRAFT UPDATED GROUNDWATER MANAGEMENT PLAN

SUMMARY

The draft updated Groundwater Management Plan has been provided on the District's website and also to the Board and the Groundwater Producers. A Public Hearing has been noticed for 5 pm on June 17, 2009 to provide an opportunity for public input on the draft updated Plan.

RECOMMENDATION

Open Public Hearing and receive comments.

DISCUSSION

The District prepared its first Groundwater Management Plan in 1989. The Plan has been updated periodically to incorporate new information, and was last updated in 2004. The Plan needs to be periodically updated to remain consistent with guidelines established by the California Department of Water Resources.

The California Water Code lists components that must be included and requires the completion of plans in order for the state to grant public funds for construction of certain groundwater projects.

The 2009 Plan discusses the District's overall goals in managing the basin as follows:

- To protect and enhance groundwater quality,
- To protect and increase the sustainable yield of the basin in a cost-effective manner, and
- To increase the efficiency of OCWD's operations.

The comment period for the draft updated Plan is now open. After the public comment period is closed, staff will respond to comments from the Board, Producers, and the public and will prepare a revised version that addresses comments received. The proposed schedule for adopting the plan is as follows:

June 17, 2009	Public Hearing at OCWD Board meeting
June 24, 2009	Deadline for public comment
July 15, 2009	Consideration of Plan Adoption by Board of Directors

According to the Department of Water Resources, plan updates should provide a historical record of progress, including projects completed and how those projects improved resource management. The 2009 Update Groundwater Management Plan explains how OCWD manages the groundwater basin in order to accomplish the stated management objectives.

Major accomplishments since the adoption of the 2004 Plan are listed and completed projects are described, examples of which are listed below:

- Analysis of 14,000 water quality samples in 2008.
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- Completion of water quality improvement projects such as the Irvine Desalter and the initiation of the North and South Basin Groundwater Protection Projects.

PRIOR RELEVANT BOARD ACTION(S) N/A

From: Dick Wilson [mailto:DWilson@anaheim.net]
Sent: Friday, June 26, 2009 11:40 AM
To: Woodside, Greg
Cc: Rick Shintaku; Don Calkins
Subject: Draft Groundwater Mgmt Plan

Greg, here are my comments on the Draft GWMP:

1. I would like to see an objective such as, "Promote incidental recharge to the extent feasible without impacting groundwater quality." This could be added to Section 1.8.2 and Section 8 and generally included throughout the document.
2. Section 4 should include a discussion of ways to increase incidental recharge. According to the document, incidental recharge accounts for about 20% of the total recharge, and this is with the vast majority of storm flows escaping over streets and into concrete storm drains. There's a huge volume of water that could be captured for future use via "dry wells," swales, wetlands, etc. If we are to sustain our groundwater basin, we will need to take advantage of this resource.
3. Section 5 should include a discussion of perchlorate contamination including where it came from, how its dispersing in the groundwater basin and how long before it is "gone."
4. Several of the figures are too small of scale. For example, on Figure ES-5, you cannot distinguish between monitoring wells and production wells. The figures should be larger, or less information provided on them. I concur that we should not disclose exact locations of production wells, but it's very important to know exactly where the monitoring wells are located.
5. In several cases it may be better to provide data in tables rather than graphs. For example, Figure ES-10 would be much easier to comprehend if the data were provided in a table. It is very difficult to assess trends for data in stacked bar graphs.
6. Overall, it's an excellent document and will be a valuable resource. OCWD should recognize that all water producers in the Basin will need to include this document in State and Federal grant applications and the Plan should include a broad spectrum of concepts for improving groundwater sustainability.

If you'd like to talk about any of these issues, please feel free to contact me.

Dick Wilson
Environmental Services Manager
Anaheim Public Utilities Department
714-765-4277
dwilson@anaheim.net

THIS MESSAGE IS INTENDED ONLY FOR THE USE OF THE INDIVIDUAL OR ENTITY TO WHICH IT IS ADDRESSED AND MAY CONTAIN INFORMATION THAT IS PRIVILEGED, CONFIDENTIAL, AND EXEMPT FROM DISCLOSURE UNDER APPLICABLE LAWS. If the reader of this message is not the intended recipient, or the employee or agent responsible for delivering the message to the intended recipient, you are hereby notified that any dissemination, distribution, forwarding, or copying of this communication is strictly prohibited. If you have received this communication in error, please notify the sender immediately by e-mail or telephone, and delete the original message immediately. Thank you.

Response to Comments received June 26, 2009 from Dick Wilson, Environmental Services Manager, Anaheim Public Utilities Department

No.	Comment	Response to Comment
1	Add objective related to promoting incidental recharge such as "Promote incidental recharge to the extent feasible without impacting groundwater quality."	A new objective promoting incidental recharge has been added to Section 1.8.2. This new objective was added to Section 8.
2	Discuss ways to increase incidental recharge.	A discussion of incidental recharge was added in Section 4.2.2.1.
3	Add a discussion of perchlorate contamination to Section 5.	A new section on perchlorate, Section 5.6, was added.
4	The scale of several figures is too small. In Figure ES-5, it is difficult to distinguish between monitoring and production wells.	Several of the figures throughout the document were enlarged for improved readability. The clarity of Figure ES-5 was improved to enable the reader to distinguish between the production and monitoring wells. Please note that in Section 3, the production wells and monitoring wells appear in separate figures (Figures 3-1 and 3-2).
5	In some cases, data should be provided in tables rather than graphs. Figure ES-10 would be easier to comprehend if data were provided in a table. It is difficult to assess trends for data in stacked bar graphs.	Figure ES-10 appears also as Figure 6-5 in Section 6. A table with the data used to create Figure 6-5 was added in Section 6.6.
6	Since water producers will need to include this document in state and federal grant applications, the plan should include a broad spectrum of concepts for improving groundwater sustainability.	Comment noted.

Orange County Water District
18700 Ward Street
Fountain Valley, CA 92708
(714) 378-3200

Recorded in Official Records, Orange County
Tom Daly, Clerk-Recorder
NO FEE
200985000650 08:03am 08/10/09
90 166 Z01
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

NOTICE OF EXEMPTION

From the Requirements of the California Environmental Quality Act (CEQA)

TO: COUNTY CLERK/County of Orange
P.O. Box 238
Santa Ana, CA 92702

FROM: Orange County Water District
Planning & Watershed Management
18700 Ward Street
Fountain Valley, CA 92708

FILED
AUG 10 2009
TOM DALY, CLERK-RECORDER
By RV DEPUTY

PROJECT TITLE: Orange County Water District Groundwater Management Plan

APPROVAL DATE: July 15, 2009

PROJECT LOCATION: Orange County Groundwater Basin

CITY: Various **COUNTY**: Orange

DESCRIPTION OF THE PROJECT: The OCWD Groundwater Management Plan discusses the groundwater basin's physical features, OCWD facilities and monitoring and operating programs.

NAME & ADDRESS OF APPLICANT: Orange County Water District, 18700 Ward Street, Fountain Valley CA 92708

NAME OF PUBLIC AGENCY APPROVING PROJECT: Orange County Water District

POSTED
AUG 10 2009
TOM DALY, CLERK-RECORDER
By RV DEPUT

EXEMPT STATUS:

- ☐ Ministerial (Sec. 15268)
- ☐ Declared Emergency (Sec. 15269 (a))
- ☐ Emergency Project (Sec. 15269(a)&(b))
- ☐ General Rule (Sec. 15061(b)(3))
- X Statutory Exemption: Section 15262
- X Categorical Exemption: Class 6 Section 15306, Class 7 Section 15307 Class 8 Section 15308

REASON(S) WHY PROJECT IS EXEMPT FROM CEQA:
The Groundwater Management Plan is an information document that discusses the Orange County Groundwater Basin and OCWD facilities and programs. The Groundwater Management Plan does not bind, commit or predispose OCWD to further consideration, approval or implementation of any potential project. Approval of the Groundwater Management Plan would not cause either a direct physical change to the environment or a reasonably foreseeable indirect physical change to the environment.

CONTACT PERSON: Greg Woodside

TELEPHONE No: 714 378-3275

SIGNITURE Dan Bott

DATE 8/6/09

TITLE Principal Planner

377417

W

CERTIFICATION OF BOARD ACTION

I do hereby certify that at its meeting held July 15, 2009, the Orange County Water District Board of Directors approved the following action:

MOTION NO. 09-80
APPROVING GROUNDWATER MANAGEMENT PLAN 2009 UPDATE AND AUTHORIZING FILING OF NOTICE OF EXEMPTION

The Groundwater Management Plan 2009 Update is approved and filing of Notice of Exemption is authorized.

IN WITNESS WHEREOF, I have executed this Certificate on August 20, 2009.

ORANGE COUNTY WATER DISTRICT

Judy-Rae Karlsen
Assistant District Secretary

APPENDIX B

REQUIRED AND RECOMMENDED COMPONENTS FOR GROUNDWATER MANAGEMENT PLANS

Appendix B
Mandatory and Recommended Components of a Groundwater Management Plan

No.	Mandatory Components of a GWMP	Water Code Section	OCWD Plan Section
1.	Basin management objectives for the groundwater basin that is subject to the plan	10753.7(a)(1)	1.8, 5.1.1, 5.1.2, 5.2.3, 6.3
2.	Monitoring and management of groundwater levels within the groundwater basin	10753.7(a)(1)	1.8.2, 2.2, 2.3, 2.4, 2.6, 2.7
3.	Monitoring protocols that are designed to detect changes in groundwater levels	10753.7(a)(4)	2.3, 2.4, 2.8, 3.1, 3.2, 3.4,
4.	Groundwater quality degradation	10753.7(a)(1)	1.8.1, 3.5, 5
5.	Monitoring protocols that are designed to detect groundwater quality	10753.7(a)(4)	3.1, 3.2, 3.3, 3.5, 3.6, 5
6.	Inelastic land surface subsidence	10753.7(a)(1)	2.7
7.	Monitoring protocols that are designed to detect inelastic land surface subsidence for basins for which subsidence has been identified as a potential problem	10753.7(a)(4)	2.7
8.	Changes in surface flow and surface water quality that directly affect groundwater levels or quality or are caused by groundwater pumping in the basin	10753.7(a)(1)	3.7, 4, 6.7
9.	Monitoring protocols that are designed to detect flow and quality of surface water that directly affect groundwater levels or quality or are caused by groundwater pumping at the basin	10753.7(a)(4)	3.7, 4, .6.5, 6.7
10.	A plan to involve other agencies that enables the local agency to work cooperatively with other public entities whose service area or boundary overlies the groundwater basin	10753.7(a)(2)	1.2, 6.2
11.	A map that details the area of the groundwater basin, as defined in the department's Bulletin No. 118, and the area of the local agency, that will be subject to the plan, as well as the boundaries of other local agencies that overlie the basin in which the agency is developing a groundwater management plan	10753.7(a)(3)	Figures 1-1, 1-5, 2-1

Appendix B
Mandatory and Recommended Components of a Groundwater Management Plan

Item	Optional Components of a GWMP	Water Code Section	OCWD Plan Section
12.	The control of saline water intrusion	10753.8(a)	3.6, 5.2
13.	Identification and management of wellhead protection areas and recharge areas	10753.8(b)	4, 5.1.5, 6.2
14.	Regulation of the migration of contaminated groundwater	10753.8(c)	5
15.	The administration of a well abandonment and well destruction program	10753.8(d)	5.1.6, 5.1.7
16.	Mitigation of conditions of overdraft	10753.8(e)	2.5, 6.5, 6.7, 6.8, 7.2.3
17.	Replenishment of groundwater extracted by water producers	10753.8(f)	4, 6
18.	Monitoring of groundwater levels and storage	10753.8(g)	1.8.2, 2.2, 2.3, 2.4, 2.6, 2.7, 2.8, 3.1, 3.2, 3.4, 6.5, 6.7, 6.8
19.	Facilitating conjunctive use operations	10753.8(h)	3.7.4, 6.3.3, 6.7, 6.8
20.	Identification of well construction policies	10753.8(i)	Figures 3-4, 3-5, 5.1.5, 5.1.6
21.	The construction and operation by the local agency of groundwater contamination cleanup, recharge, storage, conservation, water recycling and extraction projects	10753.8(j)	4, 5.2.5, 5.3.3, 5.8,5.9, 6
22.	The development of relationships with state and federal regulatory agencies	10753.8(k)	5.1.3, 6.2
23.	The review of land use plans and coordination with land use planning agencies to assess activities which create a reasonable risk of groundwater contamination	10753.8(l)	5.1.4, 5.1.5

APPENDIX C

GOALS AND BASIN MANAGEMENT OBJECTIVES DESCRIPTION AND LOCATION

Appendix C
Goals and Basin Management Objectives
Description and Location

Basin Management Objective (BMO)	How Meeting BMO will Contribute to More Reliable Supply of Groundwater	Location of Description of Planned Management Actions
General Basin Management Objectives to Accomplish All Goals		
Update the *Groundwater Management Plan* periodically	Regular publication of reports enables the District to plan for and manage the groundwater basin responsibly and efficiently, assure the timely construction of necessary projects to accomplish stated basin management objectives, and monitor the water quality of the basin and recharge water supplies.	Sections 1.4, 3.8
Update *the Long-Term Facilities Plan* periodically		Sections 1.4 and 4.5
Continue annual publication of the *Santa Ana River Water Quality Report*; the *Engineer's Report on the Groundwater Conditions, Water Supply and Basin Utilization*; the *Santa Ana River Watermaster Report*; and the *Groundwater Replenishment System Operations Annual Report*.		Sections 1.5, 2.8, 3.8, and 6.5
Goal: Protect and Enhance Groundwater Quality		
Conduct monitoring programs	Comprehensive monitoring of ground and surface water quality enables OCWD to discover contamination at an early stage and begin remediation efforts at the earliest feasible time and assures that operations are in compliance with federal, state, and local laws and regulations.	Section 3
Monitor and manage quality of recharge water supplies so that water recharged through District facilities meets or is better than primary drinking water levels and notification levels		Section 4 and 5
Monitor quality of Santa Ana River water		Section 3.7

Appendix C
Goals and Basin Management Objectives
Description and Location

Basin Management Objective (BMO)	How Meeting BMO will Contribute to More Reliable Supply of Groundwater	Location of Description of Planned Management Actions
Implement the District's Groundwater Protection Policy	The Groundwater Protection Policy proactively protects the water quality of the basin and enables the District to work to clean up contaminated areas.	Section 5
Construct and manage water quality treatment projects	Water quality treatment projects clean up contamination in order to protect the long-term quality of groundwater in the basin.	Section 5.8
Operate seawater intrusion barriers	Barriers prevent intrusion of high salinity water into the basin.	Section 3.6
Support natural resource programs in the watershed	Improvement of natural resources in the watershed contributes to higher quality source water for OCWD recharge operations.	Section 6.2.2
Participate in cooperative efforts with regulators and stakeholders within the Santa Ana River Watershed	Working with stakeholders in the watershed helps to protect the quality of source water used to recharge the groundwater basin.	Section 3.7, 5.2.5, and 6.2

Appendix C
Goals and Basin Management Objectives
Description and Location

Basin Management Objective (BMO)	How Meeting BMO will Contribute to More Reliable Supply of Groundwater	Location of Description of Planned Management Actions
Goal: Protect and Increase the Basin's Sustainable Yield in a Cost Effective Manner		
Monitor groundwater levels, recharge rates, and production rates	Proper monitoring and operation of the groundwater basin improves groundwater management by establishing safe and sustainable levels of groundwater production, determines that extent of seawater intrusion so improvements to seawater barriers can be made, and allows for management of the basin for maximum pumping of groundwater at levels that assure sustainable supplies over the long-term.	Section 2 and 3
Operate the basin in accordance with the *Groundwater Basin Storage and Operational Strategy*		
Manage recharge operations to maximize recharge of the groundwater basin	Proper and efficient management of recharge operations sustains maximum pumping of groundwater supplies.	Section 4
Research and implement new strategies and programs to increase recharge capacity	New strategies and programs increase the amount of groundwater available for pumping from the basin.	Section 4.3 and 4.4
Promote incidental recharge to the extent feasible without negatively impacting groundwater quality.	Increasing incidental recharge increases the amount of water naturally percolating into the groundwater basin, which increases the amount of water available for pumping from the basin.	Section 4.2.2.1
Plan and conduct programs that maximize the capacity of the basin to respond to and recover from droughts	Increases the amount of water the basin can provide during a drought.	Section 6.8

Appendix C
Goals and Basin Management Objectives
Description and Location

Basin Management Objective (BMO)	How Meeting BMO will Contribute to More Reliable Supply of Groundwater	Location of Description of Planned Management Actions
Support natural resource programs in the watershed	Natural resource programs, such as removal of Arundo, augment available supplies of recharge water.	Sections 5.3.3 and 6.2.2
Goal: Increase Operational Efficiency		
Manage the District's finances to provide long-term fiscal stability and to maintain financial resources to implement District programs	Fiscal stability is essential for the District to effectively manage the groundwater basin. Maintenance of reserves allows for the purchase of supplemental water supplies when they are available.	Section 7
Operate District programs in a cost-effective and efficient manner.		
Manage natural resource programs in the Santa Ana River watershed in an efficient manner.	Removal of excessive nitrate levels through the operation of Prado Wetlands saves the cost of more expensive treatment plan construction and operation. Removal of Arundo increases water supply availability.	Sections 5.3.3 and 6.2.2
Implement efficient environmental management programs, such as use of solar power where feasible.	Replacing a portion of the District's use of electricity with generation of solar power will reduce costs in the long run.	Section 4.5

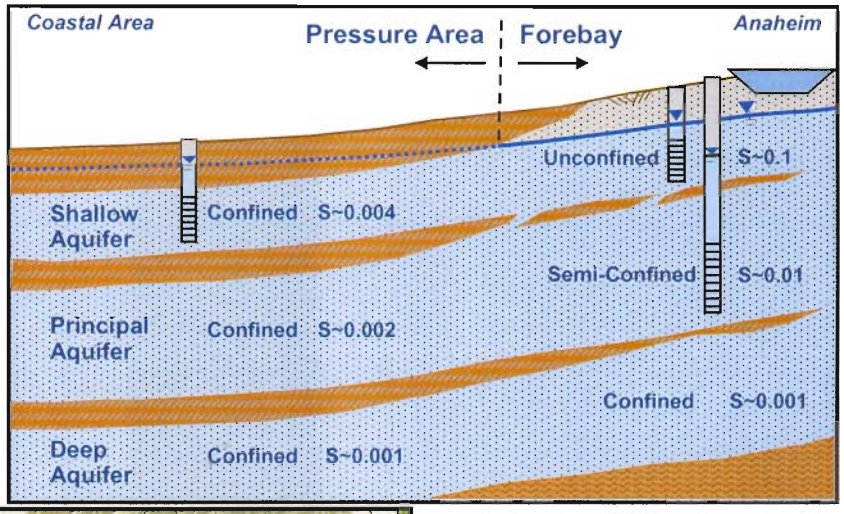
APPENDIX D

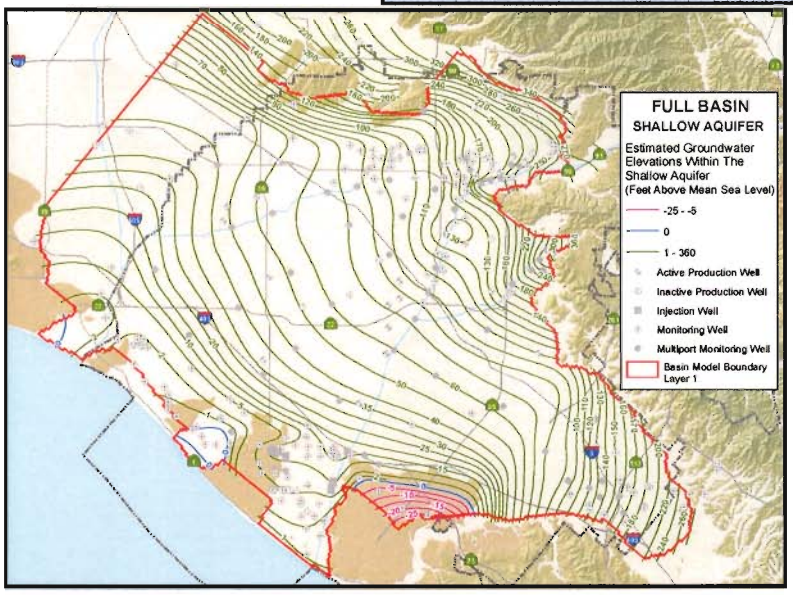
REPORT ON EVALUATION OF ORANGE COUNTY GROUNDWATER BASIN STORAGE AND OPERATIONAL STRATEGY, OCWD, FEBRUARY 2007

ORANGE COUNTY WATER DISTRICT

REPORT ON

EVALUATION OF ORANGE COUNTY GROUNDWATER BASIN STORAGE AND OPERATIONAL STRATEGY





Prepared By:

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FEBRUARY, 2007

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Acknowledgment

Much assistance was provided by District GIS staff Dan Lee and Linda Koki, specifically with implementation and automation of the new three-layer storage change algorithm, GIS programming, mapping, and graphical support.

EXECUTIVE SUMMARY

The need for this study was largely driven by the record-setting wet year of 2004-05, in which an unprecedented storage increase of 170,000 af was estimated by OCWD staff. This led to a preliminary reassessment of the traditional storage calculation which, due to cumulative uncertainty over tens of years, could not be sufficiently rectified back to the traditional full-basin benchmark of 1969.

A new methodology has been developed, tested, and documented herein for calculating accumulated overdraft and storage change based on a three aquifer layer approach, as opposed to the previous single-layer method. Also, for calculating accumulated overdraft, a new full-basin benchmark was developed for each of the three aquifer layers, thereby replacing the traditional single-layer full benchmark of 1969. Also in this report, a basin management operational strategy is proposed that sets guidelines for planned refill or storage decrease amounts based on the level of accumulated overdraft.

The new three-layer storage change approach utilizes aquifer storage parameters supported by calibration of the District's basin-wide groundwater model ("basin model") along with actual measured water level data for each of the three aquifer systems that correspond to the three aquifer layers in the basin model: the Shallow, Principal, and Deep (colored water) aquifer systems. Traditionally, the storage change calculation was based solely on groundwater levels for the Principal aquifer, from which approximately 90 percent of basin pumping occurs.

The findings of this study are enumerated below.

1. The new three-layer storage change approach is technically feasible and provides a more accurate assessment than the traditional single-layer storage change method.

2. Using the new three-layer method, the majority of the storage change occurs in the Forebay area of the basin within the unconfined Shallow aquifer where rising or falling of the water table fills or drains empty pore space.

3. Accuracy of the storage change and accumulated overdraft estimates is dependent upon good spatial distribution of water level measurements as well as the storage coefficient values used in the calculations. Water level data for the Shallow aquifer were relatively sparse in outlying Forebay areas of the basin, leading to some uncertainty in preparing groundwater elevation contours in those areas.

4. 1969 no longer represents a truly full-basin benchmark. A new full-basin water level condition was developed based on the following prescribed conditions:

    - Observed historical high water levels
    - Present-day pumping and recharge conditions
    - Protective of seawater intrusion
    - Minimal potential for mounding at or near recharge basins

The new full-basin water levels in the Forebay area are essentially at or very near the bottom of the District's deep percolation basins (e.g., Anaheim Lake). Historical water level data from 1994 have shown that this condition is achievable without detrimental effects. Water levels slightly higher than this new full condition may be physically achievable in the Forebay area but not recommended due to the likelihood of groundwater mounding and reduced percolation in recharge basins.

5. Using the new three-layer storage change calculation in conjunction with the new full benchmark and June 2006 water levels, an accumulated overdraft of 135,000 af was calculated representing June 30, 2006. Similarly, using the new three-layer method to compare the new full water levels to those of June 2005, an accumulated overdraft of 201,000 af was calculated representing June 30, 2005. Subtracting the June 2006 accumulated overdraft from that of June 2005 yielded an annual storage increase of 66,000 af for WY 2005-06.

6. Comparing the current year's water level conditions to the full basin benchmark each successive year for calculating the basin storage will eliminate the potential for cumulative discrepancies over several years.

7. An accumulated overdraft of 500,000 af represents the lowest acceptable limit of the basin's operating range. This lower limit of 500,000 af assumes that stored MWD water (CUP and Super In-Lieu) has already been removed and is only acceptable for short durations due to drought conditions. It is not recommended to manage the basin for sustained periods at this lower limit for the following reasons:

    - Seawater intrusion likely
    - Drought supply depleted
    - Pumping levels detrimental to a handful of wells
    - Increased pumping lifts and electrical costs
    - Increased potential for color upwelling from the Deep aquifer

8. An optimal basin management target of 100,000 af of accumulated overdraft provides sufficient storage space to accommodate increased supplies from one wet year while also providing enough water in storage to offset decreased supplies during a two- to three-year drought.

9. The proposed operational strategy provides a flexible guideline to assist in determining the amount of basin refill or storage decrease for the coming water year based on using the BPP formula and considering storage goals based on current basin conditions and other factors such as water availability. This strategy is not intended to dictate a specific basin refill or storage decrease amount for a given storage condition but to provide a general guideline for the District's Board of Directors.

Based on the above findings, recommendations stemming from this study are as follows:

1. Adopt the new three-layer storage change methodology along with the associated new full-basin condition that will serve as a benchmark for calculating the basin accumulated overdraft.

2. Adopt the proposed basin operating strategy including a basin operating range spanning the new full condition to an accumulated overdraft of 500,000 af, and an optimal overdraft target of 100,000 af.

3. Include in the 2007-08 CIP budget the installation of six Shallow aquifer monitoring wells to increase accuracy of the three-layer storage change calculation.

1. INTRODUCTION

This report documents the methodology, findings, and recommendations of the basin storage and overdraft evaluation completed by District staff between May 2006 and January 2007.

Prior to this study, an unusually large annual increase in basin storage of 170,000 af was estimated for WY 2004-05, which was a record-setting wet year. During that year, water levels throughout the basin rose approximately 30 feet overall, and as much as 60 feet in the Santiago recharge area which receives significant storm runoff from Villa Park Dam releases during extremely wet years.

The estimated storage increase for WY 2004-05 was so large that it caused staff to re-examine the storage calculation. Also, the large water level rise during that year raised concern that the basin could be approaching a near-full condition, leading staff to compare 2005 water levels throughout the basin to 1969 in which the basin was historically considered full. This analysis showed that the basin may have had only 40,000 af less groundwater in storage in November 2005 as compared to the 1969 benchmark. However, the traditional method of cumulatively adding the annual storage change each year to the previous year's accumulated overdraft led to an accumulated overdraft of approximately 190,000 af for November 2005.

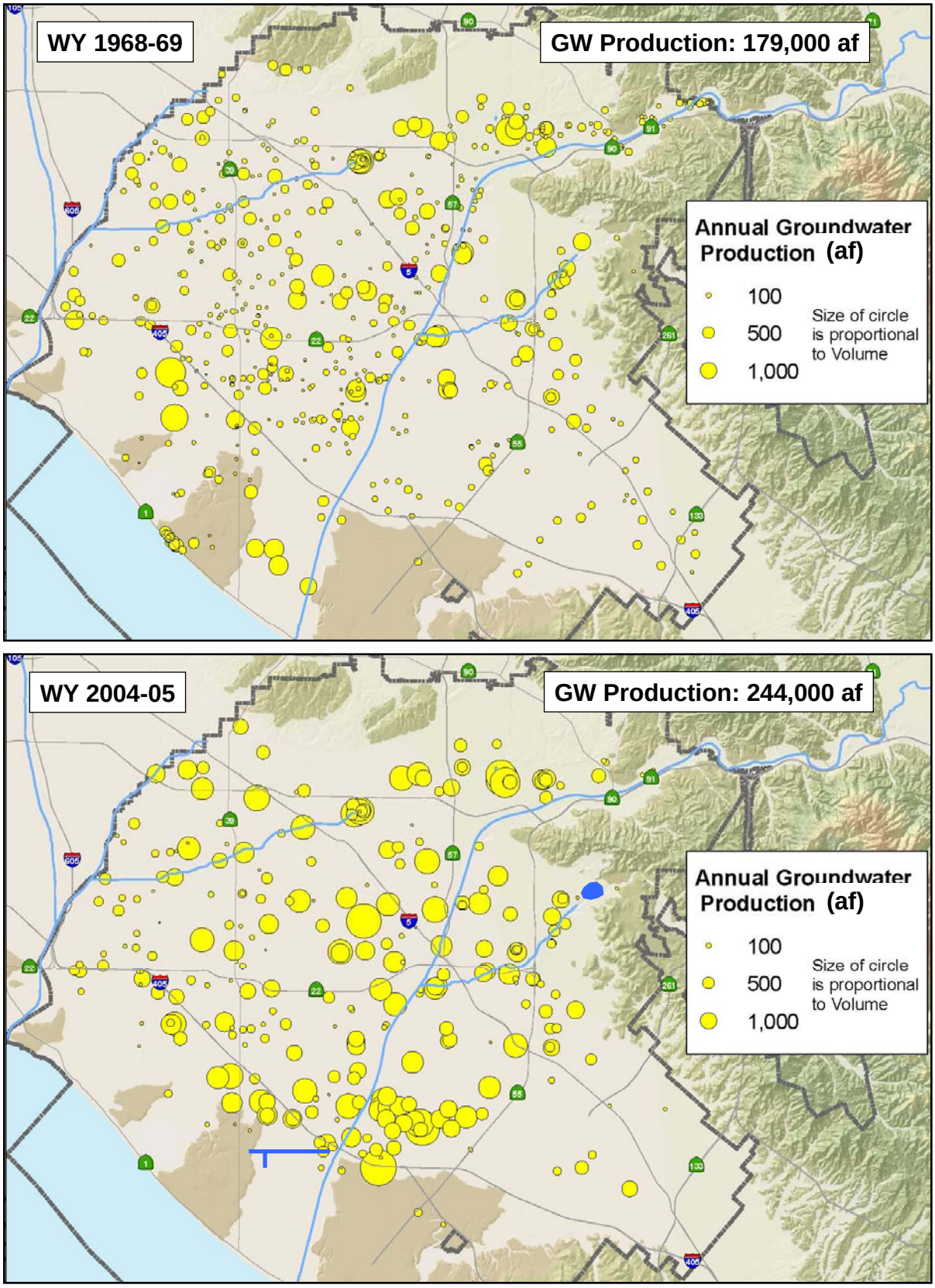
The discrepancy of 150,000 af in the two different 2005 overdraft calculations indicated that the current condition could not be properly rectified back to the 1969 benchmark. This dilemma provided the main impetus for the study documented herein and brought to light two important discoveries:

- The traditional storage change calculation contains considerable uncertainty that, when cumulatively added over tens of years, led to a large discrepancy in the accumulated overdraft relative to 1969.

- 1969 water level conditions no longer represent a full basin, primarily because of the different pumping and recharge conditions that exist today.

Figure 1-1 shows the distribution of groundwater production for WY 1968-69 (upper map) and WY 2004-05 (lower map). Each circle or "dot" represents an active production well for that year, with the size of each dot being proportional to each well's annual production. Total basin production for WY 2004-05 was only 179,000 af, whereas by WY 2004-05 it had increased to 244,000 af and would have been 70,000 af greater if not for supplemental imported water taken in-lieu of groundwater. By comparing the two production dot maps, heavy increases in pumping are evident in the coastal area since 1969, primarily due to MCWD and IRWD's Dyer Road Well Field (DRWF).

Figure 1-1. Groundwater Pumping Distribution: WY 1968-69 and WY 2004-05



In addition to changes in the amount and distribution of pumping since 1969, OCWD managed recharge operations have increased substantially such that much more water is recharged today as compared to 1969. In addition to increased Santa Ana River flows and new recharge basins being put into service in the Anaheim and Orange Forebay areas, new and improved cleaning methods have been implemented to enhance percolation rates, thus increasing the annual volume of water that is recharged annually.

Table 1-1 below summarizes the major pumping and recharge differences between WY 1968-69 and WY 2004-05.

Table 1-1. Pumping and Recharge Conditions: WY 1968-69 vs. WY 2004-05

	WY 1968-69	WY 2004-05
Pumping	Total Pumping: 179,000 af	Total Pumping: 244,000 af
	Agricultural Pumping: 34,000 af	Agricultural Pumping: 3,400 af
	No DRWF	In-Lieu: 70,000 af
	No MCWD municipal wells	Increased coastal pumping
	No Newport Beach wells	Less Irvine pumping
Recharge	No Talbert Barrier	Enhanced Talbert Barrier
	No Santiago Pits or Creek	Enhanced percolation rates
	No Kraemer or Miller Basins	Basin Cleaning Vehicle
	No Burris Pit or Five Coves	Riverview Basin

Since 1969, the largest pumping increases have been in the coastal area while the largest recharge increases have been in the inland Forebay area. Therefore, this redistribution along with increased utilization of the groundwater basin has led to a steeper groundwater gradient or “tilt” from the inland Forebay down to the coast. Because of this increased basin tilt under present conditions, water levels higher than 1969 can be maintained in the Forebay area without exceeding 1969 water levels in the coastal area. Because higher Forebay water levels translate into more basin storage, 1969 no longer represents a full basin condition by today’s standards. In other words, a modern-day full condition could likely accommodate higher water levels than 1969 in the Forebay area, as schematically illustrated in Figure 1-2.

A review of historical water level data indicates that many wells in the Anaheim area experienced higher water levels in 1994 than in 1969. Figure 1-3 shows historical water levels for City of Anaheim Well A-27, indicating that in 1994 water levels at that location (adjacent to the south side of Anaheim Lake) were 5-10 feet higher than in 1969.

Figure 1-2. Schematic of Groundwater Level Profiles Across the Basin

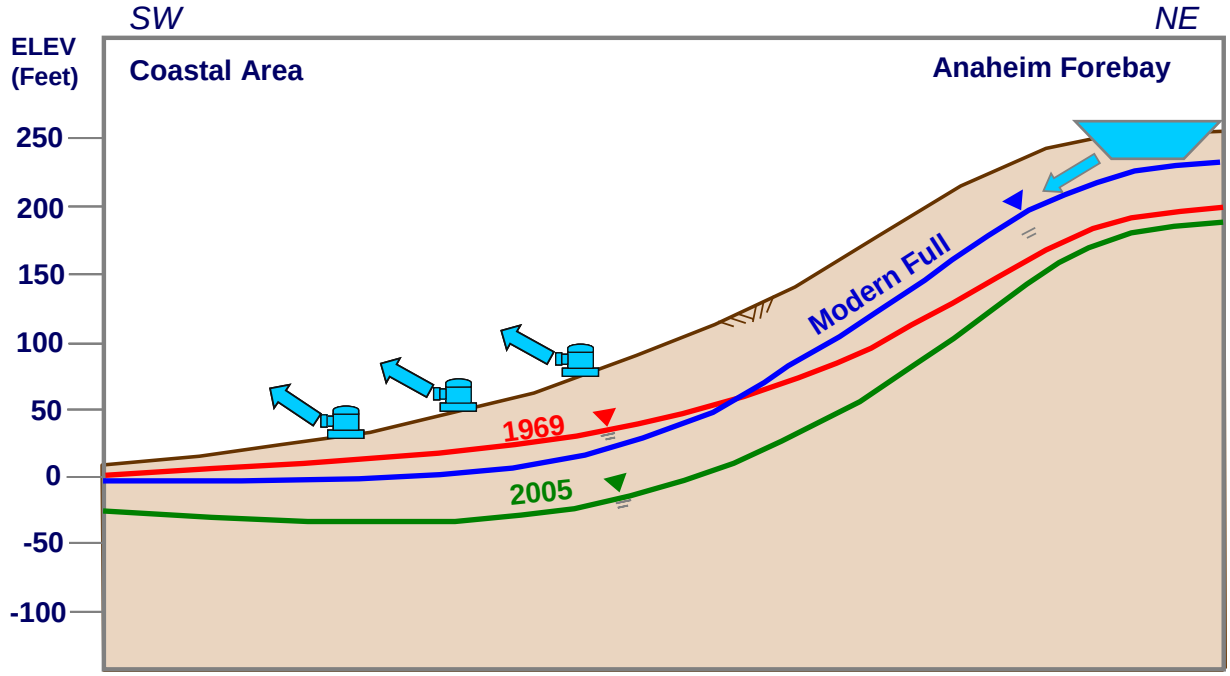
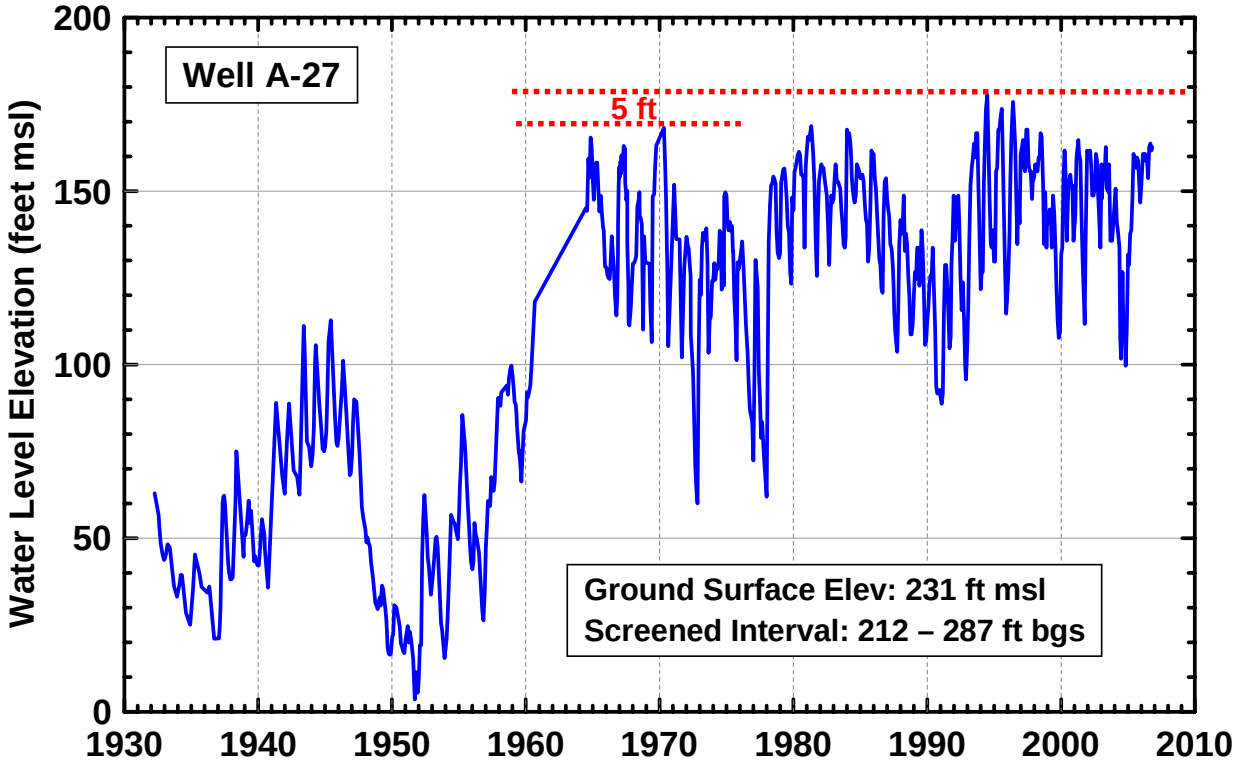


Figure 1-3. Water Level Hydrograph for City of Anaheim Well 27



2. STUDY OBJECTIVES AND WORK PLAN

Objectives of this study were three-fold:

1. Reassess and recommend modifications as necessary to staff's traditional method for calculating the annual storage change and the accumulated overdraft.

2. Develop a technically-sound full basin water level condition that takes into account current basin management practices. This new full condition would replace 1969 and become the new full benchmark used to calculate the accumulated overdraft or available storage in current and upcoming years.

3. Determine an appropriate basin storage operating range and management goal for long-term basin management purposes.

The District Board of Directors approved staff's work plan in April 2006, and work commenced shortly thereafter. All work was completed by the District's Hydrogeology Department, with oversight, direction, and review provided by District management. At the request of the Board, monthly project updates were given at the Water Issues Committee meetings as well as the monthly groundwater producers meetings to facilitate the producers' involvement in the process.

The scope of work laid out in the work plan was generally followed. Initially, it was considered that conducting basin model simulations may be beneficial in validating project results. However, after making significant progress in developing a new storage change methodology and new full basin benchmark, it became evident that it was more appropriate to use aquifer parameters and specific knowledge gained from development of the basin model rather than running new model simulations per se. As such, findings enumerated in this report were based on actual water levels observed in the field coupled with a methodology based on aquifer structure and hydraulic parameters defined during development of the basin model.

3. STORAGE CHANGE CALCULATION METHODOLOGY

In this section, the District's traditional storage change calculation is described along with its inherent limitations, followed by a discussion of the development of a new storage change calculation approach and comparison with the traditional method. But first, a conceptual explanation of aquifer storage is explained below.

3.1 Aquifer Storage Concept

Aquifers not only transmit groundwater but also provide storage volume, sometimes being referred to as "underground reservoirs." However, unlike surface water reservoirs, approximately 70 to 80 percent of the aquifer's volume is occupied by the porous medium, typically consisting of various gradations of sand and gravel as well as

silts and clays. This leaves only 20 to 30 percent of the aquifer's total volume remaining as void space that groundwater can occupy. This percentage of void or pore space is referred to as *porosity*.

Over large areas and depths, the void space within aquifers can occupy huge amounts of water. Within the Orange County groundwater basin, which spans over 300 square miles and is over 2,000 feet deep in some areas, District staff have estimated that approximately 66 million acre-feet of water lies in storage. Unfortunately, the vast majority of this water cannot be feasibly drained from the basin without incurring detrimental impacts.

Excessive long-term pumping of basin aquifers without continual replenishment would lead to a lowering of water levels and a reduction in pore pressure, which would lead to seawater intrusion and irreversible compaction of the aquifer, resulting in subsidence of the land surface. The recommended "drainable" storage volume of the basin (without requiring concurrent replenishment) is 500,000 af acre-feet as discussed in Section 6.

The parameter used to define the storage capacity of an aquifer is known as the *storage coefficient (S)*. Unlike the porosity which is a measure of the entire void space regardless of whether or not it contains water, the storage coefficient is a measure of how much water can effectively be drained or squeezed out of the saturated pore space. The storage coefficient is defined as the volume of water yielded per unit horizontal area and per unit drop of water table (unconfined aquifers) or piezometric surface (confined aquifers).

3.2 Confined and Unconfined Aquifers

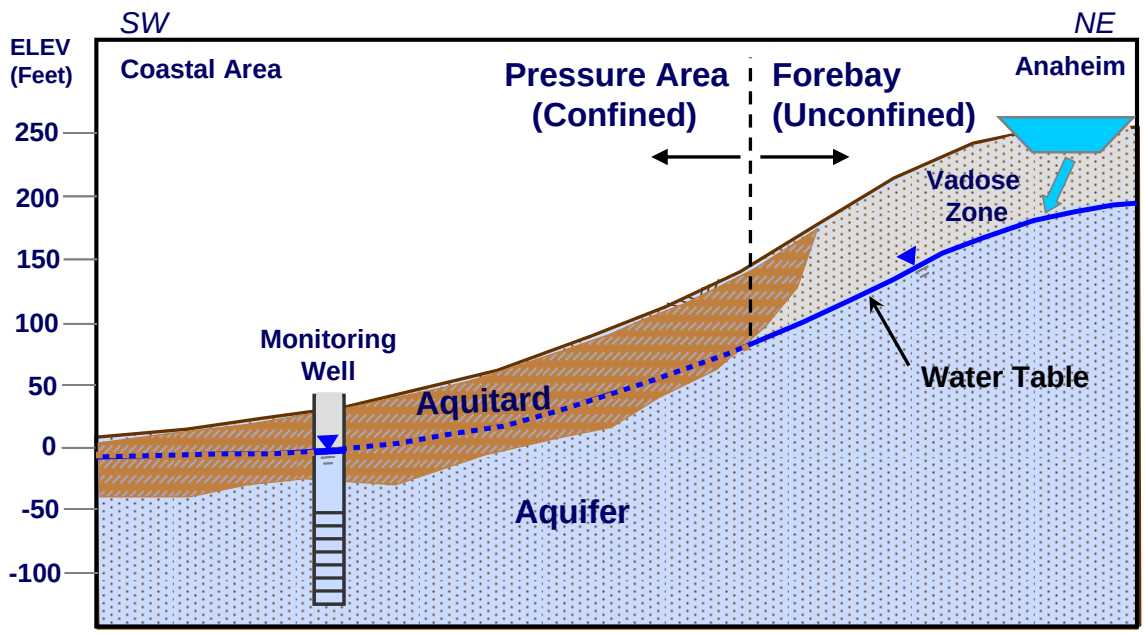
A confined aquifer is an aquifer that is confined between two aquitards, which are typically clay or silt layers with low permeability. The water in a confined aquifer cannot freely rise above the overlying clay layer and is under confining pressure. When a well is drilled through the overlying clay layer down into the aquifer, the pressure in the confined aquifer causes the water to rise inside the well (see Figure 3-1) to a level higher than the overlying aquitard. Therefore, water levels measured in wells within confined aquifers – referred to as piezometric levels – may rise and fall but the confined aquifer remains saturated. In a confined aquifer, water is added to or removed from storage primarily through the rearrangement of the unconsolidated sediments via compression or decompression; the compressibility of water contributes significantly less to the storage process. A relatively large piezometric level change in a confined aquifer represents very little change in storage within that aquifer. Storage coefficients for a confined aquifer typically range from 0.01 to as low as 0.00005.

An unconfined aquifer is an aquifer in which the water table forms the upper boundary and there is no confining layer above it (see Figure 3-1). That is, the water table can freely rise or fall. Pore space is either filled or drained when the water table rises or falls. Therefore, a unit rise or decline in the water table in an unconfined aquifer represents a relatively large storage volume. For an equivalent water level rise, an

unconfined aquifer would exhibit at least 100 times greater storage increase than a confined aquifer. Storage coefficients for unconfined aquifers typically range from 0.01 to 0.3, also referred to as *specific yield*.

In the Orange County groundwater basin, the Shallow aquifer is confined in the coastal and mid-basin areas, commonly referred to as the Pressure Area. The overlying aquitard in the Pressure area thins further inland until it is generally gone. This inland area is referred to as the Forebay area. Since few continuous aquitards exist between the water table and ground surface, it is the "intake" area of the basin where surface water can percolate down to the water table and recharge the aquifers (see Figure 3-1).

Figure 3-1. Forebay and Pressure Area Schematic Profile



3.3 Traditional Storage Change Calculation Method

<u>Water Level Change Method</u>

Traditionally, the storage change calculation was based solely on the water level changes occurring in the Principal aquifer, which is the main production zone in the basin from which approximately 90 percent of basin pumping occurs. Dating back to the 1940s, District staff have prepared a November groundwater contour map of Principal aquifer water levels. By comparing the November contour map to that of the previous year, the annual water level change was then determined. The water level change was then multiplied by a set of storage coefficient values and by the area of the basin to obtain the resulting groundwater storage change for that year. Then, the annual storage change was added to the accumulated overdraft from the previous year to obtain the current accumulated overdraft.

Over the years, the overall approach has remained relatively the same, but several refinements were made along the way. In the 1970s, a FORTRAN computer program was developed, referred to as the "Randall Model," which partially automated the storage change calculation by subdividing the basin into quarter-mile grid cells. The Randall Model computed the storage change calculation grid cell by grid cell. Although this process was somewhat automated, the water level maps had to be manually interpolated to obtain the average water level change for each quarter-mile grid cell. The storage coefficient values for each quarter-mile grid cell were referred to as "Randall" coefficients and are shown in Appendix 1. No documentation exists as to how these storage coefficient values were developed, but they were likely based on review of old well logs throughout the basin.

In the early 1990s, with improvements in computer hardware and software, District staff were able to further automate the traditional storage change calculation by using geographical information system (GIS) software to subdivide the basin into smaller, more refined grid cells. By digitizing the hand-drawn water level contour maps into the computer, the water level change at each refined grid cell could be computed without any manual interpolation. However, the overall approach remained the same and still used the same Randall storage coefficient values.

Over the last two years, an additional refinement included preparing an end-of-June water level contour map in addition to the annual November contour map. Although the November maps provide a good midpoint between the summer-high and winter-low water level conditions, the June maps coincided better with the District's water year and fiscal year (July 1 through June 30) for the annual storage change calculation.

Water Budget Method

For the past 10 to 15 years, the annual storage change calculated using the traditional water level method has been checked using a water budget method (inflows minus outflows equal the change in storage). Therefore, the water budget method uses measured groundwater production and recharge data along with a rainfall-based estimate of incidental recharge (unmeasured recharge less underflow to LA County).

The water budget method provides a good check of the storage change estimate from the water level method but is based on an assumed (unmeasured) amount of incidental recharge. In most years, the two methods agree rather closely, and the storage change value from the water level method is generally used. The incidental recharge is then adjusted in the water budget method to exactly match the chosen storage change.

Limitations of the Traditional Storage Change Method

Although the traditional water level and water budget methods yield similar storage change results in most years, there are some anomalous years in which the two estimates are significantly different. In such years, typically very wet or very dry years,

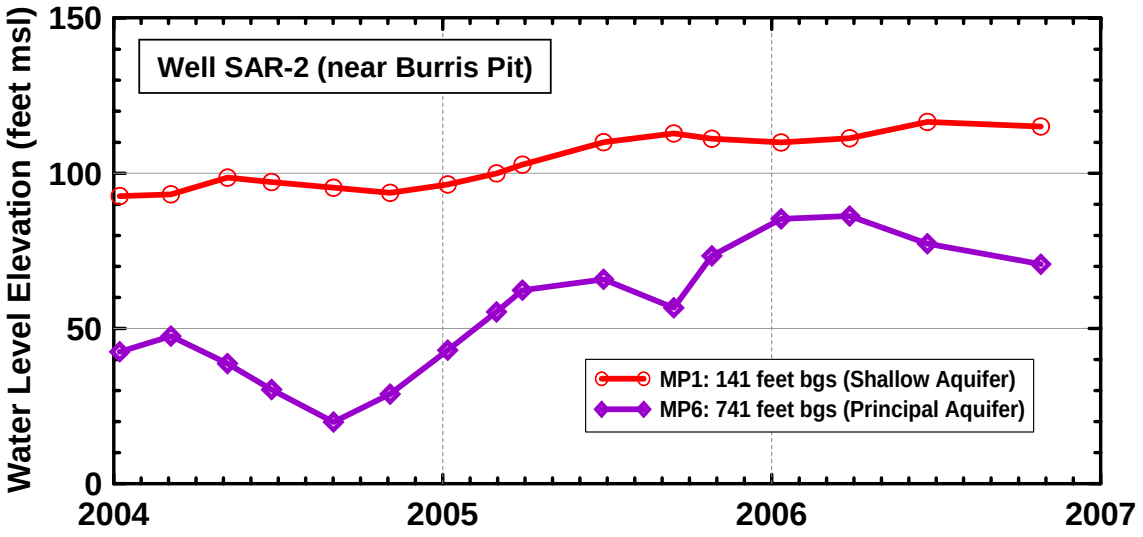
professional judgment must be exercised in determining the official change in storage. This can introduce significant uncertainty into the annual storage change estimate for those years, causing a cumulative effect after several years, which is why the current accumulated overdraft cannot be rectified back to 1969 as discussed in Section 1.

The biggest limitation of the traditional method is that it only uses the water level change in the Principal aquifer. Although most groundwater production is from the Principal aquifer, most of the storage change occurs in the Shallow aquifer where it is unconfined in the Forebay area of the basin. Where the Shallow aquifer is unconfined, large storage changes can occur due to the rising or falling of the water table which respectively fills or drains empty pore space, as was discussed in Section 3.2.

The Randall storage coefficients used in the traditional method are consistent with those of an unconfined aquifer in the Forebay area and thus are considered as being representative of the Shallow aquifer. Therefore, the traditional method uses Principal aquifer water levels as a surrogate for the Shallow aquifer, assuming that these two aquifers behave identically in the Forebay area. This is largely true in the Anaheim Lake area near the District's facilities, but in other portions of the Forebay, the Shallow and Principal aquifers often behave differently from one another, as shown in Figure 3-2. This indicates that these two aquifers are partially hydraulically separated by aquitards in portions of the Forebay and behave differently rather than as a single unconfined aquifer as the traditional method had assumed.

It should be pointed out that in earlier years, depth-specific water level data such as that presented in Figure 3-2 was simply not available to discern hydraulic differences between various aquifer zones, and in some areas of the Forebay, there are no noticeable vertical hydraulic differences. It has only been in the last few years through the use of the District's monitoring well network and development of the basin model that a better understanding of the basin has been gained.

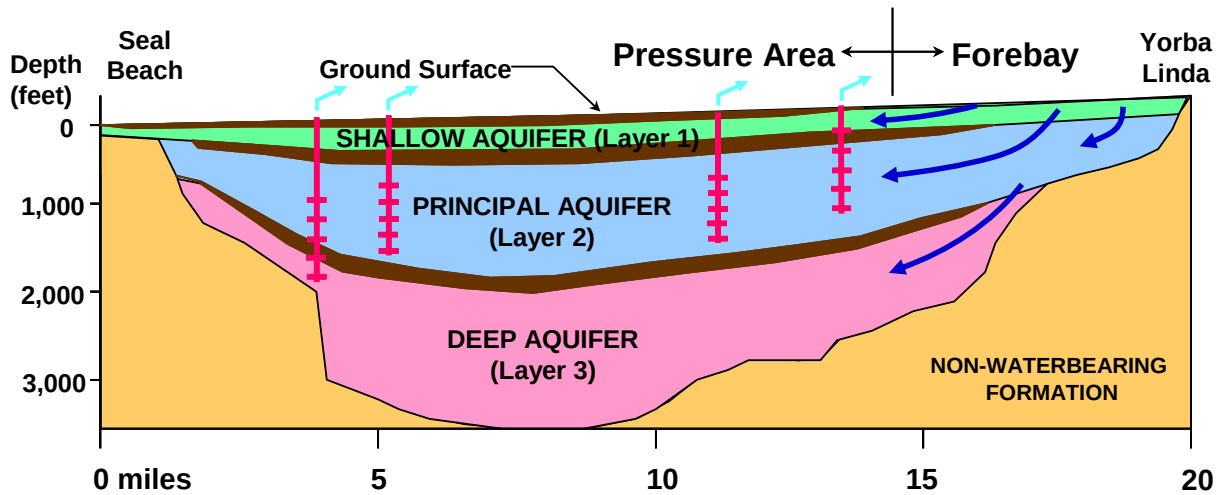
Figure 3-2. Water Level Hydrograph for OCWD Monitoring Well SAR-2



3.4 New Three-Layer Storage Change Approach

The new three-layer storage change approach uses all three aquifer systems of the basin: the Shallow, Principal, and Deep aquifer systems (see Figure 3-3). The Shallow aquifer generally ranges no deeper than approximately 250 feet below ground surface and overlies the Principal aquifer, which is generally over 1,000 feet thick throughout much of the basin and supports over 90 percent of basin pumping. The Deep aquifer contains colored water in the coastal area and is more than 2,000 feet deep throughout much of the basin. These three aquifer systems, from shallow to deep, are also referred to as aquifer layers 1, 2, and 3.

Figure 3-3. Schematic Cross-Section of the Basin Showing Three Aquifer Layers



Methodology

The new three-layer storage change approach is based largely on the aquifer configuration, structure, and storage coefficient parameter values defined during development of the basin model. Unlike the traditional method, all three of the basin's aquifer systems are included in this new methodology. Furthermore, the storage coefficient values used in this new method are specific to each aquifer layer and were refined during dynamic or transient calibration of the basin model until the resulting model-generated water levels achieved a close match with observed water level data throughout the basin.

The basic formula used to calculate the change in storage is very similar to the traditional method, but now must be carried out for each of the three aquifer layers. The storage change equation is defined as

Storage Change = (Water Level Change) x (storage coefficient) x (horizontal area)

The storage change for each of the three aquifer layers is thereby calculated and the results of all three summed to get the total storage change in the basin.

Figure 3-4 shows a schematic cross-section illustrating the three aquifer layers of the basin and how they differ in terms of their respective storage coefficient (S) values. Whereas the traditional method had presumed that the Forebay area behaved entirely as one large unconfined aquifer without any intervening clay layers, our current understanding of the basin is that only the Shallow aquifer in the Forebay area is truly unconfined. As was discussed in Sections 3.1 and 3.2, the majority of the storage change in the basin occurs specifically in the Shallow aquifer within the Forebay area where the rising or falling unconfined water table respectively fills or drains empty pore space. Shallow aquifer storage coefficient values in the Forebay area are approximately 0.1, but in some specific Forebay locations can be as high as 0.25, which is approximately equivalent to the porosity of the sediments at the water table/vadose zone interface.

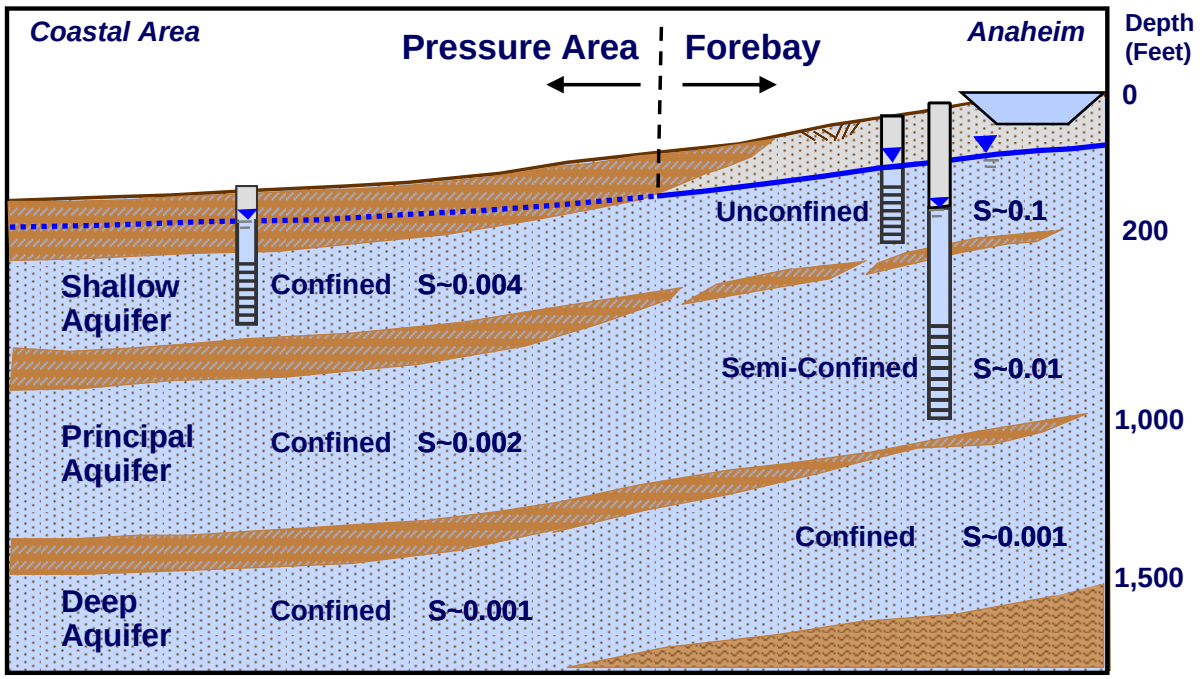
Figure 3-4 illustrates how the Shallow aquifer is confined in the Pressure area of the basin. By definition, the Pressure area ends where the water level drops below the elevation of the overlying aquitard and/or where the aquitard no longer exists. In the Pressure area, the Shallow aquifer storage coefficient values are approximately 0.004, or approximately 25 times smaller than in the unconfined Forebay area. This means that for a given water level change in the Pressure area, the resulting change in storage would be 25 times less than for that same water level change observed in the unconfined Forebay area.

As shown in Figure 3-4, the Principal aquifer is largely separated from the overlying Shallow aquifer by an extensive aquitard in the coastal and mid-basin areas. In the inland Forebay area, this intervening aquitard becomes intermittent but does not vanish completely, causing some hydraulic separation from the Shallow aquifer while still allowing large amounts of water to migrate downward into the Principal aquifer. As schematically shown in Figure 3-4, Principal aquifer water levels frequently differ from those in the Shallow aquifer due to the hydraulic separation, as was also shown in Figure 3-2 for multi-depth monitoring well SAR-2 near Burris Basin, where observed water levels in the Principal aquifer are noticeably lower than in the Shallow aquifer. The Principal aquifer is thus considered to be semi-confined in the Forebay area, with storage coefficient values of approximately 0.01, which is at least 10 times less than in the unconfined Shallow aquifer.

The Deep aquifer is generally confined throughout the entire basin and is separated from the overlying Principal aquifer by an extensive aquitard that thins somewhat in the Forebay area but remains laterally extensive. Therefore, since water level changes in the Deep aquifer represent pressure responses and thus do not involve filling or draining of pore space, storage coefficient values are typically small at approximately 0.001 throughout the entire basin.

The storage coefficient values shown in Figure 3-4 and discussed above are typical values for each of the three aquifer layers. The actual storage coefficients used in the storage change calculation not only vary for each aquifer layer but also vary spatially across the basin in both the Pressure and Forebay areas. From the basin model calibration, the different storage coefficient values within each aquifer layer are subdivided into detailed zones. For reference, these zonal storage coefficient maps are included in Appendix 2. These storage coefficient values in the Forebay area of the Shallow aquifer are generally consistent with the Randall coefficients traditionally used.

Figure 3-4. Schematic cross-section showing storage coefficients (S) values



The other component of the storage change formula not yet discussed is the water level change. To obtain the water level change involves constructing water level contour maps for each of the three aquifer layers, both for the previous and current year.

Preparation of the water level contour maps for each aquifer layer requires a considerable level of interpretation of the actual data points as well as interpolation between data points. The reported water level data is not always 100 percent accurate and must be reviewed on a well-by-well basis as the contour map is being constructed. Reasons for disqualifying or adjusting observed water level data during the contouring process may include:

- A static water level from a production well may have been measured only minutes after shutting off the well pump;
- Erroneous water level field measurement (e.g., bad equipment);

- Water level measurement taken too early or too late (for the June and November contour maps, attempt to measure all water levels within a two-week window);
- Wells are screened at different depths and some wells are screened across multiple aquifers such that water level data not entirely representative of any one aquifer layer being contoured.

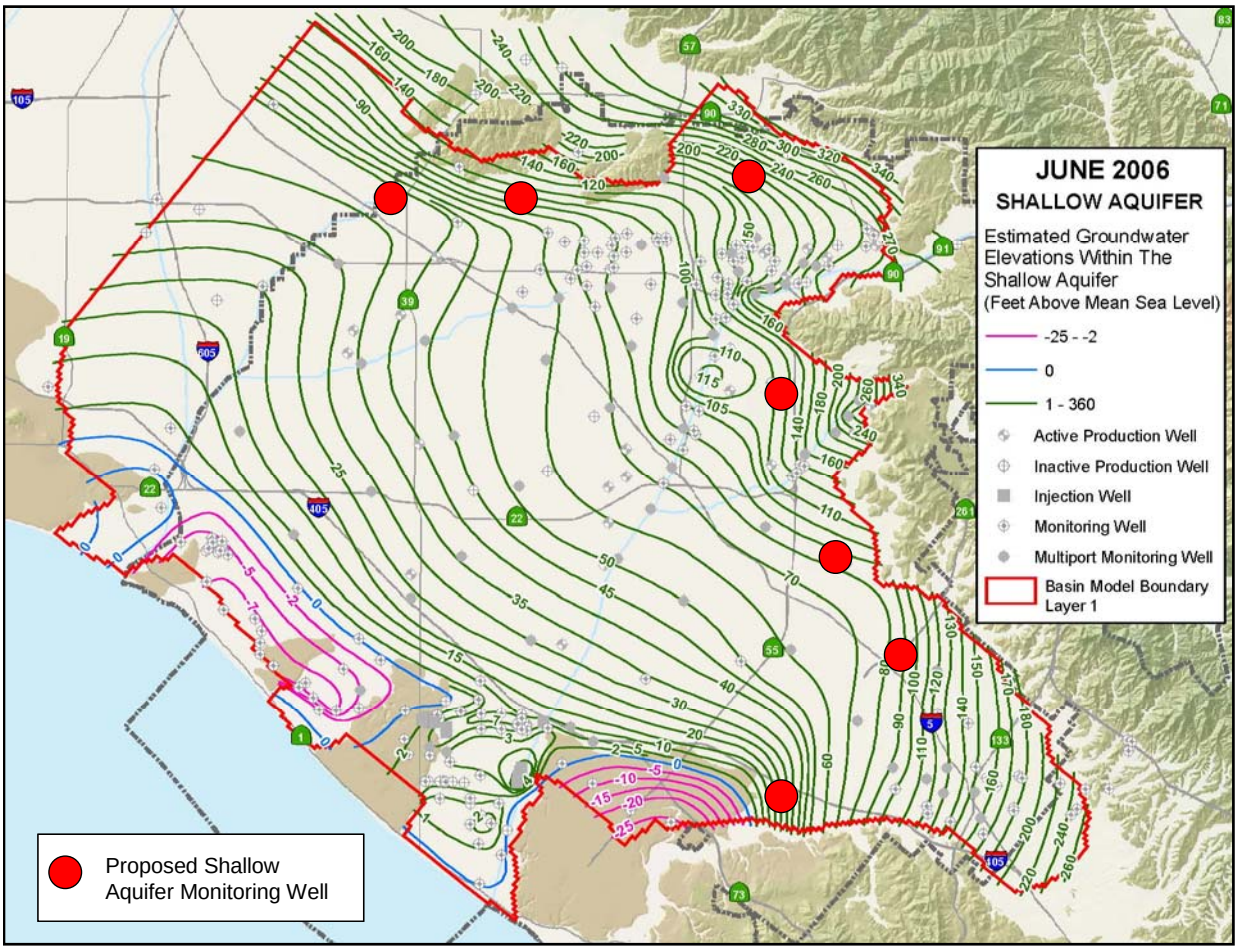
In addition to the above reasons for screening the observed water level data points, extreme care and consistency must be exercised from one year to the next when contouring and interpolating between data points, especially in sparse areas lacking sufficient data to definitively define the shape of the contours. Barring any new wells or data, water levels should be similarly interpreted in these areas from year to year so that false storage changes are not artificially created. Knowledge of the aquifer's characteristics, presence of geologic faults, regional flow regime, and vertical relationship with the other aquifers have proven useful in determining the contour patterns in a given area.

Of the three aquifer layers, the Principal aquifer has the best water level data coverage thanks to more than 200 large system production wells monitored by each respective groundwater producer, as well as District monitoring wells throughout the basin. Historically, this predominance of available water level data for the Principal aquifer and lack thereof for the Shallow and Deep aquifers is a likely reason that the traditional storage change method only considered the water level change in the Principal aquifer.

Much more water level data exists today for the Shallow aquifer than in the past, primarily due to the District's network of monitoring wells, many of which monitor multiple aquifer zones at one well site, helping to decipher the vertical relationship between the Shallow and deeper aquifers and their degree of hydraulic connection. Since the majority of the storage change in the basin occurs in the unconfined portion of the Shallow aquifer within the Forebay area, the constructed water level contours are of utmost importance in those inland areas. Unfortunately, data is sparse in a few of these outlying areas of the basin. Therefore, to increase the accuracy of the Shallow aquifer contour maps and thus the accuracy of the storage calculation, approximately six new shallow monitoring wells are recommended to fill data gaps in the areas of Buena Park, Costa Mesa, Fullerton, Orange, Irvine, and Yorba Linda. Figure 3-5 shows the approximate desired locations for these six proposed wells.

Figure 3-5 also shows the water level contours for the Shallow aquifer for June 2006. Just as for the other two aquifer layers, these contours where hand drawn based on observed water level data from wells screened in the Shallow aquifer (shown in light gray in Figure 3-5). The hand-drawn contours were then digitized into the computer for calculation purposes. Note that the contours were drawn out to the boundary of the basin model layer 1 which extends into LA County, but during the storage calculation process the LA County portion is excluded.

Figure 3-5. June 2006 Shallow Aquifer Groundwater Elevations and Proposed Wells



GIS Application for Three-Layer Storage Change Calculation

A new GIS application was developed and programmed to automate the new three-layer storage change calculation utilizing the digitized water level contour maps for each aquifer layer as well as the storage coefficient values from the basin model.

The new GIS application consists of a series of steps governed by programs written in the AML scripting language within the Arc/Info environment. A detailed description of these steps, along with all the AML codes written for this application, is included in Appendix 4.

The digitized water level contours are converted into GIS compatible files (grids) at the same refined resolution as the basin model input parameters, essentially subdividing the entire basin into 500-foot square grid cells. The GIS application then carries out the storage change formula one grid cell at a time for each aquifer layer, calculating the water level change between the two years in question and multiplying by the storage

coefficient and horizontal area of the grid cell. Then, the storage change of all grid cells is summed for each layer. The total change in storage is then the corresponding sum of all three aquifer layers.

When calculating the storage change at each grid cell, the GIS application must check to determine if the conditions are confined or unconfined. Generally, the Principal and Deep aquifers are typically confined, but the Shallow aquifer is confined in the Pressure area and unconfined in the Forebay area, with the dividing line between these two areas being dependent upon the actual water level elevations at that time. If the water level is above the top of the aquifer layer (per the basin model layer elevations), then a confined storage coefficient is used for that grid cell; otherwise, if the water level is below the top of that aquifer layer, then a larger unconfined storage coefficient is used. To further complicate matters, the water level change in question from Year 1 to Year 2 may cause a given grid cell in the Shallow aquifer to switch from confined under Year 1 conditions to unconfined under the Year 2 conditions, or vice versa. The GIS application handles this type of condition by subdividing the water level change into two components: a confined portion and an unconfined portion. This is illustrated in the sketch and "pseudo-code" algorithm that was written for this application prior to formal programming of the GIS application (Appendix 4).

The new GIS application for the three-layer storage change calculation was thoroughly tested and necessary refinements were made to the AML codes. Water level change and storage change calculations were hand checked and verified at individual grid cells having both confined and unconfined conditions. Also, the storage change results for each aquifer layer were verified to be identical in magnitude but opposite in sign if switching the order of what is predefined as Year 1 or Year 2. For example, if the storage change from Year 1 to Year 2 was calculated to be 10,000 af, then the storage change from Year 2 to Year 1 calculates to be exactly -10,000 af.

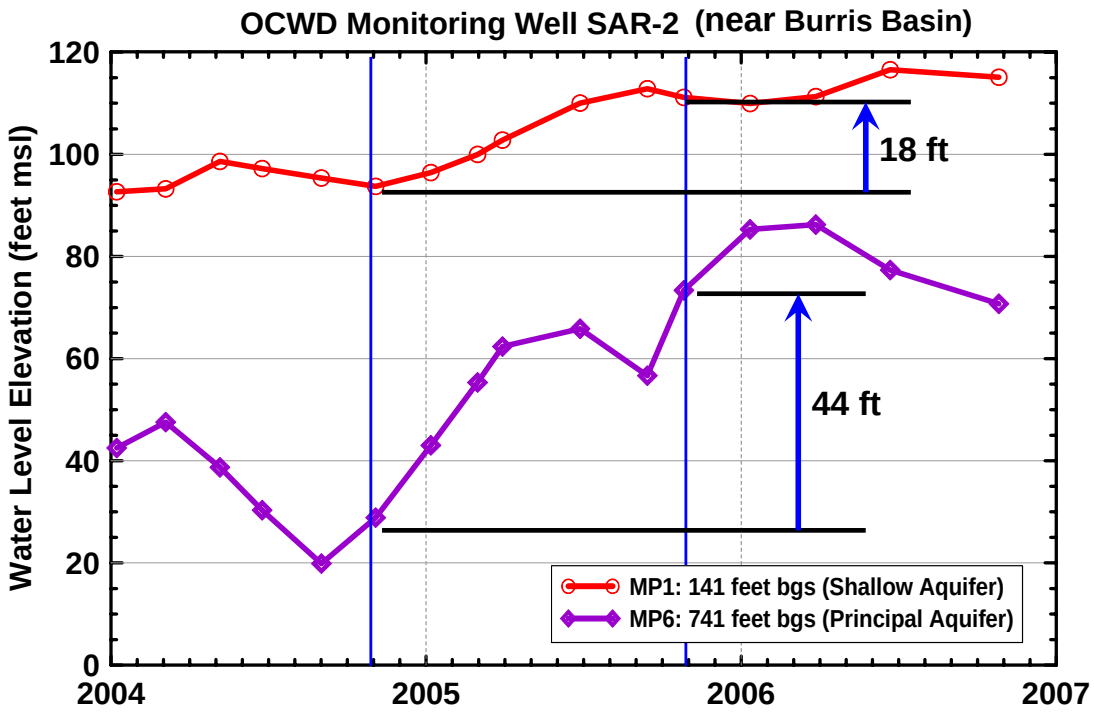
Testing the Three-Layer Method vs. the Traditional Method

Test Case 1 compared the new three-layer storage change calculation to the traditional method using the annual period November 2004 to November 2005. This first test case represented an extremely wet year with record-setting rainfall and a huge storage change of +187,000 af using the traditional method with the existing November contour maps of the Principal aquifer. Using the new three-layer approach led to a storage change of +147,000 af for the same period.

The rather large discrepancy of 40,000 af in Test Case 1 is primarily due to the inaccuracy of the traditional method presumption that Principal aquifer water levels behave identically to Shallow aquifer water levels in the Forebay area. As was shown in previous sections, this is not always the case and was especially not the case during 2004-05 when the Principal aquifer rose much more than the Shallow aquifer in most Forebay locations.

Figure 3-6 shows water levels for multi-depth monitoring well SAR-2 near Burris Basin in the Anaheim Forebay area. Notice that the water level change from November 2004 to November 2005 in the Principal aquifer zone was more than double that for the Shallow aquifer zone at that location. Since this was the case throughout much of the Forebay area, the traditional method overestimated the storage change by using Principal aquifer water levels as a surrogate for the Shallow aquifer.

Figure 3-6. November 2004-05 Water Level Change at Monitoring Well SAR-2



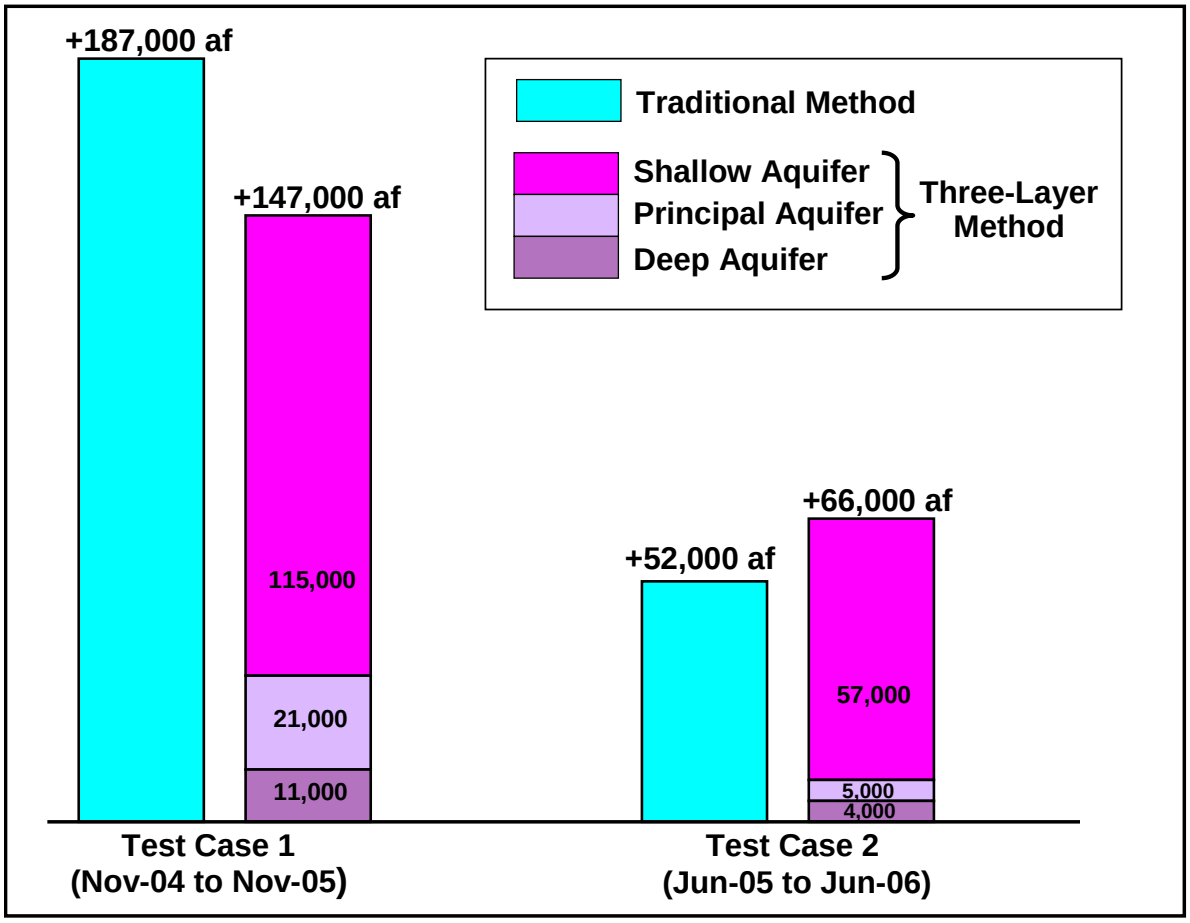
Test Case 2 compared the new three-layer method to the traditional method for the most recent water year, June 2005 through June 2006. This water year was chosen because it not only represented the most recent conditions but it was also an approximately average rainfall year in contrast to the extremely wet year in Test Case 1. As was mentioned in previous sections, care was exercised to maintain consistency of how the water level data was interpreted and hand contoured for both of these years to prevent any false or "manufactured" water level changes between the two conditions.

For Test Case 2, the traditional method yielded a storage change of +52,000 af, whereas the new three-layer method yielded a slightly higher storage change of +66,000 af. The two methods yielded much closer results for this average hydrology year, indicating that the traditional method is at least "in the ballpark" during more typical years when water levels are not as drastically rising or falling. In these closer-to-average years, the traditional method presumption that Principal aquifer water levels behave similarly to the Shallow aquifer is not grossly inaccurate. However, since the new three-layer approach is more comprehensive and utilizes all three aquifer layers, it

represents a technical improvement upon the traditional method and is the preferred approach.

Figure 3-7 summarizes the results from both test cases 1 and 2 and schematically shows the storage change per aquifer layer for the three-layer method. As expected and as was discussed in earlier sections, the majority of the storage change occurred in the Shallow aquifer. The majority of basin pumping (over 200,000 afy) occurs from the Principal aquifer, which is continuously being fed by the Shallow aquifer, which in turn is being fed by the District's recharge activities (typically over 200,000 afy). If basin pumping exceeds total recharge over a given year, then the Principal aquifer draws more water out of the Shallow aquifer than what is coming in from recharge, resulting in an annual storage decrease in the Shallow aquifer. Conversely, if recharge exceeds basin pumping over the course of a year (especially in a wet year), then more recharge is entering the Shallow aquifer than what is flowing down into the Principal aquifer, causing Shallow aquifer water levels to rise and a resulting storage increase.

Figure 3-7. Summary of Traditional vs. Three-Layer Storage Change Results

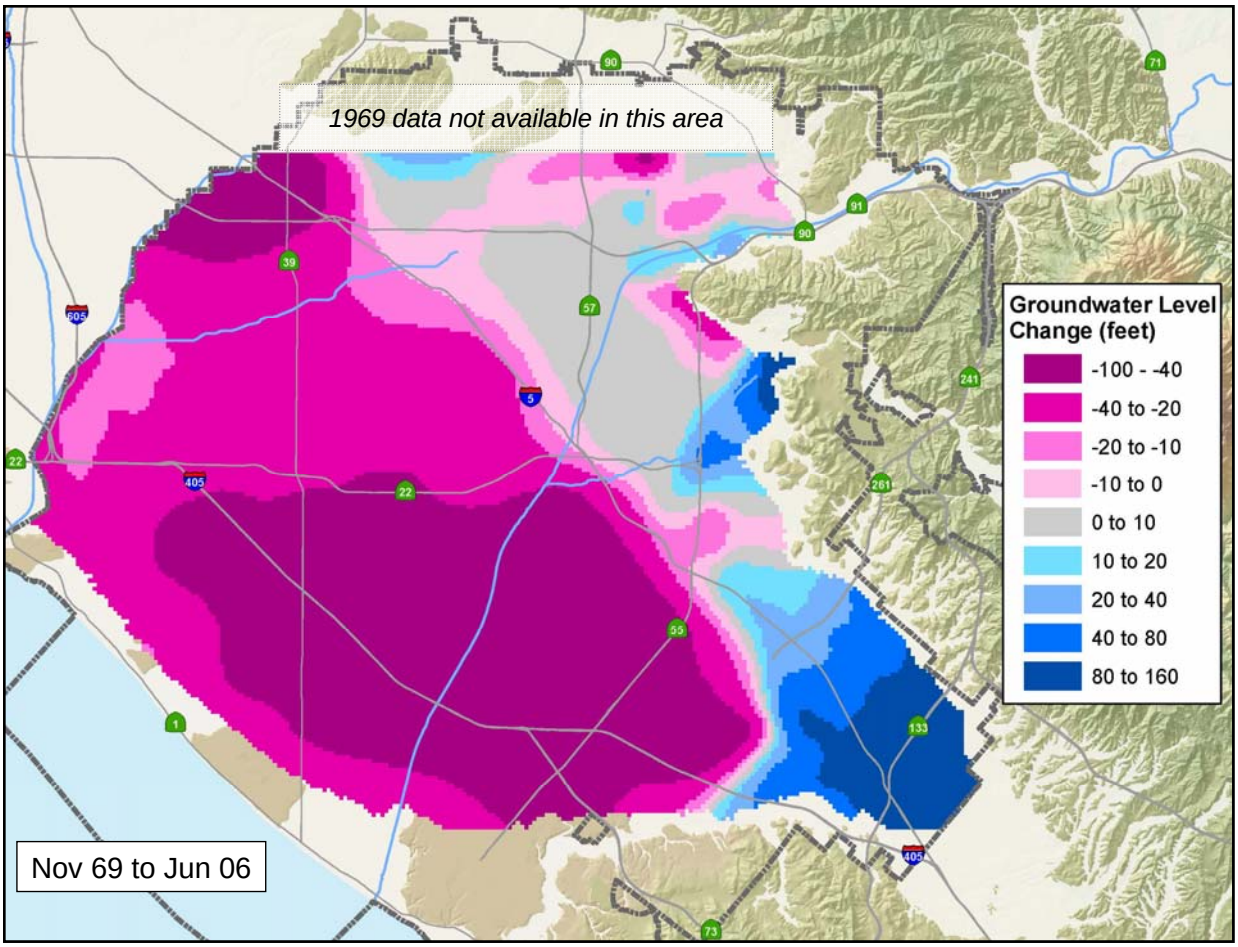


4. NEW FULL BASIN BENCHMARK

Since a new three-layer method was developed and tested for calculating the change in storage, a new full basin benchmark must be defined for all three aquifer layers so that the accumulated overdraft can ultimately be calculated.

In Section 1, it was shown that 1969 water levels no longer represented a full basin given the significantly different pumping and recharge conditions that exist today. In fact comparing the November 1969 water level contour map to the recent June 2006 Principal aquifer contour map shows that in much of the Forebay area, Principal aquifer water levels are already higher in June 2006 than they were in November 1969 when the basin had historically been considered full (see Figure 4-1). The Irvine Forebay area was over 80 feet higher in June 2006 than 1969 due to reduced agricultural pumping over the years. As was discussed in Section 1, because of increased utilization of the groundwater basin, i.e., increased pumping and recharge, higher Forebay water levels can be achieved while coastal water levels remain lower, resulting in a steeper basin gradient.

Figure 4-1. Principal Aquifer Water Level Change: November 1969 to June 2006



4.1 Assumptions and Methodology

A water level contour map representing a reasonable full condition was developed for the Shallow, Principal, and Deep aquifers. The resulting full water levels represent a "snapshot" of a peak high water level condition throughout the basin that could possibly be exceeded but with potentially detrimental impacts.

Defining how high basin water levels can rise before being considered full was largely based on a comprehensive review of relatively recent historical high basin conditions that occurred approximately in 1994 and 2006. The high basin conditions that occurred in 1969 and 1983 were briefly reviewed but were deemed of less direct value since basin pumping and recharge patterns were significantly different then.

Much of the groundwater basin achieved historical highs during 1994, with the coastal area peaking in the winter and the Forebay area in late spring or early summer. A similar lag in the seasonal timing of the coastal and Forebay area water level peak was observed during the recent high condition of 2006. Typically after a very wet winter, surplus storm runoff impounded behind Prado Dam is still being released for OCWD recharge operations well into the summer months, thus increasing Forebay recharge amounts, which in turn raise Forebay water levels at a time when coastal water levels are already beginning to decline in response to summer pumping. However, also during wet years, MWD has surplus water; thus, taking additional imported water in-lieu of groundwater pumping can extend into the summer months, which would prevent or delay coastal water levels from declining. Therefore, for the purposes here of defining a basin-wide full condition, it is assumed that water levels can concurrently peak to a full condition throughout the basin.

The full condition that was developed for all three aquifer layers represents the highest achievable water levels throughout the basin under realistic present-day operating conditions without incurring any regional-scale detrimental impacts. In general, coastal water levels were assumed to be at or very near the 1994 and 2006 winter highs, whereas the Forebay area was assumed to be at or slightly above the 1994 and June 2006 highs. In so doing, the full basin coastal water levels were high enough to be protective against seawater intrusion but not unnecessarily high to where shallow groundwater seepage could become an issue. In the Forebay area, full basin water levels were generally well below ground surface and at or near the bottom of deep recharge basins (as occurred in June 1994). Therefore, in the Forebay area, water levels any higher than this full condition may be physically possible but would likely impact recharge operations and lead to considerable mounding problems.

Other assumptions that define the new full basin condition are enumerated below.

1. Full basin flow patterns (shape of the water level contours) are representative of present-day pumping and recharge conditions (except where specifically noted) and thus are largely based on and consistent with actual water level contour maps constructed for the recent high conditions of January 2006 and June 2006.

2. Water levels in the Irvine Sub-basin were at historical highs during 2006 because of the extremely wet year 2004-05 and reduced Irvine Company agricultural pumping. The new full condition in the Irvine Sub-basin is thus based on this recent high condition, which inherently then excludes the Irvine Desalter Project (IDP). The IDP will significantly lower Irvine area water levels for many years to come, but the regional drawdown and resulting water levels in that area are uncertain and may take several years to stabilize. Previous basin model scenarios including IDP pumping estimated that approximately 50,000 af of storage decline in the Irvine Sub-basin could occur after 20 years of full-scale IDP pumping. With this in mind, the new full condition will not likely be achievable in the Irvine Sub-basin after the IDP goes on-line.

3. Based on the earlier assumption that this new full condition is protective against seawater intrusion, full basin water levels in the MCWD area were based on the historical high of 1994 rather than the somewhat lower water levels during the 2006 high condition. The 1994 water levels in the MCWD area were higher than in 2006 because the MCWD colored water project was not yet active in 1994. Therefore, the new full basin water levels in that immediate area inherently assume no MCWD colored water project (i.e., no pumping from Well MCWD-6) in order to define a condition sufficiently protective against seawater intrusion.

4. Full basin water levels in the immediate area of the Talbert Barrier were adjusted slightly higher than recent high conditions to account for the GWR Phase 1 barrier expansion soon to be on-line. Some of these new injection wells, including the four wells along the Santa Ana River just north of Adams Avenue, are already on-line and thus the observed water level rise due to these wells was used in the full basin condition.

5. Full basin water levels were raised slightly higher than either of the historical highs of 1994 or 2006 in areas where other near-term recharge projects are already planned, including La Jolla Basin and Santiago Creek recharge enhancements. However, especially in the case of Santiago Creek, full basin water levels were kept sufficiently below ground surface and known landfill elevations.

4.2 Shallow Aquifer Full Basin Water Level Map

Full basin water levels for the Shallow aquifer were based largely on the historical high water levels observed in 1994 and 2006. Only wells with a screened interval generally in the range from 100 to 250 feet below ground surface (depending on the specific area) were used to ensure that these wells were representative of the Shallow aquifer. This depth restriction excludes most large system production wells. Therefore, the majority of wells used to construct the Shallow aquifer full basin water level map were District monitoring wells, along with some small system and domestic wells having sufficient water level histories. Fortunately, the majority of the District's monitoring wells were constructed early enough so as to catch the 1994 high-basin condition.

Prior to this study, Shallow aquifer water levels were not regularly contoured, but Shallow aquifer contour maps (basin model layer 1) had been constructed during basin model development and much was learned about the hydraulic characteristics and flow patterns of the Shallow aquifer. Subsequently for testing the new three-layer storage change method described in Section 3, water level contour maps were constructed for all three aquifer layers using observed data for both June 2005 and June 2006. Fortunately, June 2006 also represented a high-basin condition from which to use as a base for making adjustments up to the new full condition.

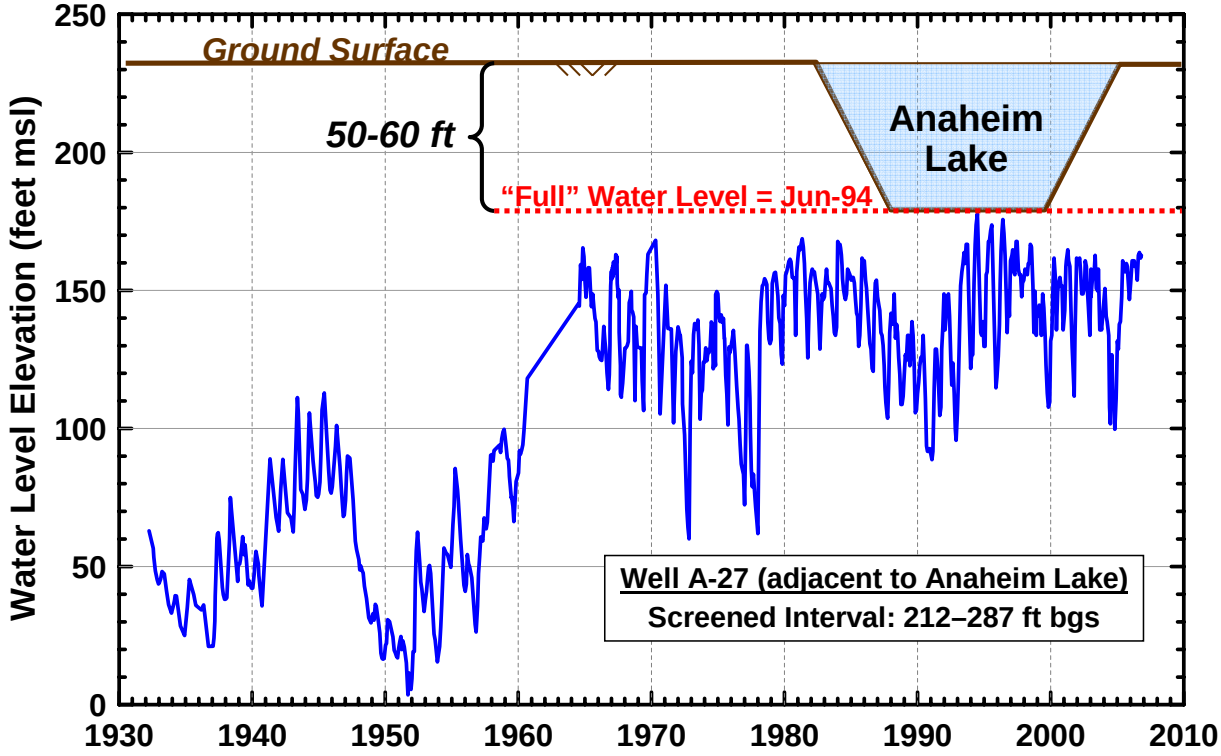
In the coastal and mid-basin areas, high water levels that peaked in January 2006 were generally adhered to and used for the full condition in those areas. This represented a condition high enough to be protective of seawater intrusion, but anything appreciably higher could potentially result in shallow groundwater seepage problems in low-lying areas. In the immediate area surrounding portions of the Talbert Barrier, the observed January 2006 water levels were adjusted upward approximately 5 feet to account for increased injection from new GWRS Phase 1 injection wells. In the area surrounding the GWRS treatment plant site where considerable construction dewatering was occurring during January 2006, full water levels were based on earlier historical highs that were nearly 15 feet higher than January 2006 in this immediate area.

In the Forebay area, full basin water levels were generally set from 0 to 15 feet above the higher of the two historical peaks that occurred in June 1994 and June 2006. The magnitude of the upward adjustment between 0 and 15 feet depended on conditions at each well location and was most significantly influenced by the relative depth of the water table from ground surface. Since relatively little pumping occurs from the Shallow aquifer, the unconfined water table in the Forebay area is largely considered to be a subdued reflection of topography, with the exception of directly beneath recharge basins where the Shallow aquifer water table tends to rise in response to percolation. From analysis of the Forebay historical highs (June 1994 and/or June 2006), Shallow aquifer water levels generally peak at an elevation that corresponds to a depth of approximately 50 to 60 feet below ground surface. Therefore, when setting the full basin water level elevations at various well points and especially in areas where little or no data existed, the 50- to 60-foot depth to water rule of thumb was generally maintained.

Since the majority of the storage change in the basin occurs in the Shallow aquifer within the Forebay area, the full basin water level condition in this area is crucial. A discussion of the full basin Shallow aquifer water level adjustments for specific regions of the Forebay is described below.

At Anaheim Lake and Kraemer Basin, full basin water levels were set at June 1994 observed levels with no upward adjustment since these levels were essentially at or even a couple feet above the deepest portion of Anaheim Lake, which is approximately 50 to 60 feet deep (see Figure 4-2), which is consistent with the depth to water rule of thumb mentioned above. Water levels any higher at this location, if even achievable, would likely impede percolation from these basins and thus would not be desirable.

Figure 4-2. Full Basin Water Level at Anaheim Well 27



At Santiago Pits, full basin water levels were set at the historical high of March 1993 (just slightly higher than June 1994) with no upward adjustment. This same identical high was reached but not exceeded more recently in June 2005 after the extremely wet winter of 2004-05. Having the observed water levels peak at the same exact same level in 1993 and 2005 may likely indicate that this repeatable historical high may represent the highest physically achievable water level for this area.

In the Anaheim/Fullerton area west of the District's spreading grounds, full basin water levels were set 10 to 15 feet higher than the new historical high of June 2006. Water levels in June 2006 exceeded the previous historical high of June 1994 and appear to still be on an upward trend. The upward adjustment of 10 to 15 feet from the June 2006 observed condition once again brought the water table up to approximately 50-60 feet from ground surface.

Along the Santa Ana River downstream of Lincoln Avenue, full basin water levels were set 5 to 10 feet higher than the new historical high of June 2006, which exceeded the previous high of June 1994 in this area as well. The upward adjustment of 5 to 10 feet above the historical high once again brought the full condition up as shallow as 40-50 feet from ground surface, likely being influenced by the recharge from the Santa Ana River and Burris Basin. This full level also corresponds approximately to the bottom elevation of Burris Basin, analogous to the full level adjacent to Anaheim Lake.

In the Irvine Forebay area, full basin water levels were set within 5 feet of the historical high, which either occurred in 1994, 1999, or 2006 depending on the exact location within this general area. Recall from the previous section that this new full condition is prior to full-scale IDP pumping. Although the majority of IDP pumping will be from the Principal aquifer, Shallow aquifer water levels will likely also decline.

Finally, in the mid-basin Pressure area, full condition water levels were modestly adjusted upward 5 to 10 feet from the new historical high of June 2006, which again significantly exceeded the previous high of June 1994. This slight upward adjustment maintains a reasonable gradient from the coast to the upwardly adjusted full water levels in the Anaheim Forebay area.

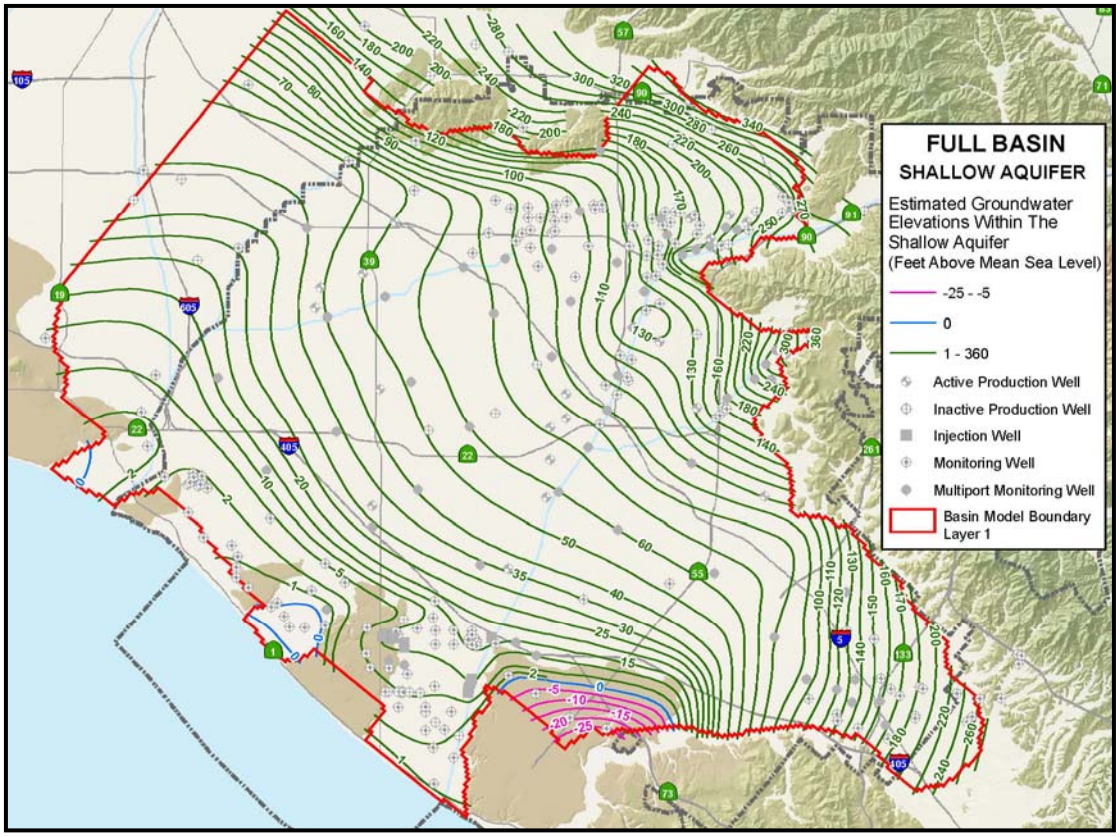
After making all the full condition water level adjustments at monitoring well points in the various areas described, the resulting full water levels were plotted on a map and hand contoured similarly to the observed water levels of June 2006. In fact, the June 2006 contour map was used as a guide or backdrop on the light table while contouring the full condition to ensure consistency, especially in outlying areas lacking data.

Figure 4-3 shows the resulting full water level contour map constructed for the Shallow aquifer. Also shown for reference is the June 2006 Shallow aquifer contour map directly below it. Note the similarity in the shape of the contours between the two maps. The various well points screened in the Shallow aquifer that were used for constructing these contour maps are shown in light gray. The red boundary represents the basin model layer 1 boundary which represents the extent of the Shallow aquifer along the mountain fronts where the aquifer terminates and on the western boundary represents an arbitrary cutoff 5 miles into LA County. Contouring the water levels slightly into LA County adds confidence to the shape of the contours in west Orange County and at least qualitatively indicates the direction of flow across the county line.

Figure 4-4 shows the same two Shallow aquifer water level conditions (Full and June 2006), but in units of depth to water below ground surface rather than elevation. As was discussed above, notice that much of the Forebay area is within the 40 feet below ground surface or greater range since the Shallow aquifer water levels generally follow ground surface topography where the aquifer is unconfined (Forebay), except near recharge facilities where the depth to water is more shallow due to percolation raising the water table.

The depth to water also becomes shallower in the Pressure area of the basin where the Shallow aquifer is confined. However, these “water levels” are actually pressure or piezometric levels since the water is confined or trapped below the overlying aquitard. Water can only rise to this elevation if a well is drilled through the aquitard down into this aquifer or if the aquitard is thin or discontinuous. Notice that there is a large area in Irvine where the piezometric level is actually above ground surface in both the observed June 2006 and Full condition. This area has historically experienced artesian conditions when basin levels are relatively high.

Figure 4-3. Shallow Aquifer Groundwater Contours: Full Basin and June 2006



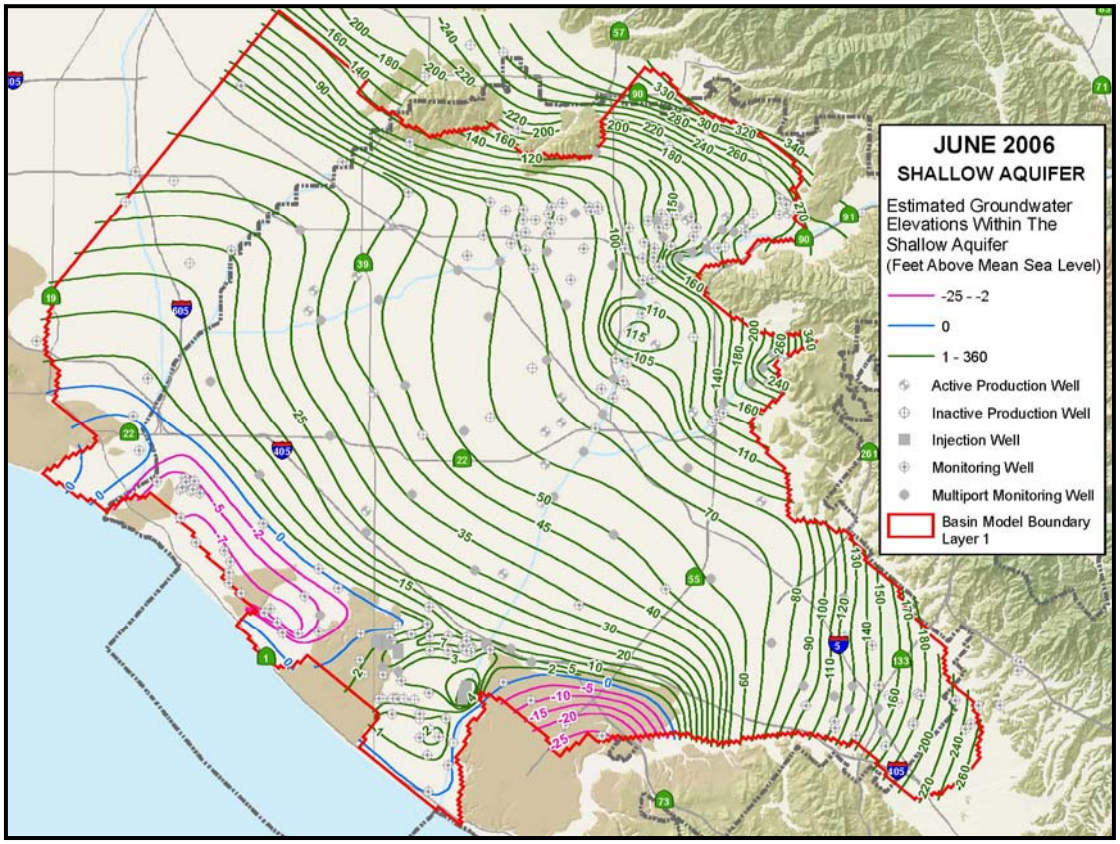
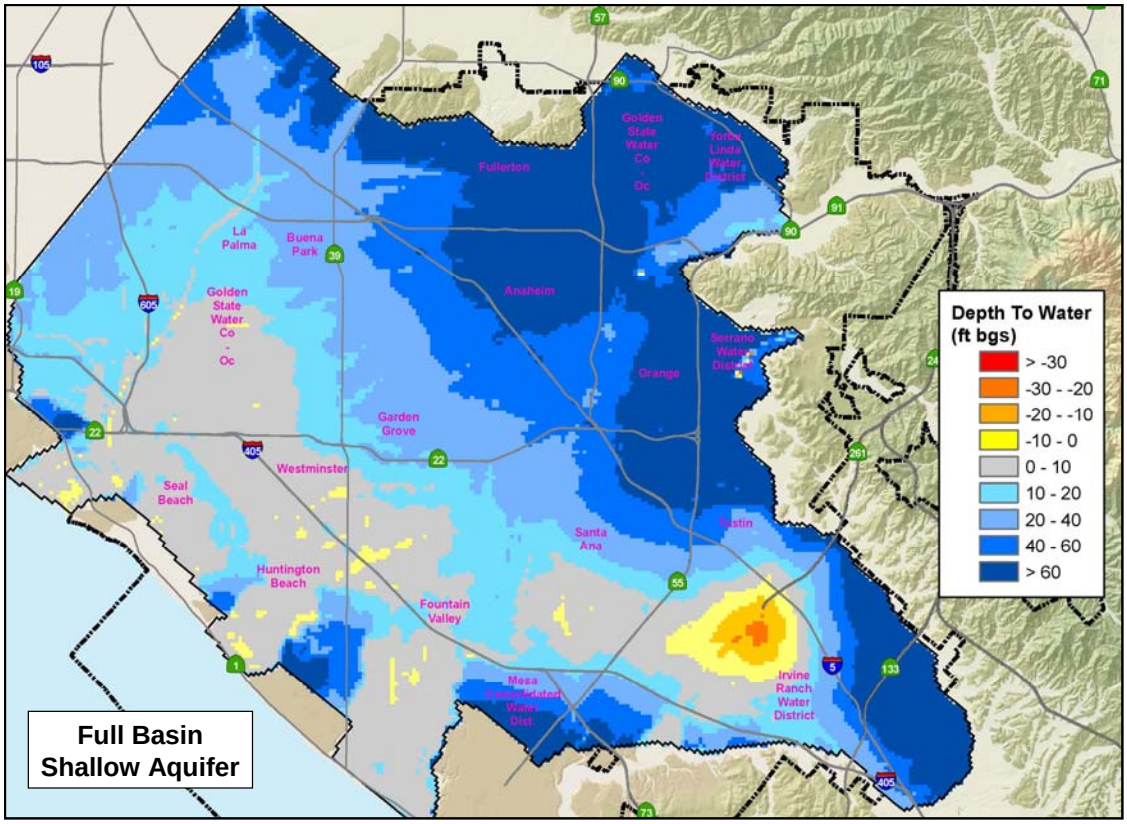
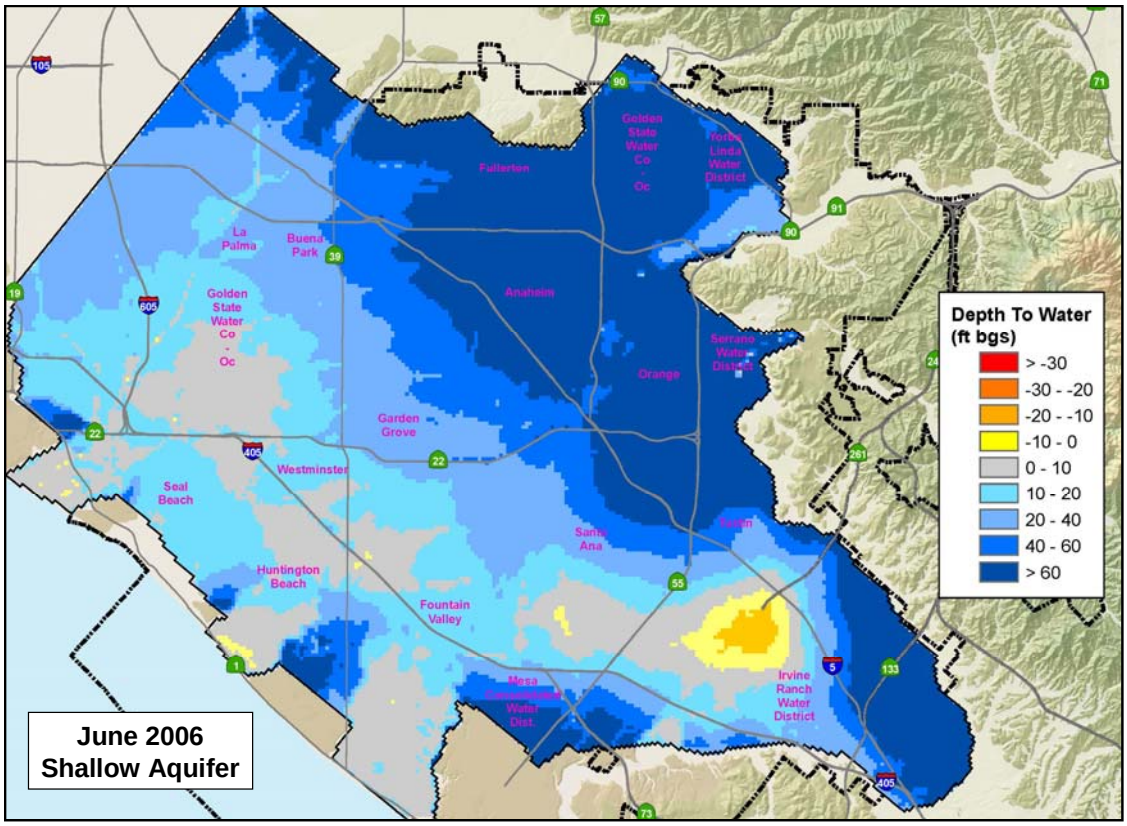


Figure 4-4. Shallow Aquifer Depth to Water: Full Basin and June 2006





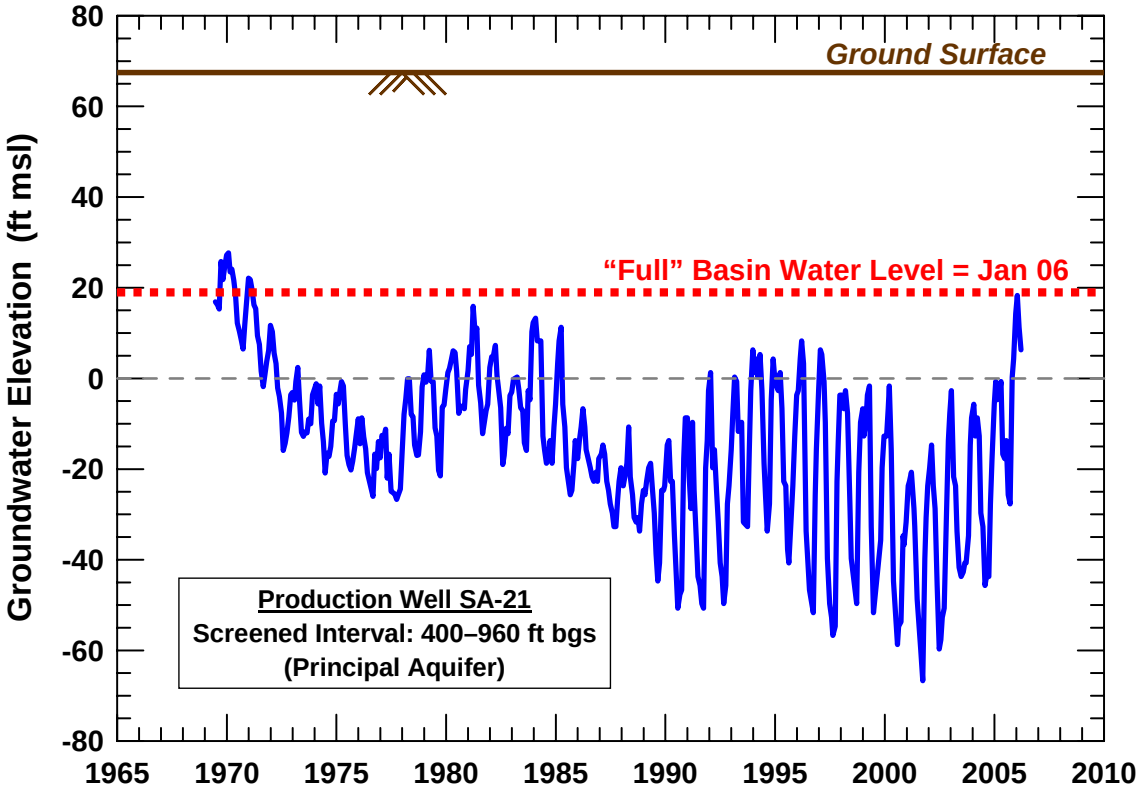
4.3 Principal Aquifer Full Basin Water Level Map

As with the Shallow aquifer, full basin water levels for the Principal aquifer were also based on the historical high water levels observed in 1994 and 2006. Wells with a screened interval generally within a range between 300 to 1,000 feet below ground surface (depending on the specific area) were used to represent the Principal aquifer. This depth interval includes most large system production wells, which along with District monitoring wells, were used to construct the Principal aquifer full basin water level map.

Prior to developing the full basin condition for the Principal aquifer, the high-basin water level condition of January 2006 was analyzed and contoured to determine the flow patterns and contour shapes for a most recent, near-full, actual condition. In subsequent months, observed water levels in the Forebay area increased further to a new historical high in June 2006, whereas in the coastal area January 2006 remained a historical high.

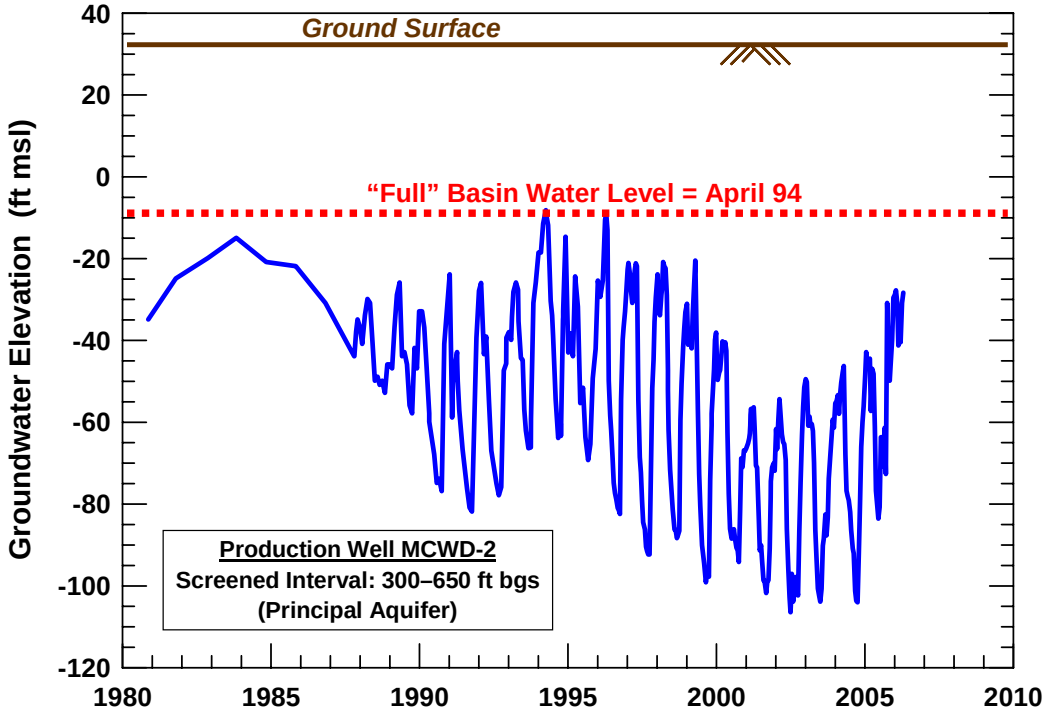
In the coastal area, full basin water levels were generally set at or within 5 feet of the observed peak January 2006 water levels, as was also done for the Shallow aquifer. In fact, this was the case for the majority of the Pressure area, where January 2006 water levels were noticeably higher than the previous high of 1994 (see Figure 4-5).

Figure 4-5. Full Basin Water Level at Santa Ana Well 21



The exception to using January 2006 water levels for the full condition in the Pressure area was in the MCWD area where the high condition of April 1994 was used. At this location, January 2006 water levels were 15 to 20 feet lower than April 1994 because of current pumping from the MCWD colored water project that did not exist in 1994. As was mentioned in the Section 4.1 assumptions, since the full condition must be sufficiently high in the coastal area to be protective of seawater intrusion, the older but higher April 1994 water levels were used in this area for the full condition even though it is not representative of present-day pumping in this immediate area (see Figure 4-6).

Figure 4-6. Full Basin Water Level at Mesa Consolidated Water District Well 2

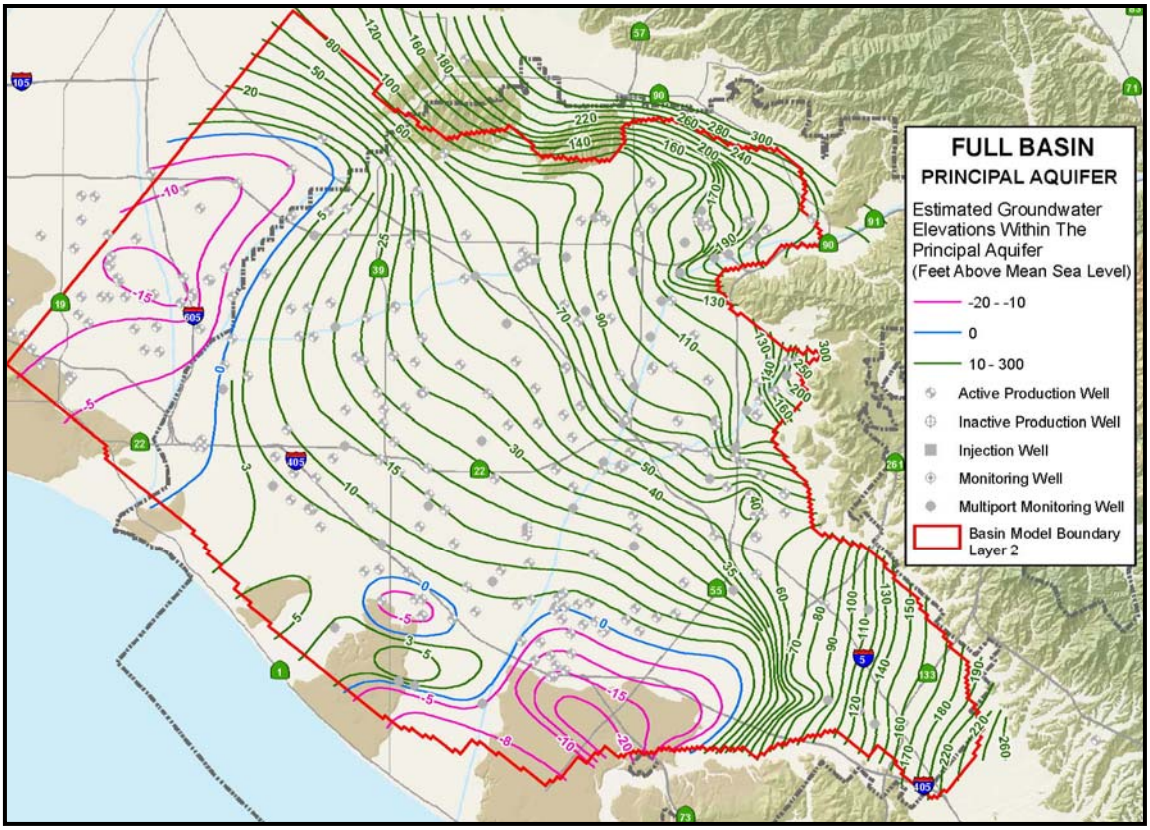


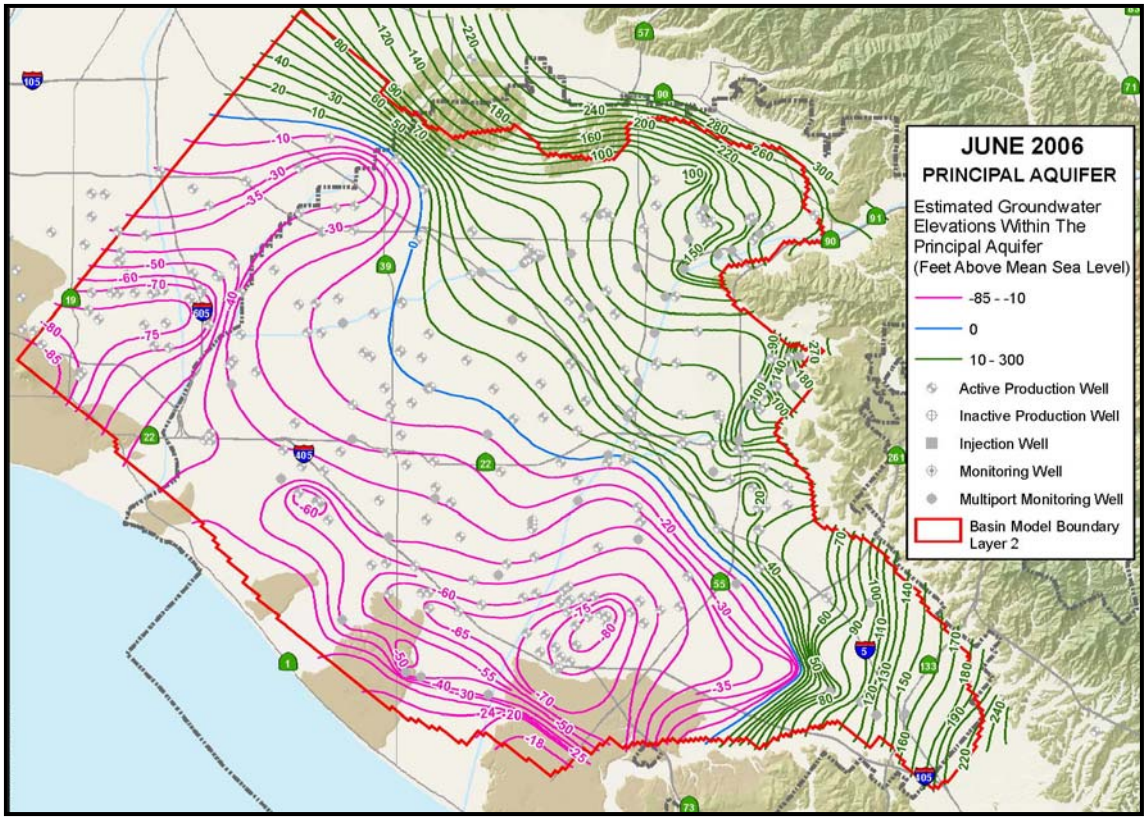
Throughout most of the Irvine Sub-basin, January 2006 represented a historical high similar to the rest of the Pressure area. Thus, full basin water levels in Irvine were also set within 5 feet of observed January 2006 levels. However, in north Irvine near the Santa Ana mountain front, 1999 water levels were used since they were nearly 15 feet higher than January 2006 in that immediate area.

In the Anaheim and Orange Forebay areas, full basin water levels were generally set at or within 5 feet of the historical high that occurred during March through June of 1994 depending on the exact location. For the majority of the Forebay area, 1994 still represented a historical high for the Principal aquifer, higher than January or June 2006.

Although the full water levels were based on different historical highs in different areas of the basin (coastal vs. inland), resulting gradients and flow patterns were reasonable and similar to those contoured for the observed data of June 2006 (see Figure 4.7).

Figure 4-7. Principal Aquifer Groundwater Contours: Full Basin and June 2006





4.4 Deep Aquifer Full Basin Water Level Map

For the Deep aquifer, the main data source for developing the full basin condition was water level data from the District's deep multi-port monitoring (Westbay) well network. Approximately two-thirds of these 56 wells were sufficiently deep and in appropriate locations overlying the Deep aquifer. Depending on the specific location, the monitoring ports of these wells that tap the Deep aquifer generally range from approximately 1,500 to 2,000 feet below ground surface.

In addition to the District's deep monitoring wells, a few other scattered well points that tap the Deep aquifer were used, such as two deep monitoring wells owned by the Water Replenishment District in LA County (very close to the county line).

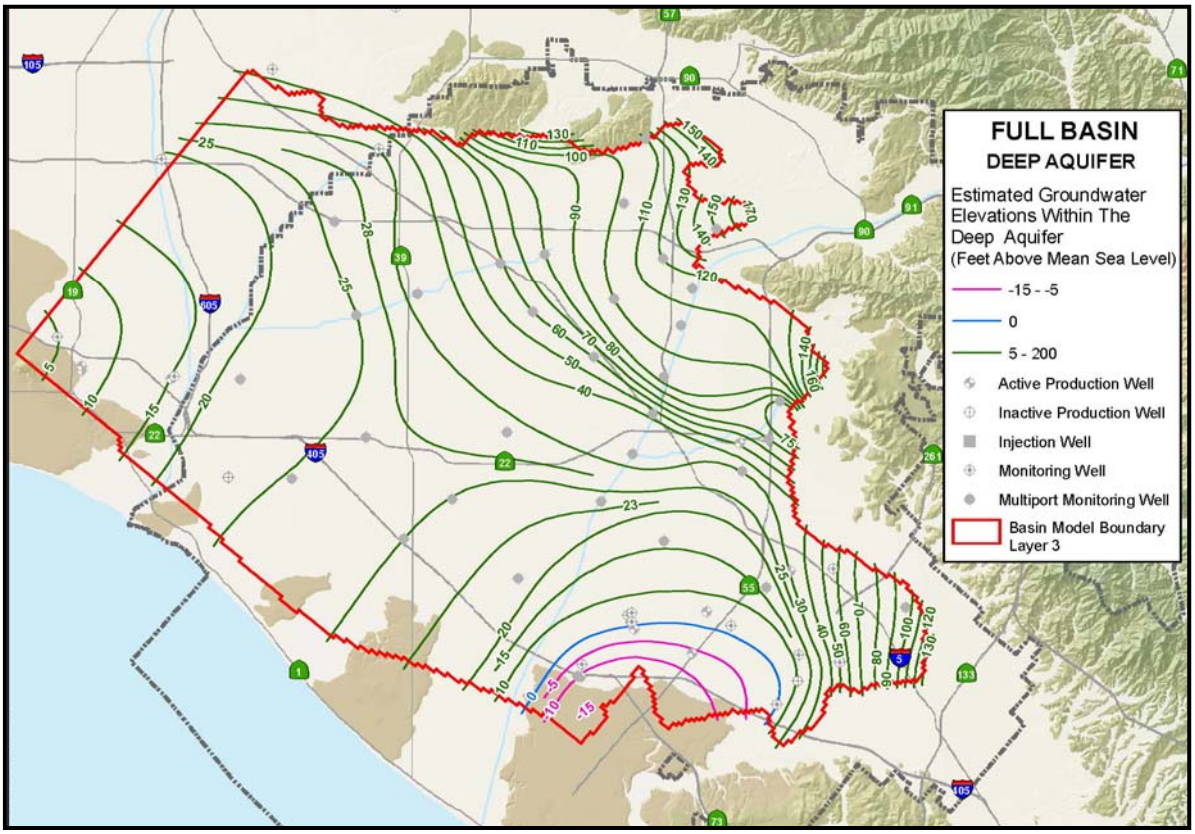
The new full condition for the Deep aquifer was predominantly based on the historical high that occurred in 1994. Throughout the basin, the recent June 2006 Deep aquifer water levels were still well below the historical high of 1994, likely due to the IRWD Deep Aquifer Treatment System (DATS) Project which began pumping approximately 8,000 afy of colored water in December 2001 from this otherwise little-used zone. Also, there was no MCWD colored water project yet in 1994. Fortunately, most of the District's deep monitoring wells are old enough to have captured the historical high condition of 1994.

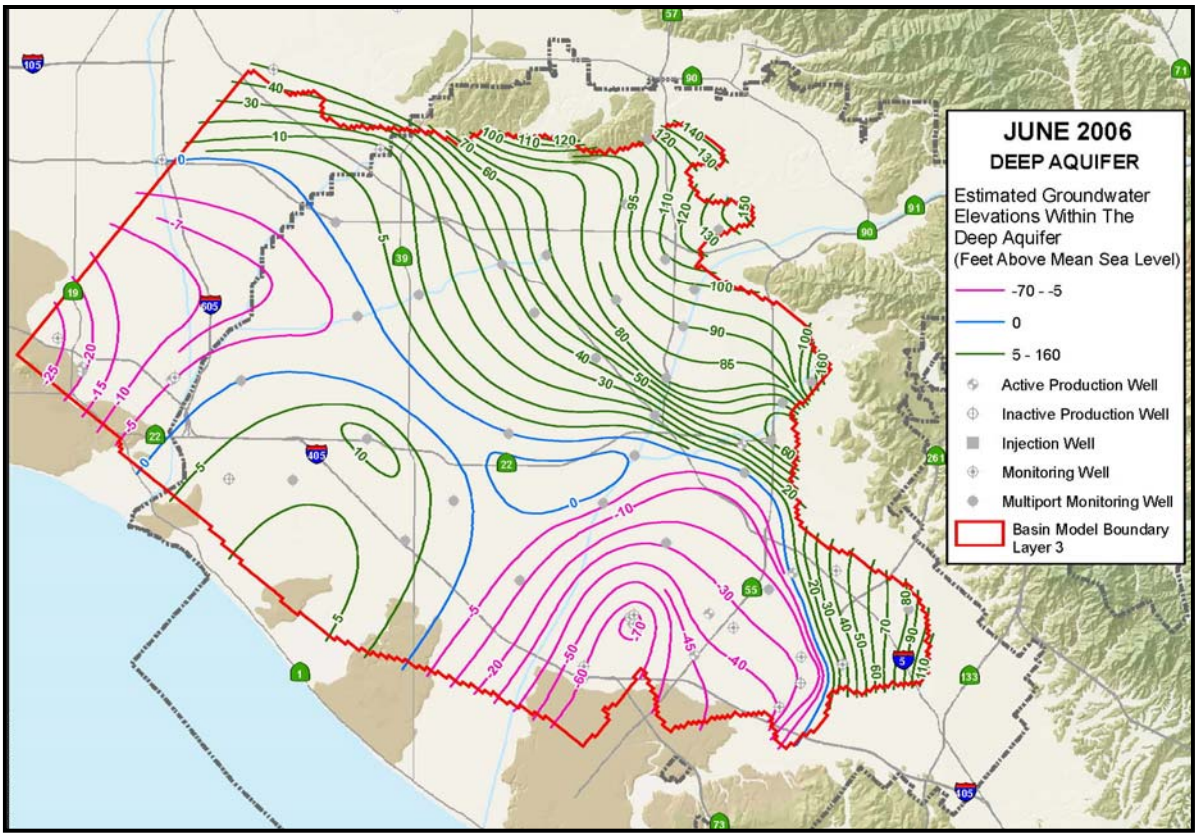
It is somewhat speculative as to how high the piezometric level of the Deep aquifer can rise. Therefore, full water levels were conservatively adjusted only 0 to 5 feet higher than the observed historical peak that occurred April to June of 1994. In so doing, the observed vertical piezometric head difference between the overlying Principal aquifer and the Deep aquifer was maintained. Throughout most of the basin, Deep aquifer piezometric levels typically ranged from 10 to 30 feet higher than the more heavily pumped Principal aquifer, except in the furthest inland locations near the mountain front and near recharge facilities where the Deep aquifer levels are actually lower than the Principal aquifer due to being more vertically removed from surficial recharge.

While contouring the resulting Deep aquifer full basin piezometric levels (also referred to as water levels for simplicity), the Principal aquifer full condition contour map was used as a backdrop on the light table to ensure that the Deep aquifer full contours maintained the vertical head difference discussed above. Also, in areas lacking data, the contours were drawn with similar patterns as those predicted during basin model calibration.

Figure 4-8 shows the resulting contour maps for both the new full condition and also June 2006 for comparison. The contour shapes are quite similar for both maps except in the area near the aforementioned DATS wells. The Full map assumes no DATS pumping since it was based on the historical high water levels of 1994, whereas the June 2006 map shows a relatively deep pumping depression in that immediate area. However, due to the confined nature of the Deep aquifer, the storage coefficients of this zone are very small (see Appendix 2) and thus even a relatively large water level difference leads to a small storage change.

Figure 4-8. Deep Aquifer Groundwater Contours: Full Basin and June 2006





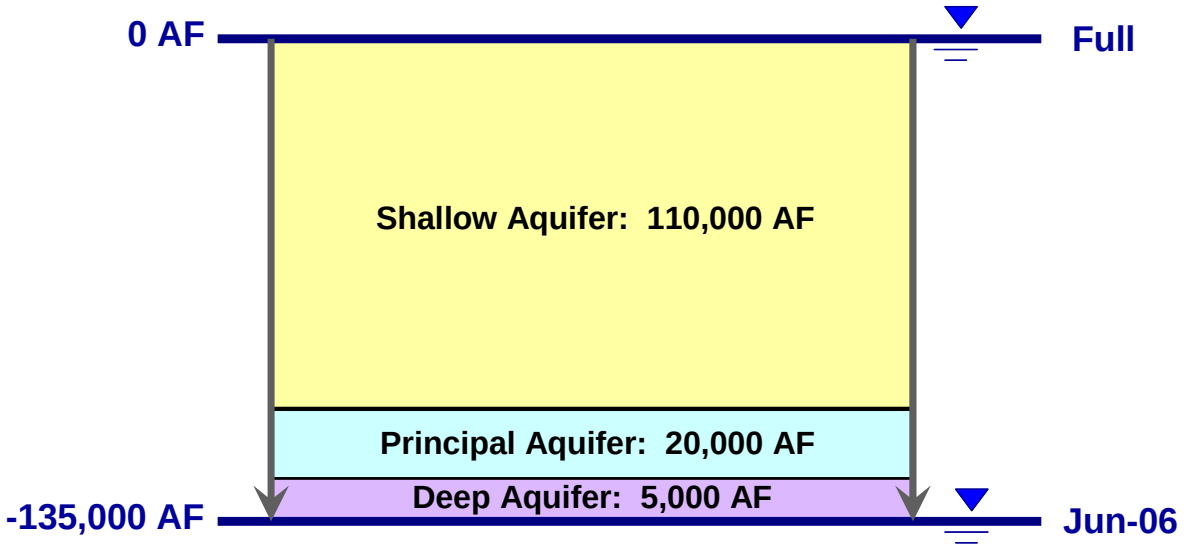
5. ACCUMULATED OVERDRAFT FROM NEW FULL CONDITION

The accumulated overdraft is the amount of storage capacity below full, sometimes referred to as dewatered storage or available storage capacity. In various literature, overdraft often has a negative connotation implying that a basin is in a steady state of decline or has been drawn-down below some critical threshold to where negative impacts such as subsidence and seawater intrusion begin to occur. In this report, use of the term "accumulated overdraft," which is defined in the District Act, is not intended to have any negative connotation and is strictly used as a measure of available basin storage below the new full benchmark or zero-overdraft condition established in Section 4.

5.1 Accumulated Overdraft as of June 30, 2006

The new three-layer storage change methodology was used to calculate the accumulated overdraft for June 2006. Three groundwater contour maps (one for each aquifer layer) representing June 30, 2006 had already been constructed for testing the new three-layer approach described in Section 3. For the storage change calculation, Year 1 was set to the new full water level condition and Year 2 was set to the June 2006 water level condition. The resulting change in storage from the new full condition to June 2006 was -135,000 af, or in other words, the accumulated overdraft as of June 30, 2006 was 135,000 af below the new full benchmark. The breakdown per aquifer layer is schematically shown below in Figure 5-1.

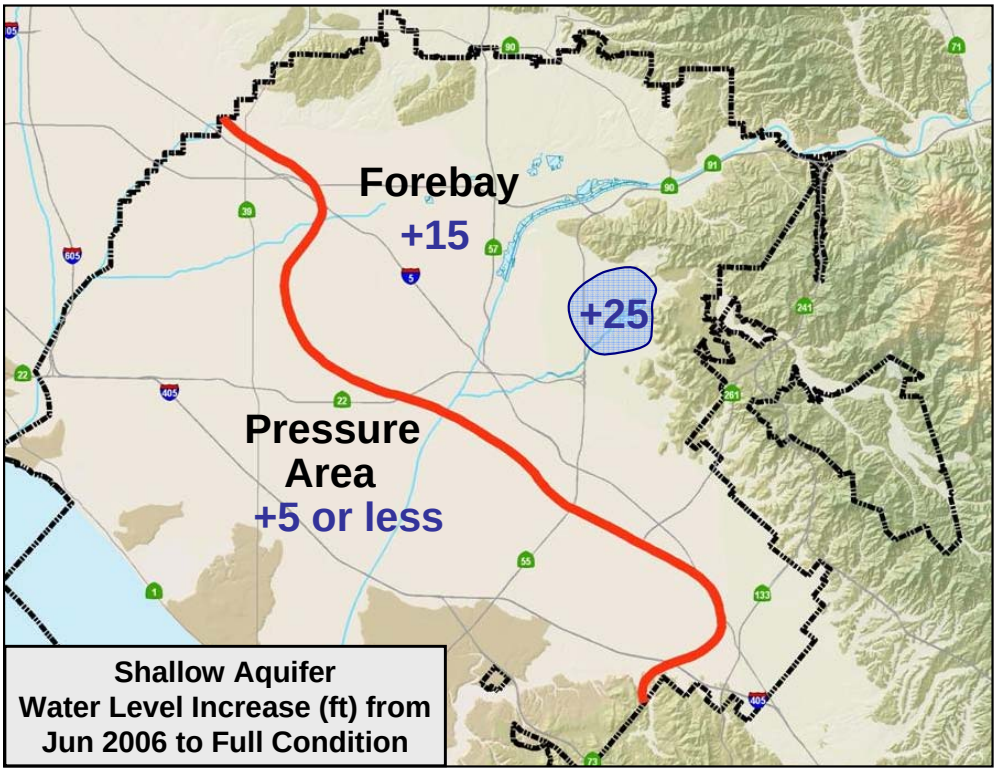
Figure 5-1. Three-Layer Accumulated Overdraft for June 2006



To put the Shallow aquifer storage change from the full condition (110,000 af) into perspective, Shallow aquifer water levels in most of the Forebay area were approximately 15 feet higher in the full condition as compared to June 2006 (Figure 5-2). In the coastal area, full water levels were only about 5 feet higher than June 2006. And since much more storage change occurs in the Forebay than the Pressure area per foot of water level change, nearly all of the Shallow aquifer storage change from full to June 2006 occurred in the Forebay area. Therefore, in general, a 15-foot Shallow aquifer water level change throughout the Forebay caused approximately 100,000 af of storage change.

Detailed water level change maps for June 2006 to the new full condition for all three aquifer layers are shown in Appendix 3.

Figure 5-2. Average Shallow Aquifer Water Level Difference from June 2006 to Full



5.2 Accumulated Overdraft as of June 30, 2005

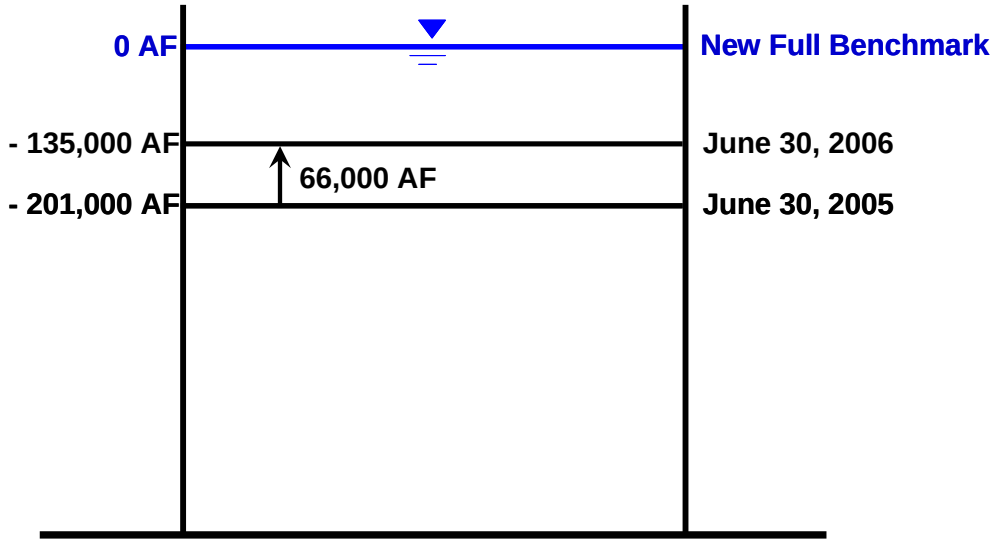
Using the new three-layer storage change method, the accumulated overdraft was calculated for June 2005 by directly comparing to the new full benchmark once again. In the storage change calculation, Year 1 was set to the new full water level condition and Year 2 was set to the June 2005 water level condition. The resulting total change in storage from the new full to June 2005 was -201,000 af, or in other words, the accumulated overdraft was 201,000 af below the new full benchmark.

The June 30, 2005 accumulated overdraft for each aquifer layer was as follows:

Shallow aquifer:	166,000 af
Principal aquifer:	25,000 af
Deep aquifer:	10,000 af
Total:	201,000 af

The difference between the June 2005 and June 2006 accumulated overdraft was 66,000 af, which represents the annual increase in storage from July 1, 2005 through June 30, 2006 (see figure 5-3). As a check, this storage change of 66,000 af was exactly the same as that calculated directly using the new three-layer method with Year 1 as June 2005 and Year 2 as June 2006 (see previous Figure 3-7). Therefore, this confirmed that the new three-layer approach yields exactly the same results summing the annual storage change over multiple years or calculating the storage change using the start and end of the multiple year period. In addition, the new method has been shown to yield the same identical storage change, but opposite in sign, when reversing the order of Year 1 vs. Year 2.

Figure 5-3. Accumulated Overdraft Schematic for June 2005 and June 2006

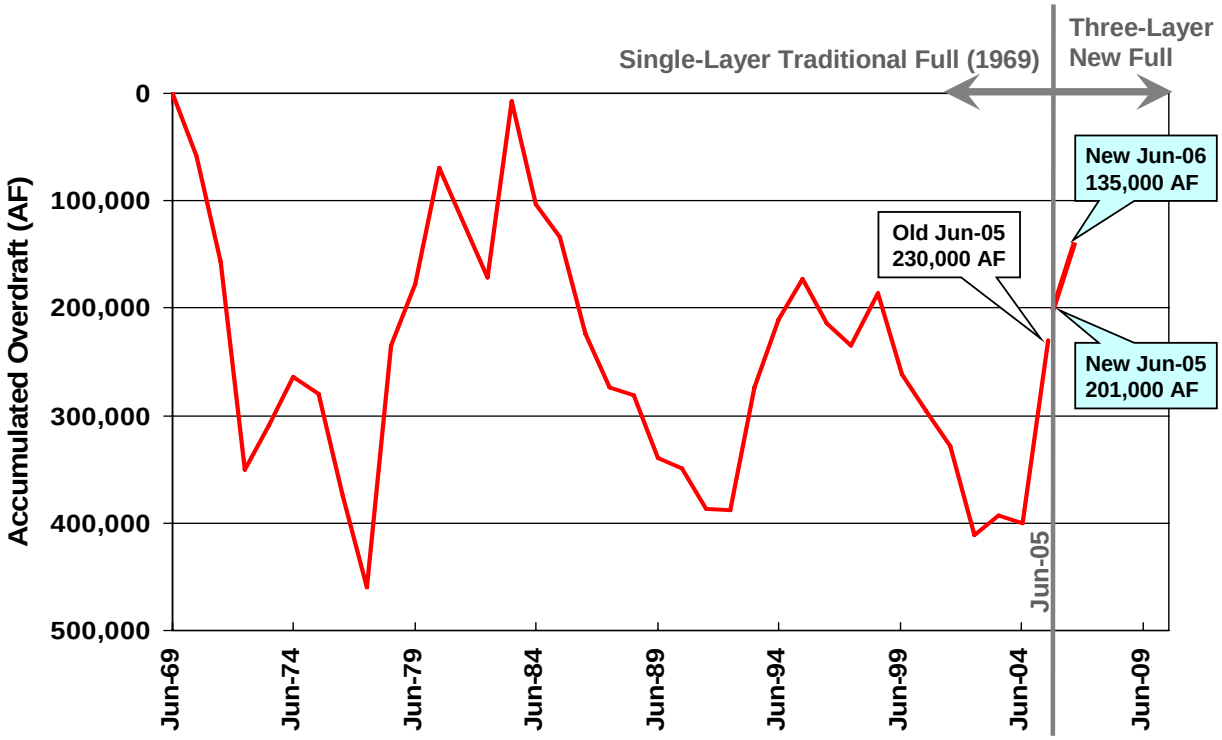


5.3 Historical vs. New Accumulated Overdraft Estimates

The new accumulated overdraft estimate of 201,000 af for June 2005 is 29,000 af less than the traditional method estimate of 230,000 af published in the 2004-05 OCWD Engineer's Report. This discrepancy is relatively minor when considering the major differences between the traditional single-layer and new three-layer storage change methods and also their two corresponding different full basin benchmarks. Since the historical accumulated overdraft levels are all relative to the 1969 condition as being the

zero-overdraft benchmark, the two new accumulated overdraft estimates for June 2005 and June 2006 are plotted on the same familiar historical overdraft graph in Figure 5-4. However, this graph has been divided at the June 2005 line due to the two different zero-overdraft benchmarks of 1969 water levels and the new full condition.

Figure 5-4. Historical and New Accumulated Overdraft



5.4 Implementation of New Three-Layer Storage Change Method

To prevent or minimize any accumulation of potential discrepancy from year to year when implementing this new storage change method, it is important to follow the steps enumerated below.

1. Hand-contour water levels collected on or about June 30 for each of the three aquifer layers, maintaining consistency with how the water level data is interpreted from year to year, unless new well data in a specific area causes a different interpretation.

2. Use the GIS to calculate the water level change and corresponding storage change from the three-layer full benchmark to the current June condition. The resulting storage change below the full condition represents the accumulated overdraft for June of that year.

3. Subtract the previous year's accumulated overdraft from the current year to obtain the annual change in storage for that water year.

4. This step is a quality control check. Use the three-layer storage change method once again to calculate the water level change and storage change from the previous June (Year 1) to the current June (Year 2). This storage change should exactly equal the storage change calculated in Step 3.

5. Calculate incidental recharge for that water year by inputting the annual storage change estimate from Step 3 or 4 (if they are the same) into the water budget method described in Section 3.3. The resulting incidental recharge should be reasonable given the annual rainfall for the year in question; otherwise, additional error checking should be done for the water budget terms as well as the input data for the storage change calculation. It should be pointed out though that incidental recharge is not solely a function of rainfall because the flow across the LA County line – along with all other unknown inflows and outflows – is lumped into the incidental recharge term. That being said, incidental recharge for a somewhat typical year with average rainfall is thought to be approximately 60,000 afy but could vary by upwards of 20,000 af based on changes in outflow to LA County, which unfortunately is difficult to quantify.

6. The water budget method should not be used to determine or adjust the official storage change estimate calculated using the new three-layer method. It can be used to calculate preliminary monthly storage change estimates (using assumed incidental recharge) prior to performing the annual three-layer storage calculation. However, the annual storage change and accumulated overdraft official record for that year should be the exact value from the three-layer storage method steps above. This will prevent an accumulation of unknown discrepancy when rectifying back to previous years.

6. BASIN OPERATING RANGE AND STRATEGY

The level of accumulated overdraft in the basin, both for the current and upcoming year, affects important basin management decisions, including determining imported water needs and setting the Basin Pumping Percentage (BPP), both of which have major financial effects on the District and groundwater producers. Therefore, it is crucial to have an operational strategy to ensure that the basin is managed within acceptable overdraft limits to prevent detrimental impacts to the basin while also striving to maximize water reliability and financial efficiency.

In the discussion that follows, all storage and overdraft conditions are defined for June 30 of a given year, which is the ending date of the water year (July 1 through June 30) and thus the date represented by the June annual contour maps used for the storage change calculation. Seasonal fluctuations in water levels and basin storage occur throughout the water year and are tracked monthly for reporting purposes, and are used, along with the end-of-year accumulated overdraft, in making management decisions.

6.1 Basin Operating Range and Optimal Target

The operating range of the basin is considered to be the maximum allowable storage range without incurring detrimental impacts. The upper limit of the operating range is defined by the new full basin condition, which represents the zero-overdraft benchmark. Although it may be physically possible to fill the basin higher than this full condition, it could lead to detrimental impacts such as percolation reductions in recharge facilities and increased risk of shallow groundwater seepage in low-lying coastal areas.

The lower limit of the operating range is considered to be 500,000 af overdraft and represents the lowest acceptable level in the basin, not the lowest achievable. This level also assumes that all MWD water stored in the basin (e.g., Conjuctive Use Storage Project and Super In-Lieu) has already been withdrawn. Although it is considered to be generally acceptable to allow the basin to decline to 500,000 af overdraft for brief periods due to severe drought conditions and lack of supplemental imported water supplies, it is not considered to be an acceptable management practice to intentionally manage the basin for sustained periods at this lower limit for the following reasons:

- Seawater intrusion likely
- Drought supply depleted
- Pumping levels detrimental to a handful of wells
- Increased pumping lifts and electrical costs
- Increased potential for color upwelling from the Deep aquifer

Of course, detrimental impacts like those listed above do not suddenly happen when the overdraft gets down to exactly 500,000 af; rather, they occur incrementally, or the potential for their occurrence grows as the basin declines to lower levels. However, basin model computer simulations indicate that many of these detrimental impacts become evident at an overdraft of approximately 500,000 af. For example, at 500,000 af overdraft, model-simulated water levels in the Talbert Gap area were marginally low and not protective of seawater intrusion, even with the increased injection from GWRS Phase 1. Furthermore, worst case basin model runs at 700,000 af overdraft indicated seawater intrusion becoming even worse and considerably more production wells being impacted by low pumping levels. Thus, an accumulated overdraft level of 700,000 af did not appear to be acceptable, not even for short durations. At overdraft levels significantly below 500,000 af overdraft, the potential for land subsidence could also become an issue.

Based on historical hydrology and recharge water availability, an accumulated overdraft of 100,000 af best represents an optimal basin management target. This optimal target level provides sufficient storage space to accommodate anticipated recharge from a single wet year while also providing water in storage for at least 2 or 3 consecutive years of drought.

Table 6-1 shows that basin storage could increase by as much as 100,000 af in a somewhat typical wet year based on predicted increased supplies. The Captured Santa Ana River Flows and Natural Incidental Recharge terms were both based on an average of four historical wet years: 1992-93, 1994-95, 1997-98, and 2004-05. Based on historical rainfall records for the Orange County area, wet years typically do not occur back-to-back. Therefore, the optimal overdraft target of 100,000 af provides the storage capacity to capture the increased supplies from this one typically wet year.

Table 6-1. Anticipated Supply Increases for a Typical Wet Year

Increased Supplies (Above Average Annual Amounts)	1 Year (AF)
Captured Santa Ana River Flows *	50,000
Natural Incidental Recharge *	30,000
Reduced Demand (Pumping)	20,000
Potential Storage Increase **	**100,000**

***** Average of four wet years: 92-93, 94-95, 97-98, 04-05
****** Assumes no mid-year BPP change

Table 6-2 shows that basin storage could decrease by approximately 90,000 af in a dry year based on reduced supplies. However, unlike wet years, historical rainfall records for this area show that dry years often occur for 2 or 3 consecutive years. Therefore, the 90,000 af of reduced supplies in a dry year could result in a 270,000 af decrease in basin storage after 3 consecutive years of drought. Assuming the basin to be at the optimal target of 100,000 af going into a three-year drought, the accumulated overdraft at the end of the drought would be 370,000 af, which is still within the acceptable operating range.

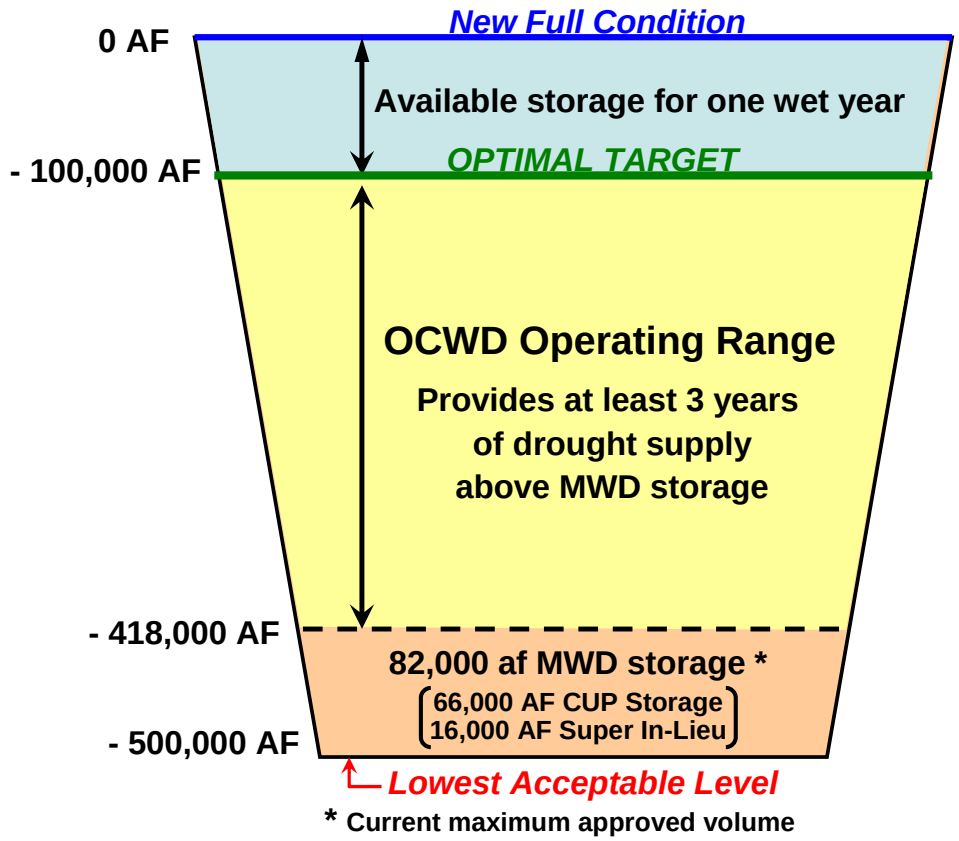
Table 6-2. Anticipated Supply Reductions for Typical Dry Years

Reduced Supplies (From Average Annual Amounts)	1 Year (AF)	3 Years (AF)
MWD Replenishment Water	-30,000	-90,000
Santa Ana River Flows	-40,000	-120,000
Natural Incidental Recharge	-20,000	-60,000
Total Potential Storage Change*	**-90,000**	**-270,000**

* Assumes no mid-year BPP change

Figure 6-1 schematically illustrates the various overdraft levels discussed above in relation to one another; namely, the new full benchmark, the optimal overdraft target of 100,000 af, and the lower limit of the operating range at 500,000 af accumulated overdraft.

Figure 6-1. Strategic Basin Operating Levels and Optimal Target



6.2 Basin Management Operational Strategy

The primary "tool" for managing the basin is the Basin Production Percentage (BPP). Each year in April, the District's Board of Directors sets the BPP for the upcoming water year. In addition to purchasing replenishment water, adjusting the BPP allows the District to effectively increase or decrease basin storage. Figure 6-2 shows the formula used to calculate the BPP each year. Only the two terms highlighted in blue and red in the BPP formula are adjustable at the District's discretion, namely the planned amount of recharge (including replenishment water purchases) and the planned amount of basin refill or storage decrease for the coming year.

The amount of recharge planned and budgeted for the coming year may be limited by factors outside the District's control, such as the availability of imported water for either direct replenishment or In-Lieu. For example, following statewide wet years, MWD may

offer incentives (financial or otherwise) for local water agencies to take additional amounts of surplus imported water, whereas during a long-term statewide drought the surplus imported water may simply not be available.

Figure 6-2. BPP Formula

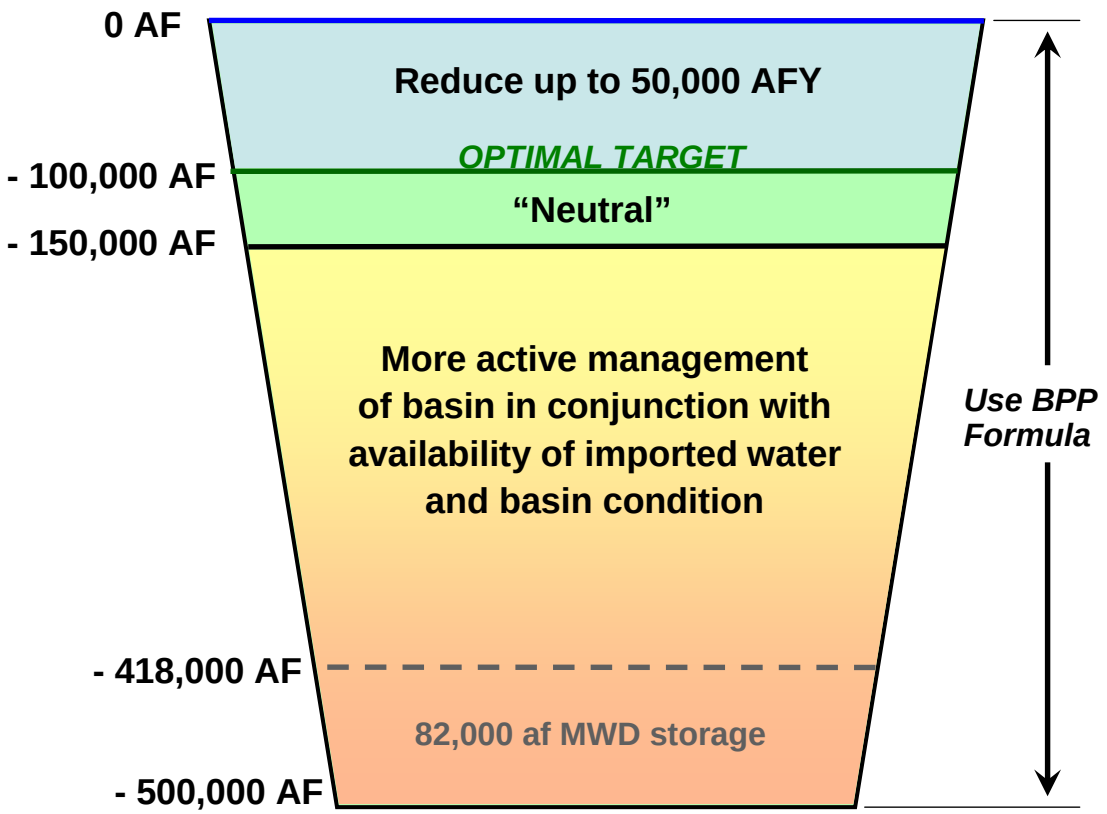
$$\text{BPP} = \frac{\text{Water Recharged} - \text{Basin Refill or Decrease} - \text{Water Quality Improvement Projects (Pumping Above BPP)}}{\text{Last Calendar Year's Total Water Demand} - \text{Reclaimed \& Local Supplies}}$$

The planned amount of basin refill or storage decrease for the coming year is within the District's control but is also considered within the context of financial impacts to both the District and the groundwater producers. Therefore, unless the basin is near the bottom of the acceptable operating range or close to being full, a moderate amount of basin refill or decrease would typically be proposed that aims to move toward the optimal overdraft target. If the basin is already at or near the 100,000 af overdraft target, then a neutral stance can be taken that attempts to balance basin production and recharge with no planned storage change.

Figure 6-3 schematically illustrates the generalized basin refill or storage decrease strategy based on the accumulated overdraft. When the basin is higher than the optimal overdraft target and nearly full, the amount of planned storage decrease of up to 50,000 af for the coming year may be recommended. This may be accomplished by a combination of raising the BPP and reducing replenishment purchases.

The proposed operational strategy illustrated in Figure 6-3 provides a flexible guideline to assist in determining the amount of basin refill or storage decrease for the coming water year based on using the BPP formula and considering storage goals based on current basin conditions and other factors such as water availability. This strategy is not intended to dictate a specific basin refill or storage decrease amount for a given storage condition but to provide a general guideline for the District's Board of Directors.

Figure 6-3. Basin Management Operational Strategy



7. FINDINGS

Findings of this study are enumerated below.

1. The new three-layer storage change approach is technically feasible and provides a more accurate assessment than the traditional single-layer storage change method.

2. Using the new three-layer method, the majority of the storage change occurs in the Forebay area of the basin within the unconfined Shallow aquifer where rising or falling of the water table fills or drains empty pore space.

3. Accuracy of the storage change and accumulated overdraft estimates is dependent upon good spatial distribution of water level measurements as well as the storage coefficient values used in the calculations. Water level data for the Shallow aquifer were relatively sparse in outlying Forebay areas of the basin, leading to some uncertainty in preparing groundwater elevation contours in those areas.

4. 1969 no longer represents a truly full-basin benchmark. A new full-basin water level condition was developed based on the following prescribed conditions:

    - Observed historical high water levels
    - Present-day pumping and recharge conditions
    - Protective of seawater intrusion
    - Minimal potential for mounding at or near recharge basins

    The new full-basin water levels in the Forebay area are essentially at or very near the bottom of the District's deep percolation basins (e.g., Anaheim Lake). Historical water level data from 1994 have shown that this condition is achievable without detrimental effects. Water levels slightly higher than this new full condition may be physically achievable in the Forebay area but not recommended due to the likelihood of groundwater mounding and reduced percolation in recharge basins.

5. Using the new three-layer storage change calculation in conjunction with the new full benchmark and June 2006 water levels, an accumulated overdraft of 135,000 af was calculated representing June 30, 2006. Similarly, using the new three-layer method to compare the new full water levels to those of June 2005, an accumulated overdraft of 201,000 af was calculated representing June 30, 2005. Subtracting the June 2006 accumulated overdraft from that of June 2005 yielded an annual storage increase of 66,000 af for WY 2005-06.

6. Comparing the current year's water level conditions to the full basin benchmark each successive year for calculating the basin storage will eliminate the potential for cumulative discrepancies over several years.

7. An accumulated overdraft of 500,000 af represents the lowest acceptable limit of the basin's operating range. This lower limit of 500,000 af assumes that stored MWD water (CUP and Super In-Lieu) has already been removed and is only acceptable for short durations due to drought conditions. It is not recommended to manage the basin for sustained periods at this lower limit for the following reasons:

    - Seawater intrusion likely
    - Drought supply depleted
    - Pumping levels detrimental to a handful of wells
    - Increased pumping lifts and electrical costs
    - Increased potential for color upwelling from the Deep aquifer

8. An optimal basin management target of 100,000 af of accumulated overdraft provides sufficient storage space to accommodate increased supplies from one wet year while also providing enough water in storage to offset decreased supplies during a two- to three-year drought.

9. The proposed operational strategy provides a flexible guideline to assist in determining the amount of basin refill or storage decrease for the coming water year based on using the BPP formula and considering storage goals based on current basin conditions and other factors such as water availability. This strategy is not intended to dictate a specific basin refill or storage decrease amount for a given storage condition but to provide a general guideline for the District's Board of Directors.

8. RECOMMENDATIONS

Based on the findings of this study are the following recommendations:

1. Adopt the new three-layer storage change methodology along with the associated new full-basin condition that will serve as a benchmark for calculating the basin accumulated overdraft.

2. Adopt the proposed basin operating strategy including a basin operating range spanning the new full condition to an accumulated overdraft of 500,000 af, and an optimal overdraft target of 100,000 af.

3. Include in the 2007-08 CIP budget the installation of six Shallow aquifer monitoring wells to increase accuracy of the three-layer storage change calculation.

9. BIBLIOGRAPHY

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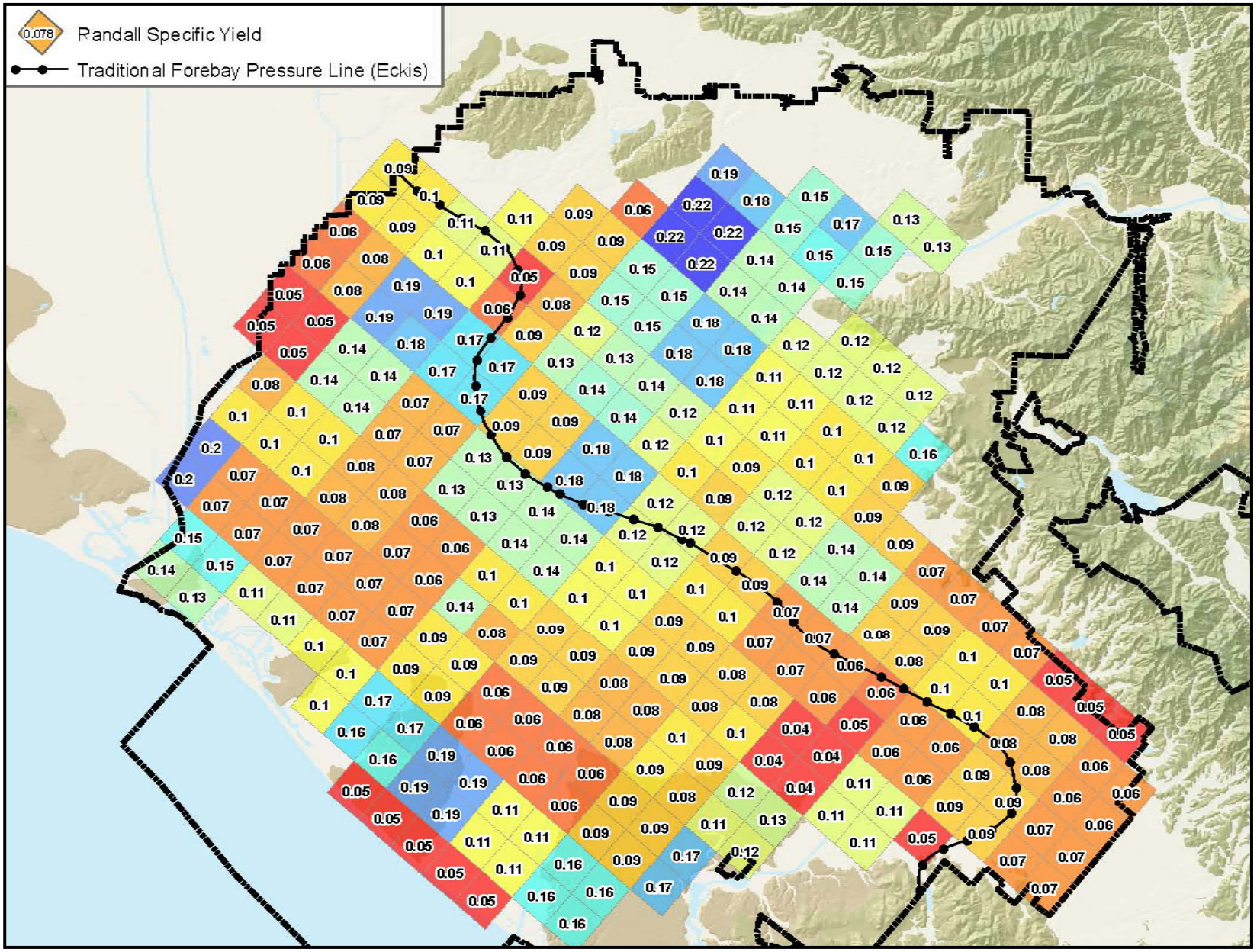
APPENDIX 1

“Randall” Specific Yield Values

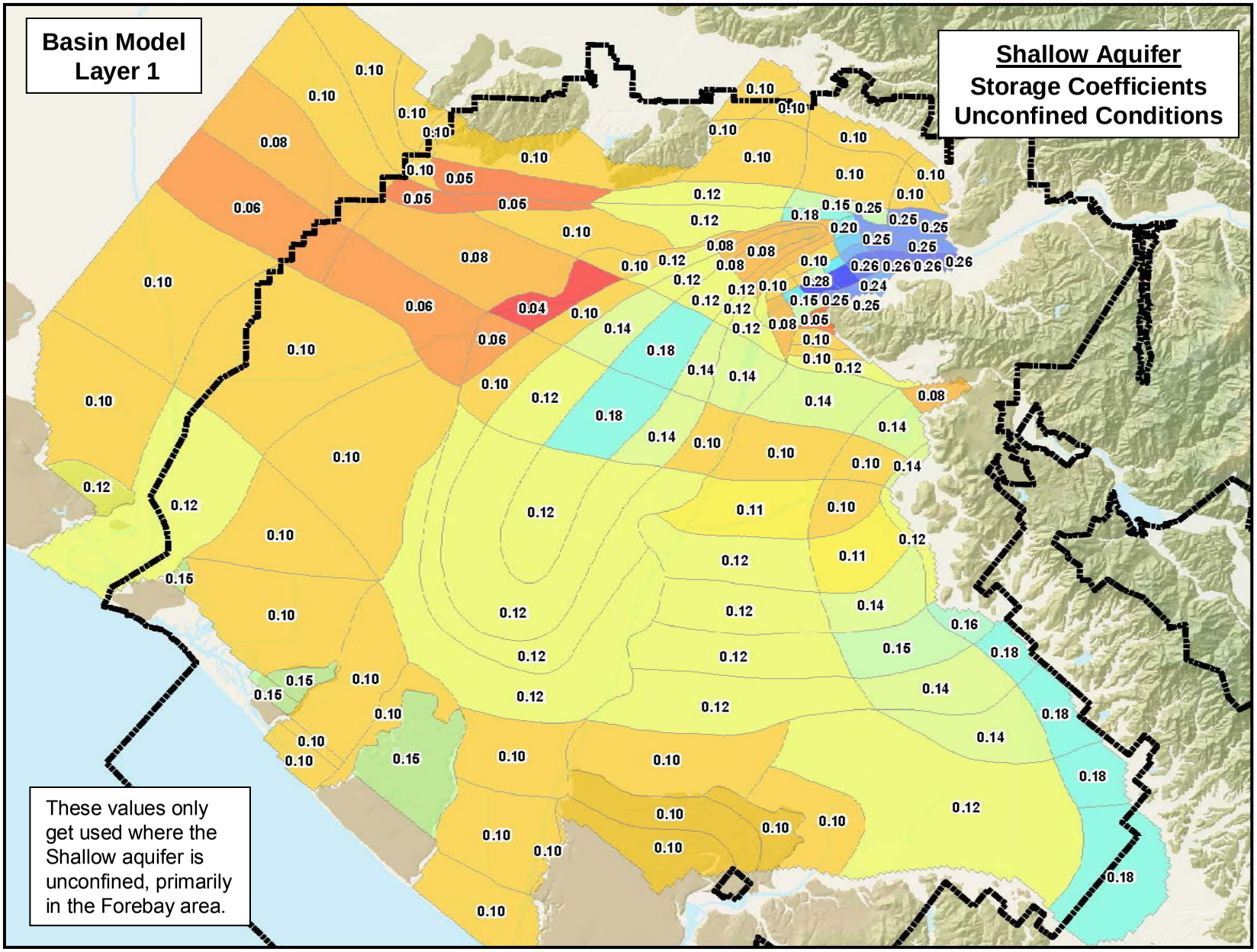
From Traditional Storage Change Method

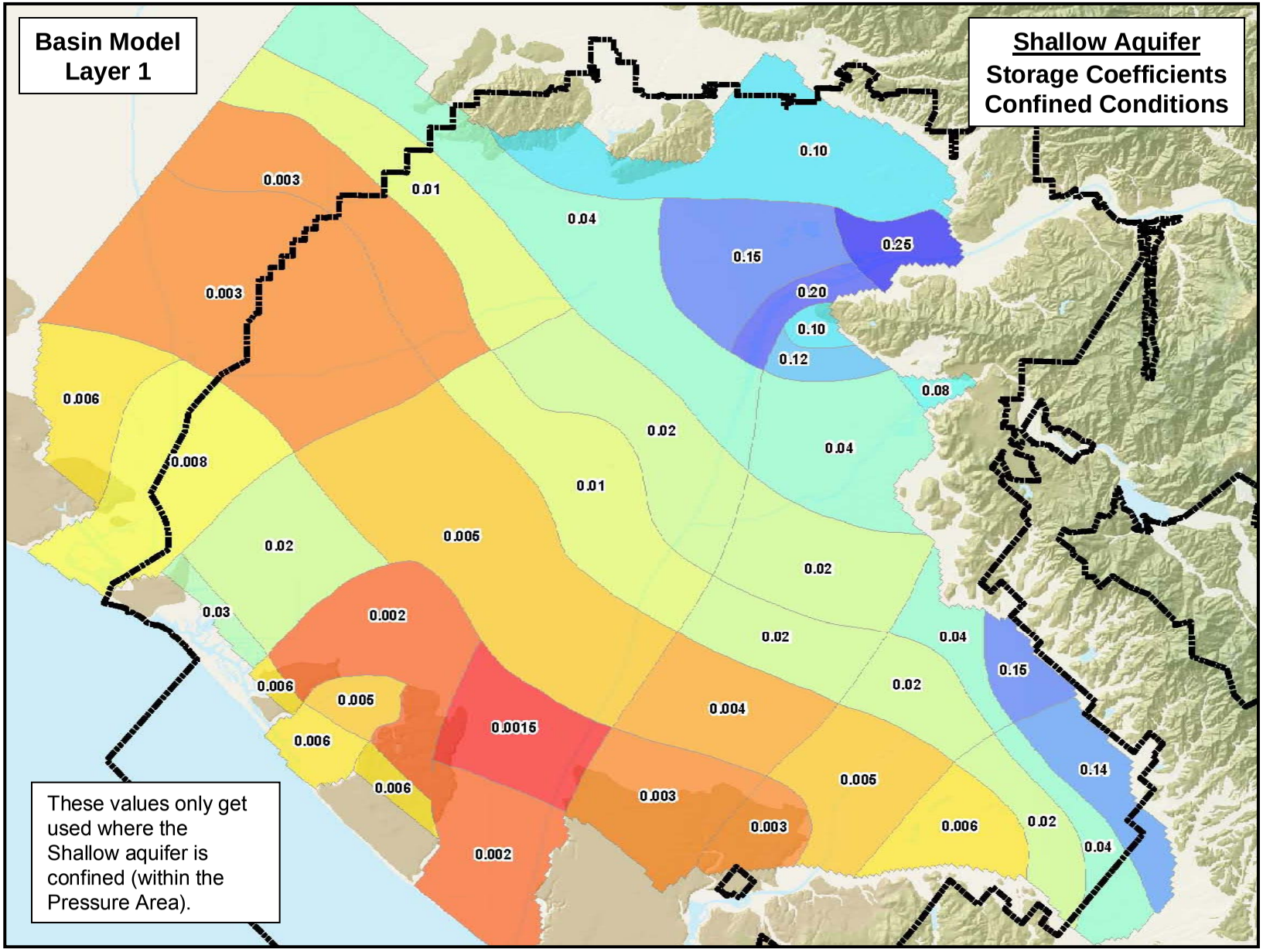

0.078
Randall Specific Yield
Traditional Forebay Pressure Line (Eckis)

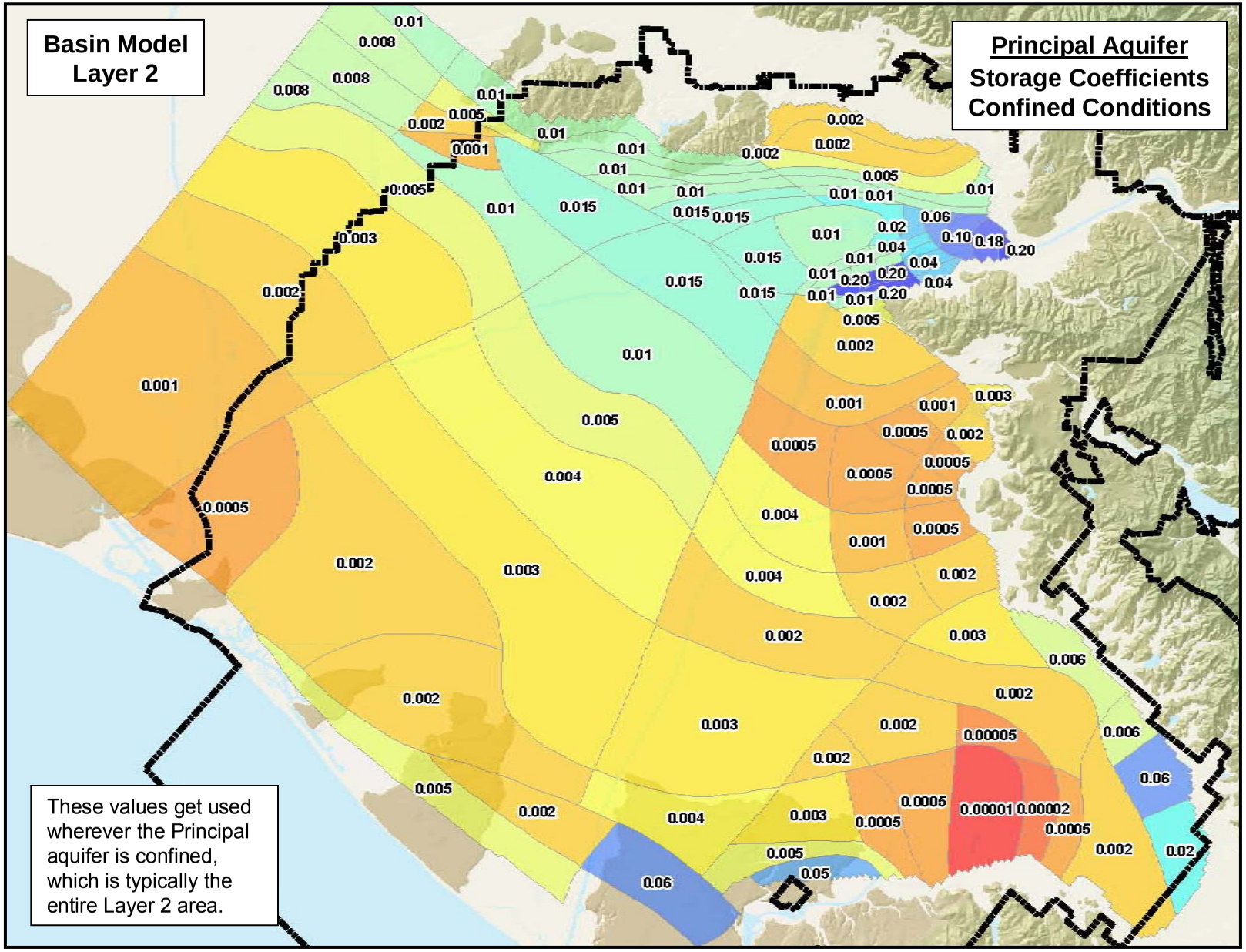
APPENDIX 2

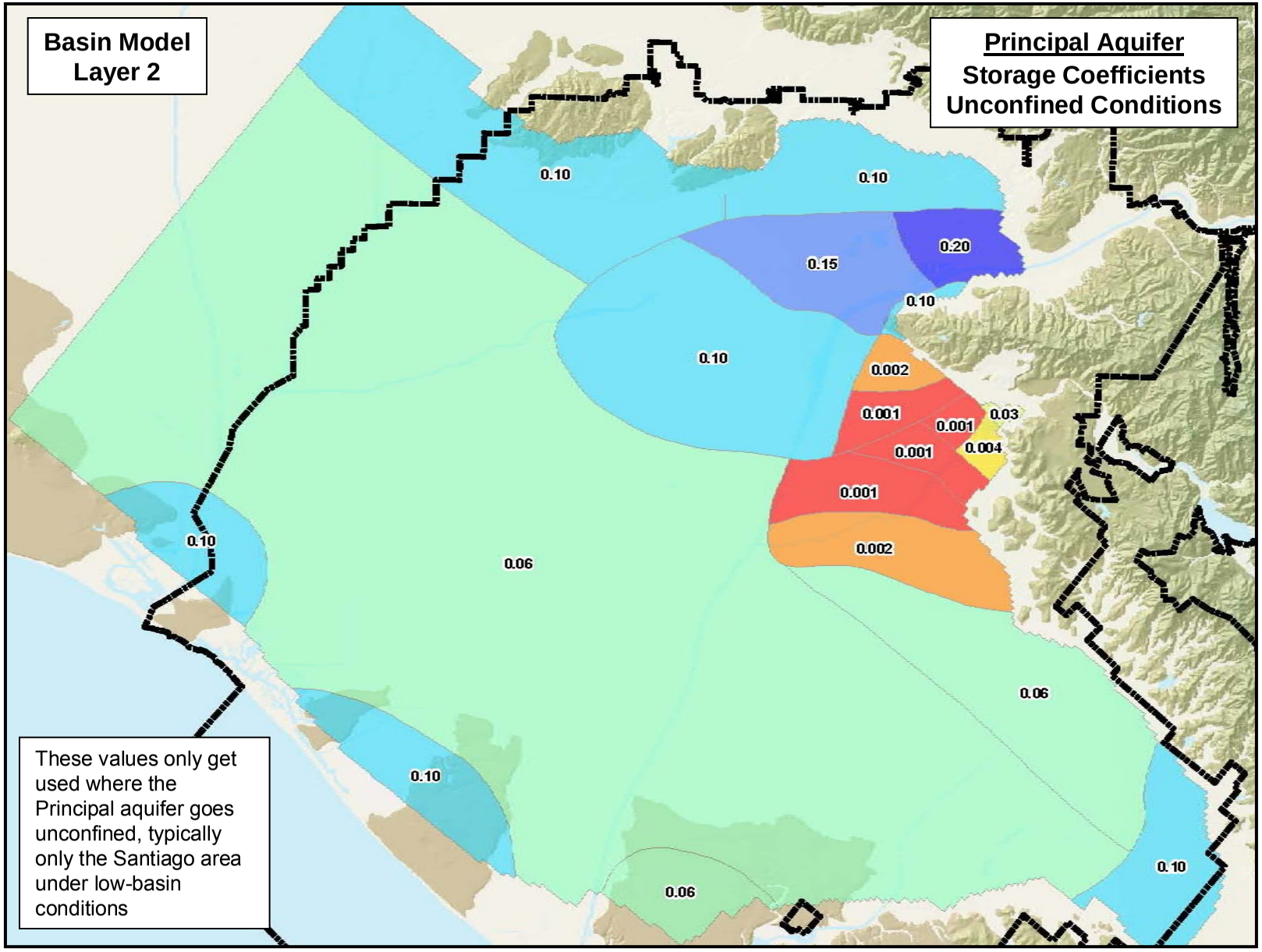
Basin Model Storage Coefficient Values

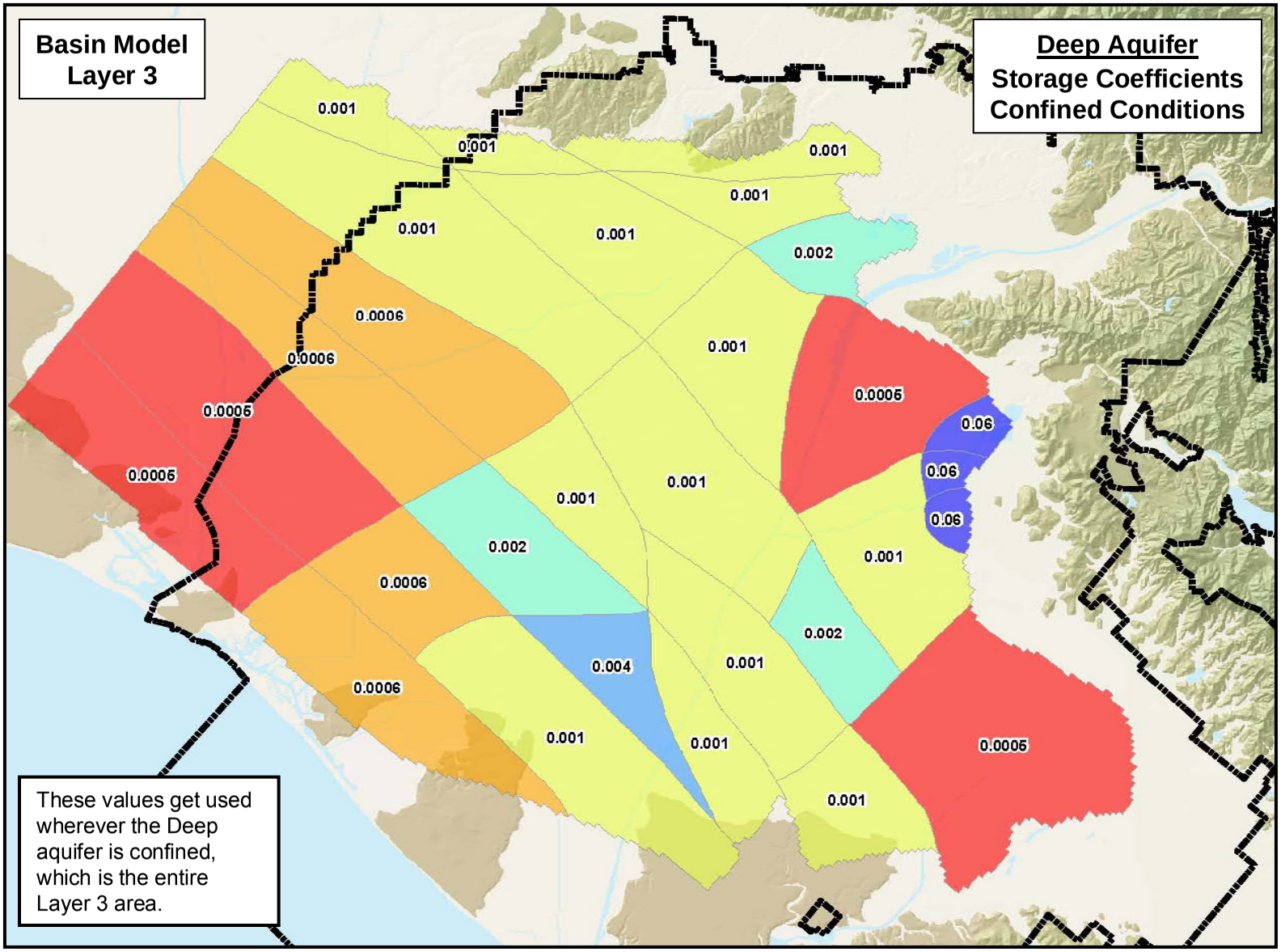
For Three-Layer Storage Change Method

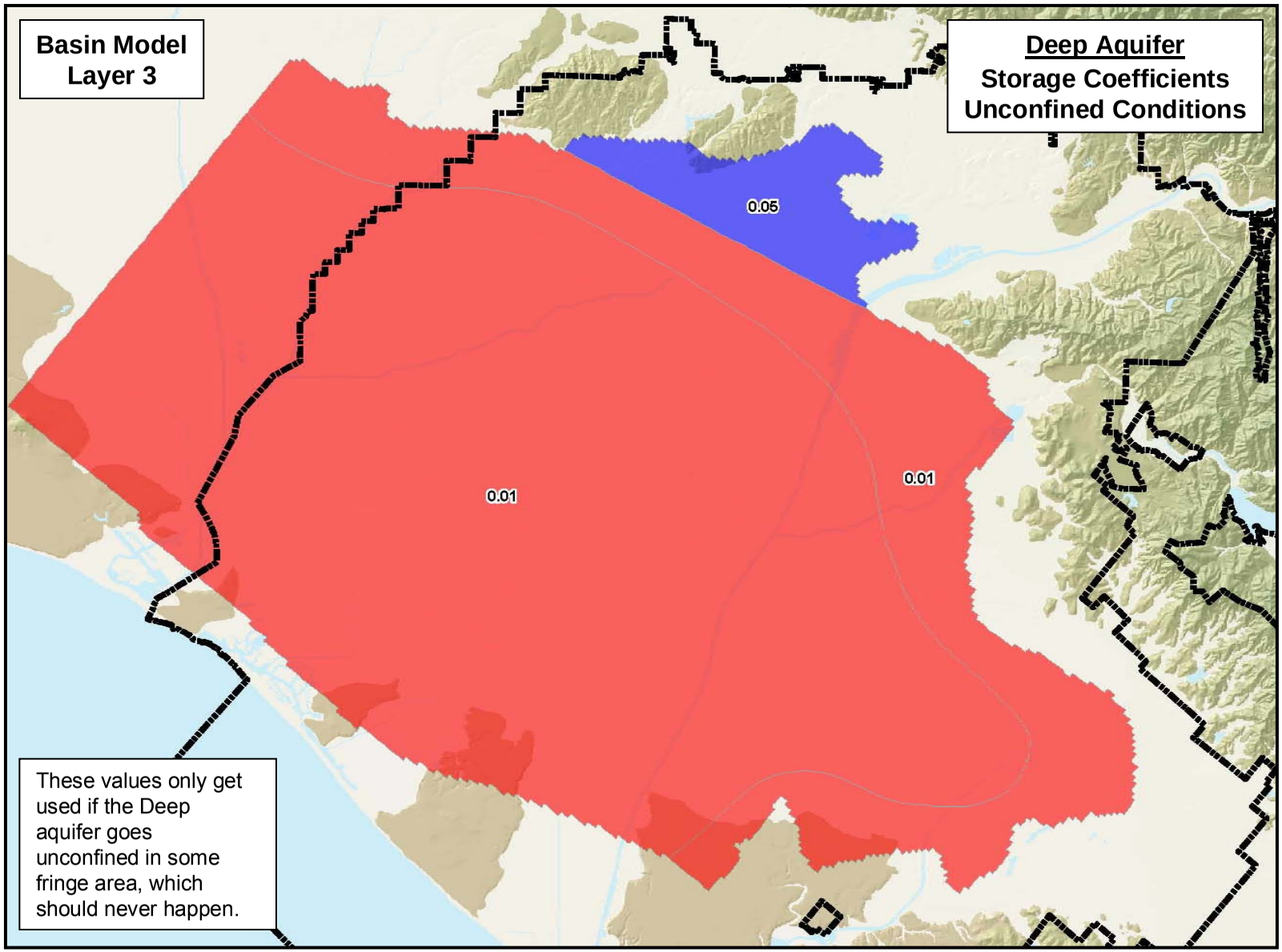

Basin Model
Layer 1
Shallow Aquifer
Storage Coefficients
Unconfined Conditions
These values only get used where the Shallow aquifer is unconfined, primarily in the Forebay area.


Basin Model
Layer 1
Shallow Aquifer
Storage Coefficients
Confined Conditions
0.10
0.003
0.01
0.04
0.15
0.25
0.003
0.20
0.10
0.12
0.08
0.006
0.02
0.04
0.008
0.01
0.02
0.005
0.02
0.03
0.002
0.02
0.04
0.15
0.006
0.005
0.02
0.004
0.0015
0.006
0.14
0.006
0.003
0.005
0.003
0.006
0.02
0.002
0.04
These values only get used where the Shallow aquifer is confined (within the Pressure Area).


Basin Model
Layer 2
Principal Aquifer
Storage Coefficients
Confined Conditions
These values get used wherever the Principal aquifer is confined, which is typically the entire Layer 2 area.


Basin Model
Layer 2
Principal Aquifer
Storage Coefficients
Unconfined Conditions
0.10
0.10
0.20
0.15
0.10
0.10
0.002
0.001
0.03
0.001
0.004
0.001
0.001
0.002
0.10
0.06
0.06
0.10
0.06
0.10
These values only get used where the Principal aquifer goes unconfined, typically only the Santiago area under low-basin conditions

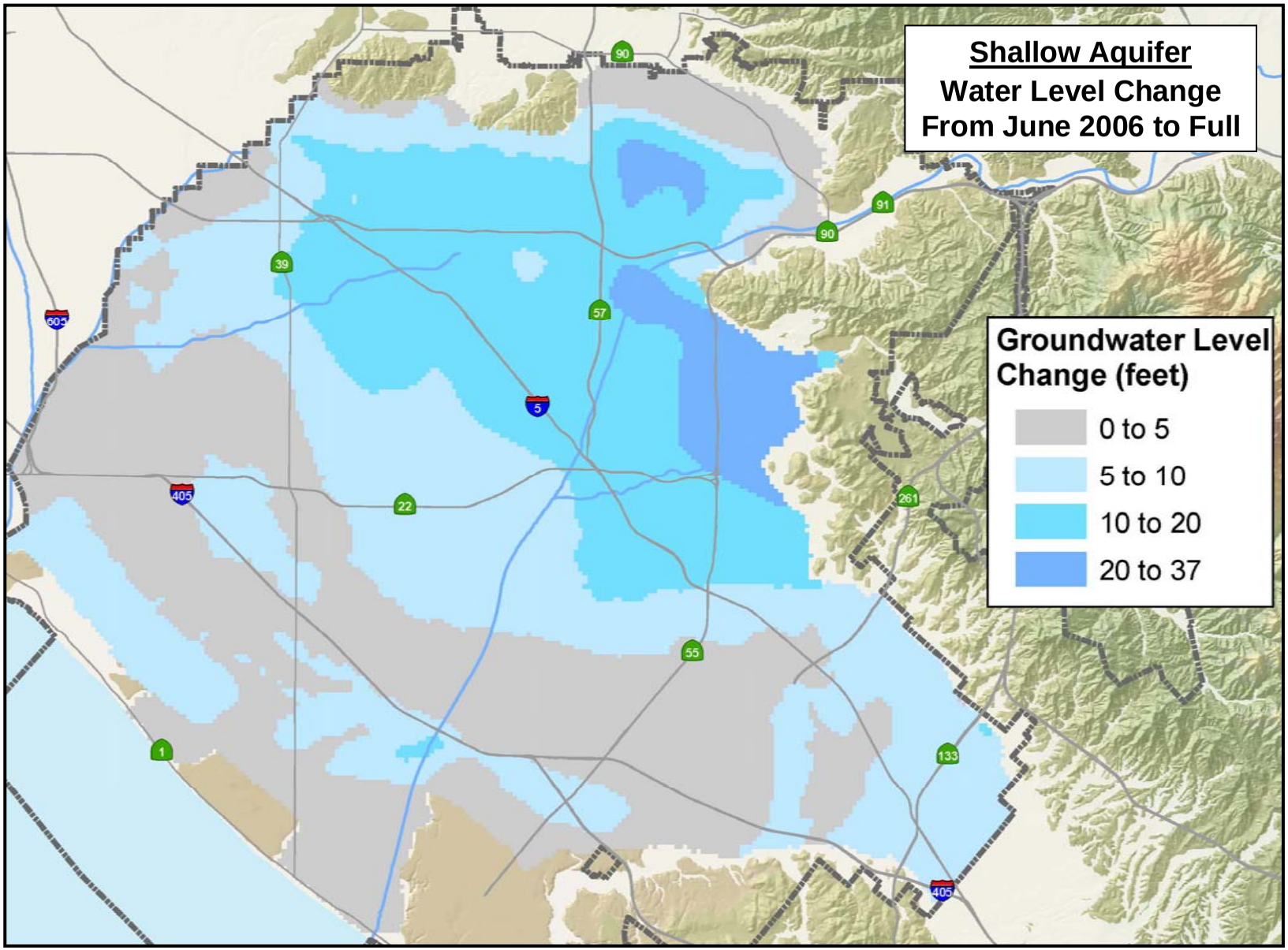

Basin Model
Layer 3
Deep Aquifer
Storage Coefficients
Confined Conditions
0.001
0.001
0.001
0.001
0.001
0.002
0.0006
0.0006
0.001
0.0006
0.0006
0.0006
0.06
0.06
0.06
0.001
0.001
0.002
0.001
0.0006
0.002
0.004
0.001
0.0006
0.001
0.001
0.0006
0.001
These values get used wherever the Deep aquifer is confined, which is the entire Layer 3 area.

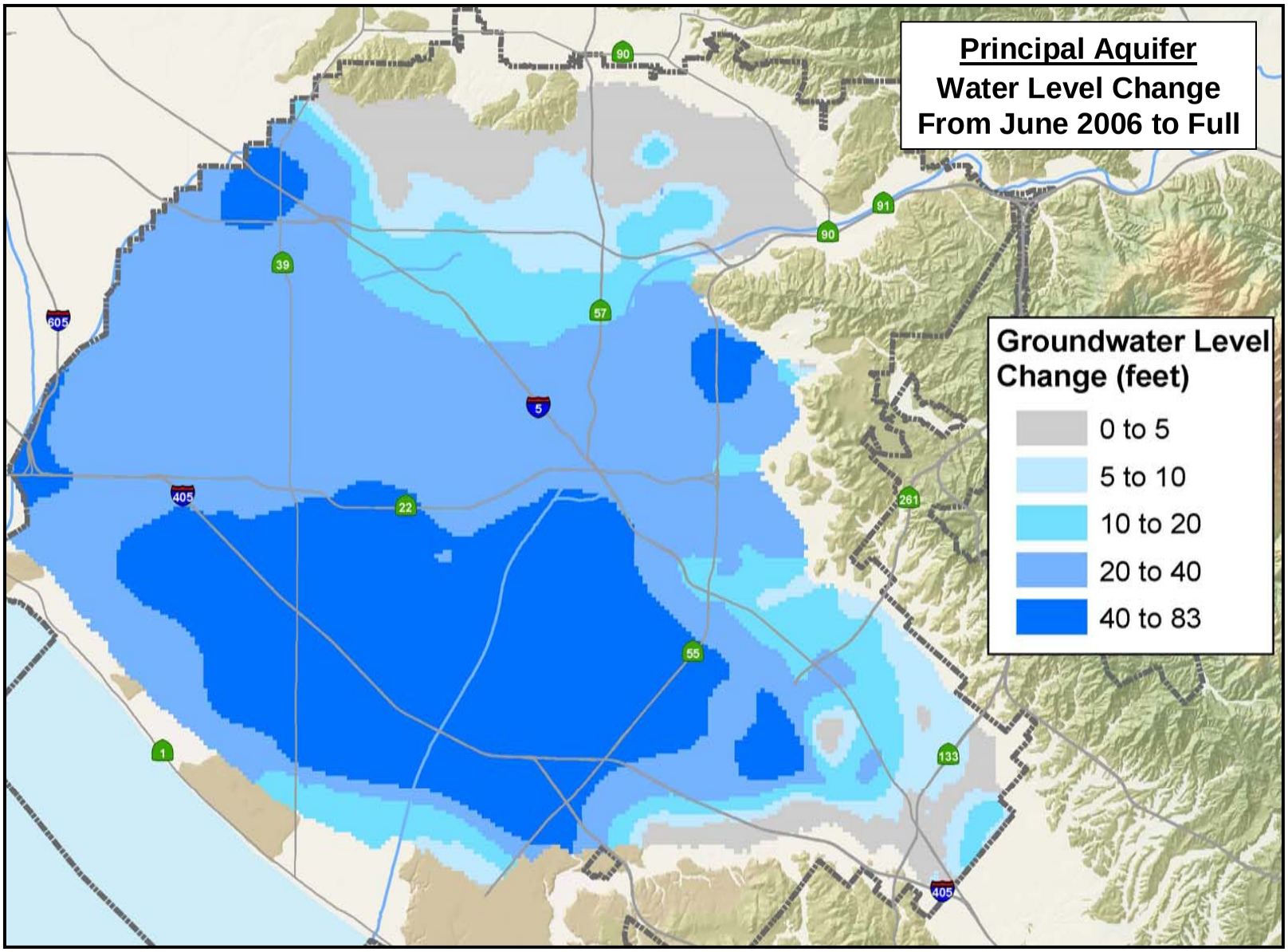

Basin Model
Layer 3
Deep Aquifer
Storage Coefficients
Unconfined Conditions
0.05
0.01
0.01
These values only get used if the Deep aquifer goes unconfined in some fringe area, which should never happen.

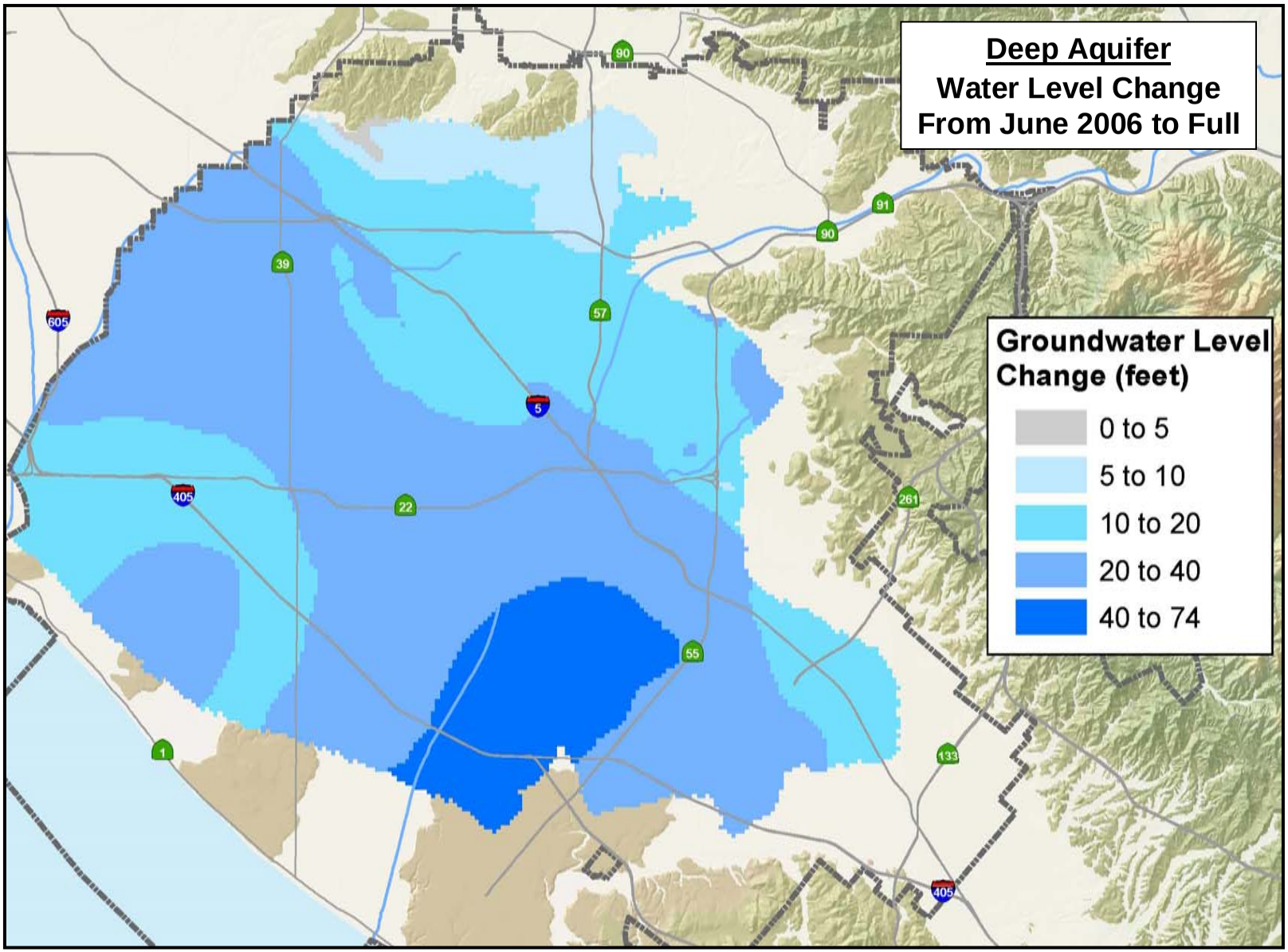
APPENDIX 3

Water Level Change Maps

For June 2006 to the New Full Condition


Shallow Aquifer
Water Level Change
From June 2006 to Full
Groundwater Level Change (feet)
0 to 5
5 to 10
10 to 20
20 to 37
90
91
90
39
57
605
5
405
22
261
55
1
133
405


Principal Aquifer
Water Level Change
From June 2006 to Full
Groundwater Level Change (feet)
0 to 5
5 to 10
10 to 20
20 to 40
40 to 83
90
91
39
57
605
5
405
22
261
55
1
133


Deep Aquifer
Water Level Change
From June 2006 to Full
Groundwater Level Change (feet)
0 to 5
5 to 10
10 to 20
20 to 40
40 to 74
90
91
39
57
605
5
405
22
261
55
1
133

APPENDIX E

OCWD MONITORING WELLS

APPENDIX E - OCWD ACTIVE GROUNDWATER MONITORING WELLS
(Excluding Westbay Multiport Wells)

Well Name	Well Type	Casing Sequence No.	Cased Depth (ft.)	Top Perforation (ft.)	Bottom Perforation (ft.)
ABS-2	SINGLE CASING	1	175	155	165
AM-1	SINGLE CASING	1	137	97	115
AM-2	SINGLE CASING	1	156	87	100
AM-3	SINGLE CASING	1	112	91	107
AM-4	SINGLE CASING	1	296	187	205
AM-5	SINGLE CASING	1	247	230	245
AM-5A	SINGLE CASING	1	180	168	175
AM-6	SINGLE CASING	1	296	232	250
AM-7	SINGLE CASING	1	297	210	225
AM-8	SINGLE CASING	1	297	268	285
AM-9	SINGLE CASING	1	317	285	303
AM-10	SINGLE CASING	1	298	217	235
AM-11	SINGLE CASING	1	276	218	240
AM-12	SINGLE CASING	1	294	210	225
AM-13	SINGLE CASING	1	275	252	270
AM-14	SINGLE CASING	1	317	297	315
AM-15	SINGLE CASING	1	318	300	317
AM-15A	SINGLE CASING	1	231	214	220
AM-16	SINGLE CASING	1	320	300	315
AM-16A	SINGLE CASING	1	227	215	222
AM-17	SINGLE CASING	1	318	290	308
AM-18	SINGLE CASING	1	316	291	309
AM-18A	SINGLE CASING	1	234	208	215
AM-19	SINGLE CASING	1	237	217	225
AM-19A	SINGLE CASING	1	126	115	123
AM-20	SINGLE CASING	1	397	361	379
AM-20A	SINGLE CASING	1	268	250	258
AM-21	SINGLE CASING	1	269	250	258
AM-21A	SINGLE CASING	1	179	157	165
AM-22	SINGLE CASING	1	356	339	353
AM-22A	SINGLE CASING	1	239	216	224
AM-23	SINGLE CASING	1	351	330	347
AM-24	SINGLE CASING	1	378	335	350
AM-24A	SINGLE CASING	1	306	279	294
AM-25	SINGLE CASING	1	362	340	358
AM-25A	SINGLE CASING	1	219	188	195
AM-26	SINGLE CASING	1	388	377	383
AM-27	SINGLE CASING	1	336	287	305
AM-28	SINGLE CASING	1	398	358	376
AM-29	SINGLE CASING	1	367	340	358
AM-29A	SINGLE CASING	1	95	75	95
AM-30	SINGLE CASING	1	375	349	367
AM-30A	SINGLE CASING	1	398	152	159
AM-31	SINGLE CASING	1	358	335	353
AM-31A	SINGLE CASING	1	360	162	170
AM-32	SINGLE CASING	1	398	335	353
AM-33	SINGLE CASING	1	378	354	372
AM-33A	SINGLE CASING	1	238	206	221
AM-34	SINGLE CASING	1	354	317	335
AM-34A	SINGLE CASING	1	271	252	260
AM-35	SINGLE CASING	1	400	332	350

NA: Not Available

APPENDIX E - OCWD ACTIVE GROUNDWATER MONITORING WELLS
(Excluding Westbay Multiport Wells)

Well Name	Well Type	Casing Sequence No.	Cased Depth (ft.)	Top Perforation (ft.)	Bottom Perforation (ft.)
AM-36	SINGLE CASING	1	398	369	387
AM-37	SINGLE CASING	1	378	349	367
AM-38	SINGLE CASING	1	358	316	334
AM-39	SINGLE CASING	1	188	168	188
AM-39A	SINGLE CASING	1	135	115	135
AM-40	SINGLE CASING	1	191	175	190
AM-40A	SINGLE CASING	1	166	145	165
AM-41	SINGLE CASING	1	200	190	200
AM-41A	SINGLE CASING	1	166	156	166
AM-42	SINGLE CASING	1	190	180	190
AM-42A	SINGLE CASING	1	130	115	130
AM-43	SINGLE CASING	1	100	80	100
AM-44	SINGLE CASING	1	160	140	160
AM-44A	SINGLE CASING	1	88	78	88
AM-45	SINGLE CASING	1	132	102	132
AM-46	SINGLE CASING	1	124	94	124
AM-47	SINGLE CASING	1	247	227	242
AM-47A	SINGLE CASING	1	170	160	170
AM-48	SINGLE CASING	1	305	270	300
AM-48A	SINGLE CASING	1	151	116	146
AM-49	SINGLE CASING	1	155	120	150
AMD-9	NESTED	1	230	200	220
AMD-9	NESTED	2	480	450	470
AMD-9	NESTED	3	610	580	600
AMD-9	NESTED	4	926	896	916
AMD-10	NESTED	1	322	292	312
AMD-10	NESTED	2	470	440	460
AMD-10	NESTED	3	580	550	570
AMD-10	NESTED	4	804	774	794
AMD-10	NESTED	5	964	934	954
AMD-11	NESTED	1	328	298	318
AMD-11	NESTED	2	426	396	416
AMD-11	NESTED	3	630	600	620
AMD-11	NESTED	4	716	686	706
AMD-11	NESTED	5	936	906	926
AMD-12	NESTED	1	360	330	350
AMD-12	NESTED	2	530	490	520
AMD-12	NESTED	3	625	595	615
AMD-12	NESTED	4	755	725	745
AMD-12	NESTED	5	970	940	960
FM-1	SINGLE CASING	1	359	348	356
FM-1A	SINGLE CASING	1	197	164	172
FM-2	SINGLE CASING	1	352	320	338
FM-2A	SINGLE CASING	1	237	226	234
FM-3	SINGLE CASING	1	298	257	263
FM-4	SINGLE CASING	1	355	327	345
FM-4A	SINGLE CASING	1	170	142	160
FM-5	SINGLE CASING	1	141	121	141
FM-6	SINGLE CASING	1	320	150	310
FM-7	SINGLE CASING	1	197	187	197
FM-7A	SINGLE CASING	1	170	160	170

NA: Not Available

APPENDIX E - OCWD ACTIVE GROUNDWATER MONITORING WELLS
(Excluding Westbay Multiport Wells)

Well Name	Well Type	Casing Sequence No.	Cased Depth (ft.)	Top Perforation (ft.)	Bottom Perforation (ft.)
FM-8	SINGLE CASING	1	139	114	134
FM-9	SINGLE CASING	1	245	220	240
FM-9A	SINGLE CASING	1	191	166	186
FM-10	SINGLE CASING	1	240	215	235
FM-10A	SINGLE CASING	1	176	151	171
FM-11	SINGLE CASING	1	261	236	256
FM-11A	SINGLE CASING	1	159	134	154
FM-12	SINGLE CASING	1	231	206	226
FM-12A	SINGLE CASING	1	160	135	155
FM-13	SINGLE CASING	1	235	210	230
FM-13A	SINGLE CASING	1	165	140	160
FM-14	SINGLE CASING	1	259	234	254
FM-14A	SINGLE CASING	1	172	147	167
FM-15	SINGLE CASING	1	243	218	238
FM-15A	SINGLE CASING	1	145	120	140
FM-16	SINGLE CASING	1	273	248	268
FM-16A	SINGLE CASING	1	150	125	145
FM-17	SINGLE CASING	1	275	250	270
FM-18	SINGLE CASING	1	254	224	244
FM-18A	SINGLE CASING	1	156	121	151
FM-19A	SINGLE CASING	1	140	115	135
FM-19B	SINGLE CASING	1	265	230	260
FM-19C	SINGLE CASING	1	390	365	385
FM-20	SINGLE CASING	1	246	221	241
FM-20A	SINGLE CASING	1	155	130	150
FM-21	SINGLE CASING	1	275	260	270
FM-21A	SINGLE CASING	1	165	140	160
FM-22	SINGLE CASING	1	267	242	265
FM-22A	SINGLE CASING	1	175	150	170
FM-23	SINGLE CASING	1	253	234	249
FM-23A	SINGLE CASING	1	149	128	143
FM-24	SINGLE CASING	1	295	271	291
FM-24A	SINGLE CASING	1	184	154	174
FM-25	SINGLE CASING	1	152	132	152
FM-26	SINGLE CASING	1	155	145	155
FM-27	SINGLE CASING	1	125	105	125
IDM-3	NESTED	1	214	174	194
IDM-3	NESTED	2	330	290	310
IDM-3	NESTED	3	682	652	672
IDM-4	NESTED	1	166	136	156
IDM-4	NESTED	2	302	272	292
IDM-4	NESTED	3	684	654	674
IDP-2R	NESTED	1	205	155	195
IDP-2R	NESTED	2	350	300	340
IDP-3	SINGLE CASING	1	525	125	505
IDP-4	SINGLE CASING	1	430	125	410
KBS-1	SINGLE CASING	1	230	209	219
KBS-3	SINGLE CASING	1	90	80	90
KBS-4	SINGLE CASING	1	158	138	158
KBS-4A	SINGLE CASING	1	90	80	90
MCAS-4	SINGLE CASING	1	275	181	238

NA: Not Available

APPENDIX E - OCWD ACTIVE GROUNDWATER MONITORING WELLS
(Excluding Westbay Multiport Wells)

Well Name	Well Type	Casing Sequence No.	Cased Depth (ft.)	Top Perforation (ft.)	Bottom Perforation (ft.)
MCAS-5A	SINGLE CASING	1	133	120	130
MCAS-6	SINGLE CASING	1	285	167	222
MCAS-8	SINGLE CASING	1	435	392	410
MCAS-9	SINGLE CASING	1	450	372	445
MCAS-10	SINGLE CASING	1	389	347	377
MSP-10P	SINGLE CASING	1	50	40	50
MSP-10T	SINGLE CASING	1	140	70	140
OCWD-7	SINGLE CASING	1	48	28	48
OCWD-33Z11	NESTED	1	384	338	379
OCWD-33Z11	NESTED	2	490	435	485
OCWD-34F10	NESTED	1	231	215	225
OCWD-34F10	NESTED	2	291	270	285
OCWD-34F10	NESTED	3	346	315	340
OCWD-34F10	NESTED	4	465	420	460
OCWD-34H25	NESTED	1	356	300	350
OCWD-34H25	NESTED	2	470	410	465
OCWD-34H5	NESTED	1	360	300	340
OCWD-34H5	NESTED	2	475	405	455
OCWD-34L10	NESTED	1	191	165	185
OCWD-34L10	NESTED	2	266	225	260
OCWD-34L10	NESTED	3	371	311	365
OCWD-34L10	NESTED	4	455	405	450
OCWD-34N21	NESTED	1	NA	329	366
OCWD-34N21	NESTED	2	NA	424	464
OCWD-34U8	NESTED	1	180	149	174
OCWD-34U8	NESTED	2	240	224	234
OCWD-34U8	NESTED	3	325	279	319
OCWD-34U8	NESTED	4	389	359	384
OCWD-34V20	NESTED	1	313	235	307
OCWD-34V20	NESTED	2	422	387	417
OCWD-35F20	NESTED	1	NA	70	95
OCWD-35F20	NESTED	2	NA	115	125
OCWD-35F20	NESTED	3	NA	145	180
OCWD-35F20	NESTED	4	NA	235	265
OCWD-35H11	NESTED	1	225	200	220
OCWD-35H11	NESTED	2	163	125	158
OCWD-35H11	NESTED	3	82	44	77
OCWD-35H12	SINGLE CASING	1	159	137	147
OCWD-35J1	NESTED	1	260	190	240
OCWD-35J1	NESTED	2	190	130	170
OCWD-35K1	NESTED	1	263	193	243
OCWD-35K1	NESTED	2	190	130	170
OCWD-35N01	NESTED	1	90	80	85
OCWD-35N01	NESTED	2	80	39	79
OCWD-35T9	SINGLE CASING	1	432	390	411
OCWD-36FP1Z	SINGLE CASING	1	NA	504	514
OCWD-36FP14Z1	SINGLE CASING	1	135	115	125
OCWD-AIR1	NESTED	1	255	200	250
OCWD-AIR1	NESTED	2	515	410	510
OCWD-AIR1	NESTED	3	855	675	850
OCWD-AIR1	NESTED	4	1485	1375	1460

NA: Not Available

APPENDIX E - OCWD ACTIVE GROUNDWATER MONITORING WELLS
(Excluding Westbay Multiport Wells)

Well Name	Well Type	Casing Sequence No.	Cased Depth (ft.)	Top Perforation (ft.)	Bottom Perforation (ft.)
OCWD-AN1	SINGLE CASING	1	115	35	115
OCWD-AN2	SINGLE CASING	1	115	35	115
OCWD-BP1	SINGLE CASING	1	40	20	40
OCWD-BP2	SINGLE CASING	1	70	50	70
OCWD-BP3	SINGLE CASING	1	205	185	205
OCWD-BP4	SINGLE CASING	1	180	140	180
OCWD-BP5	NESTED	1	75	55	75
OCWD-BP5	NESTED	2	167	147	167
OCWD-BP6	SINGLE CASING	1	168	148	168
OCWD-BP7	NESTED	1	57	47	57
OCWD-BP7	NESTED	2	168	148	168
OCWD-BS15	SINGLE CASING	1	75	60	70
OCWD-BS16	SINGLE CASING	1	85	60	80
OCWD-BS18	SINGLE CASING	1	87	72	82
OCWD-BS19	SINGLE CASING	1	88	63	83
OCWD-CTG1	NESTED	1	265	160	260
OCWD-CTG1	NESTED	2	725	420	720
OCWD-CTG1	NESTED	3	1025	800	1025
OCWD-CTG1	NESTED	4	1225	1060	1220
OCWD-CTG5	NESTED	1	620	420	620
OCWD-CTG5	NESTED	2	1000	880	1000
OCWD-CTG5	NESTED	3	1120	1040	1120
OCWD-CTK1	NESTED	1	660	410	655
OCWD-CTK1	NESTED	2	1020	780	1015
OCWD-CTK1	NESTED	3	1320	1260	1315
OCWD-FBM1	SINGLE CASING	1	140	38	138
OCWD-FBM2	SINGLE CASING	1	140	39	139
OCWD-FC1	SINGLE CASING	1	185	165	185
OCWD-FC2	SINGLE CASING	1	115	95	115
OCWD-FH1	SINGLE CASING	1	140	120	140
OCWD-GA1	SINGLE CASING	1	40	30	40
OCWD-GA2	SINGLE CASING	1	40	30	40
OCWD-GA3	SINGLE CASING	1	40	30	40
OCWD-GA4	SINGLE CASING	1	40	30	40
OCWD-GA5	SINGLE CASING	1	40	30	40
OCWD-GA6	SINGLE CASING	1	40	30	40
OCWD-GA7	SINGLE CASING	1	40	30	40
OCWD-GA9	SINGLE CASING	1	29	19	29
OCWD-I27M1	SINGLE CASING	1	22	17	22
OCWD-I28M1	SINGLE CASING	1	24	19	24
OCWD-KB1	SINGLE CASING	1	200	180	200
OCWD-KR2	SINGLE CASING	1	394	NA	NA
OCWD-LB1	NESTED	1	35	25	35
OCWD-LB1	NESTED	2	168	148	168
OCWD-LB2	SINGLE CASING	1	30	15	30
OCWD-LB3	NESTED	1	46	36	46
OCWD-LB3	NESTED	2	165	145	165
OCWD-LV1	SINGLE CASING	1	155	135	155
OCWD-M1	SINGLE CASING	1	115	75	110
OCWD-M2	SINGLE CASING	1	155	85	150
OCWD-M4	NESTED	1	125	80	120

NA: Not Available

APPENDIX E - OCWD ACTIVE GROUNDWATER MONITORING WELLS
(Excluding Westbay Multiport Wells)

Well Name	Well Type	Casing Sequence No.	Cased Depth (ft.)	Top Perforation (ft.)	Bottom Perforation (ft.)
OCWD-M4	NESTED	2	180	145	175
OCWD-M4	NESTED	3	275	235	270
OCWD-M4	NESTED	4	335	295	330
OCWD-M5	NESTED	1	100	65	95
OCWD-M5	NESTED	2	165	115	160
OCWD-M5	NESTED	3	265	215	260
OCWD-M5	NESTED	4	310	285	305
OCWD-M6A	NESTED	1	130	65	125
OCWD-M6A	NESTED	2	170	150	165
OCWD-M6A	NESTED	3	290	260	285
OCWD-M6B	SINGLE CASING	1	240	185	235
OCWD-M7A	NESTED	1	140	70	135
OCWD-M7A	NESTED	2	175	155	170
OCWD-M7A	NESTED	3	225	190	220
OCWD-M7B	SINGLE CASING	1	265	240	260
OCWD-M8	NESTED	1	155	50	150
OCWD-M8	NESTED	2	210	185	205
OCWD-M8	NESTED	3	255	225	250
OCWD-M8	NESTED	4	315	275	310
OCWD-M9	NESTED	1	120	90	115
OCWD-M9	NESTED	2	160	135	155
OCWD-M9	NESTED	3	230	185	225
OCWD-M9	NESTED	4	300	250	295
OCWD-M10	NESTED	1	165	80	160
OCWD-M10	NESTED	2	200	175	195
OCWD-M10	NESTED	3	245	215	240
OCWD-M10	NESTED	4	310	280	305
OCWD-M11	NESTED	1	110	70	105
OCWD-M11	NESTED	2	155	125	150
OCWD-M11	NESTED	3	230	170	225
OCWD-M11	NESTED	4	295	260	290
OCWD-M12	NESTED	1	115	70	110
OCWD-M12	NESTED	2	225	130	220
OCWD-M12	NESTED	3	265	240	260
OCWD-M12	NESTED	4	355	330	350
OCWD-M13	NESTED	1	100	65	95
OCWD-M13	NESTED	2	205	140	200
OCWD-M13	NESTED	3	300	230	295
OCWD-M13	NESTED	4	400	360	395
OCWD-M14A	NESTED	1	95	60	90
OCWD-M14A	NESTED	2	185	120	180
OCWD-M14A	NESTED	3	305	200	300
OCWD-M14B	SINGLE CASING	1	345	320	340
OCWD-M15A	NESTED	1	90	60	85
OCWD-M15A	NESTED	2	180	115	175
OCWD-M15A	NESTED	3	295	195	290
OCWD-M15B	SINGLE CASING	1	340	310	335
OCWD-M16	NESTED	1	95	65	90
OCWD-M16	NESTED	2	165	115	160
OCWD-M16	NESTED	3	275	180	270
OCWD-M16	NESTED	4	320	295	315

NA: Not Available

APPENDIX E - OCWD ACTIVE GROUNDWATER MONITORING WELLS
(Excluding Westbay Multiport Wells)

Well Name	Well Type	Casing Sequence No.	Cased Depth (ft.)	Top Perforation (ft.)	Bottom Perforation (ft.)
OCWD-M17A	NESTED	1	100	60	95
OCWD-M17A	NESTED	2	190	130	185
OCWD-M17A	NESTED	3	350	330	345
OCWD-M17B	SINGLE CASING	1	310	210	305
OCWD-M18	NESTED	1	95	65	90
OCWD-M18	NESTED	2	180	110	175
OCWD-M18	NESTED	3	295	195	290
OCWD-M18	NESTED	4	340	310	335
OCWD-M19	NESTED	1	115	60	110
OCWD-M19	NESTED	2	200	130	195
OCWD-M19	NESTED	3	270	215	265
OCWD-M20	NESTED	1	110	60	105
OCWD-M20	NESTED	2	200	170	195
OCWD-M20	NESTED	3	275	255	270
OCWD-M21	NESTED	1	105	65	100
OCWD-M21	NESTED	2	190	150	185
OCWD-M21	NESTED	3	265	205	260
OCWD-M21	NESTED	4	345	320	340
OCWD-M22	NESTED	1	110	70	105
OCWD-M22	NESTED	2	215	140	210
OCWD-M22	NESTED	3	275	230	270
OCWD-M23A	NESTED	1	95	65	90
OCWD-M23A	NESTED	2	170	110	165
OCWD-M23A	NESTED	3	265	190	260
OCWD-M23B	SINGLE CASING	1	325	295	320
OCWD-M24	NESTED	1	100	70	95
OCWD-M24	NESTED	2	170	115	165
OCWD-M24	NESTED	3	235	185	230
OCWD-M24	NESTED	4	315	290	310
OCWD-M25	SINGLE CASING	1	195	65	185
OCWD-M26	SINGLE CASING	1	145	70	135
OCWD-M27	SINGLE CASING	1	120	60	110
OCWD-M28	SINGLE CASING	1	155	80	145
OCWD-M30	SINGLE CASING	1	120	90	110
OCWD-M31	SINGLE CASING	1	172	82	162
OCWD-M36	NESTED	1	95	80	90
OCWD-M36	NESTED	2	180	165	175
OCWD-M36	NESTED	3	255	240	250
OCWD-M36	NESTED	4	305	290	300
OCWD-M37	NESTED	1	135	120	130
OCWD-M37	NESTED	2	195	180	190
OCWD-M37	NESTED	3	245	230	240
OCWD-M37	NESTED	4	312	297	307
OCWD-M37	NESTED	5	353	338	348
OCWD-M38	NESTED	1	114	94	104
OCWD-M38	NESTED	2	176	156	166
OCWD-M38	NESTED	3	254	234	244
OCWD-M38	NESTED	4	356	336	346
OCWD-M38	NESTED	5	536	516	526
OCWD-M39	NESTED	1	90	70	80
OCWD-M39	NESTED	2	130	100	120

NA: Not Available

APPENDIX E - OCWD ACTIVE GROUNDWATER MONITORING WELLS
(Excluding Westbay Multiport Wells)

Well Name	Well Type	Casing Sequence No.	Cased Depth (ft.)	Top Perforation (ft.)	Bottom Perforation (ft.)
OCWD-M39	NESTED	3	180	150	170
OCWD-M39	NESTED	4	220	200	210
OCWD-M39	NESTED	5	280	250	270
OCWD-M40	NESTED	1	115	85	105
OCWD-M40	NESTED	2	190	160	180
OCWD-M40	NESTED	3	235	205	225
OCWD-M40	NESTED	4	530	330	520
OCWD-M41	NESTED	1	86	66	76
OCWD-M41	NESTED	2	115	95	105
OCWD-M41	NESTED	3	220	200	210
OCWD-M41	NESTED	4	256	236	246
OCWD-M41	NESTED	5	400	370	390
OCWD-M42	NESTED	1	130	100	120
OCWD-M42	NESTED	2	157	137	147
OCWD-M42	NESTED	3	230	210	220
OCWD-M42	NESTED	4	290	260	280
OCWD-M42	NESTED	5	530	500	520
OCWD-M42	NESTED	6	638	608	628
OCWD-M43	NESTED	1	156	136	146
OCWD-M43	NESTED	2	320	290	310
OCWD-M43	NESTED	3	360	340	350
OCWD-M43	NESTED	4	410	380	400
OCWD-M43	NESTED	5	550	520	540
OCWD-M44	NESTED	1	65	50	60
OCWD-M44	NESTED	2	125	100	120
OCWD-M44	NESTED	3	155	140	150
OCWD-M44	NESTED	4	280	245	275
OCWD-M44	NESTED	5	310	295	305
OCWD-M44A	SINGLE CASING	1	125	100	125
OCWD-M44	NESTED	1	65	50	60
OCWD-M44	NESTED	2	125	100	120
OCWD-M44	NESTED	3	155	140	150
OCWD-M44	NESTED	4	280	245	275
OCWD-M44	NESTED	5	310	295	305
OCWD-M45	NESTED	1	215	195	205
OCWD-M45	NESTED	2	270	250	260
OCWD-M45	NESTED	3	355	335	345
OCWD-M45	NESTED	4	400	380	390
OCWD-M45	NESTED	5	800	780	790
OCWD-M46	NESTED	1	380	350	370
OCWD-M46	NESTED	2	440	420	430
OCWD-M46	NESTED	3	545	515	535
OCWD-M46	NESTED	4	670	640	660
OCWD-M46	NESTED	5	920	890	910
OCWD-M46A	SINGLE CASING	1	380	350	370
OCWD-M46	NESTED	1	380	350	370
OCWD-M46	NESTED	2	440	420	430
OCWD-M46	NESTED	3	545	515	535
OCWD-M46	NESTED	4	670	640	660
OCWD-M46	NESTED	5	920	890	910
OCWD-M47	NESTED	1	385	355	375

NA: Not Available

APPENDIX E - OCWD ACTIVE GROUNDWATER MONITORING WELLS
(Excluding Westbay Multiport Wells)

Well Name	Well Type	Casing Sequence No.	Cased Depth (ft.)	Top Perforation (ft.)	Bottom Perforation (ft.)
OCWD-M47	NESTED	2	490	470	480
OCWD-M47	NESTED	3	610	580	600
OCWD-M47	NESTED	4	775	745	765
OCWD-M47	NESTED	5	970	940	960
OCWD-M48	NESTED	1	110	80	100
OCWD-M48	NESTED	2	205	175	195
OCWD-M48	NESTED	3	490	470	480
OCWD-MOOR	SINGLE CASING	1	470	NA	NA
OCWD-RVW1	SINGLE CASING	1	78	67	77
OCWD-RVW1A	SINGLE CASING	1	49	39	49
OCWD-T2	NESTED	1	33	20	30
OCWD-T2	NESTED	2	180	70	170
OCWD-T2	NESTED	3	370	300	360
OCWD-T3	NESTED	1	95	65	85
OCWD-T3	NESTED	2	180	110	170
OCWD-T4	SINGLE CASING	1	176	68	168
OCWD-T5	NESTED	1	200	110	190
OCWD-T5	NESTED	2	305	285	295
OCWD-W1	SINGLE CASING	1	398	NA	NA
OCWD-YLR1	SINGLE CASING	1	40	35	40
OCWD-YLR2	SINGLE CASING	1	37	32	37
OCWD-YLR3	SINGLE CASING	1	36	31	36
OM-1	SINGLE CASING	1	245	217	235
OM-2	SINGLE CASING	1	250	211	219
OM-2A	SINGLE CASING	1	130	118	125
OM-4	SINGLE CASING	1	237	221	230
OM-4A	SINGLE CASING	1	119	112	117
OM-6	SINGLE CASING	1	249	196	204
OM-8	SINGLE CASING	1	319	285	293
OM-8A	SINGLE CASING	1	178	156	164
SCS-3	SINGLE CASING	1	42	31	42
SCS-4	SINGLE CASING	1	32	21	32
SCS-5	SINGLE CASING	1	43	22	43
SCS-6	NESTED	1	29	23	29
SCS-6	NESTED	2	153	147	153
SCS-7	NESTED	1	36	20	36
SCS-7	NESTED	2	141	125	141
SCS-8	SINGLE CASING	1	129	108	129
SCS-9	SINGLE CASING	1	178	153	173
SCS-10	SINGLE CASING	1	221	206	216
SCS-B1	NESTED	1	43	18	43
SCS-B2	NESTED	1	10	5	10
SCS-B2	NESTED	2	29	19	29
SCS-B3	NESTED	1	10	5	10
SCS-B3	NESTED	2	25	16	26
TIC-67	SINGLE CASING	1	902	245	900
W-14659	SINGLE CASING	1	27	12	27
W-15061	SINGLE CASING	1	NA	NA	NA

NA: Not Available

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
ABS-1/1/WB1/MP1	WESTBAY MULTIPORT	1	27	25	35
ABS-1/1/WB1/MP2	WESTBAY MULTIPORT	2	77	75	85
ABS-1/1/WB1/MP3	WESTBAY MULTIPORT	3	257	255	265
AMD-1/1/WB1/MP1	WESTBAY MULTIPORT	1	105	104	114
AMD-1/1/WB1/MP2	WESTBAY MULTIPORT	2	135	135	145
AMD-1/1/WB1/MP3	WESTBAY MULTIPORT	3	180	180	190
AMD-1/1/WB1/MP4	WESTBAY MULTIPORT	4	245	246	256
AMD-1/1/WB1/MP5	WESTBAY MULTIPORT	5	329	330	340
AMD-1/1/WB1/MP6	WESTBAY MULTIPORT	6	383	384	394
AMD-1/1/WB1/MP7	WESTBAY MULTIPORT	7	523	524	534
AMD-1/1/WB1/MP8	WESTBAY MULTIPORT	8	762	760	770
AMD-1/1/WB1/MP9	WESTBAY MULTIPORT	9	1037	1038	1048
AMD-1/1/WB1/MP10	WESTBAY MULTIPORT	10	1392	1390	1400
AMD-2/1/WB1/MP1	WESTBAY MULTIPORT	1	157	156	166
AMD-2/1/WB1/MP2	WESTBAY MULTIPORT	2	262	260	270
AMD-2/1/WB1/MP3	WESTBAY MULTIPORT	3	387	384	394
AMD-2/1/WB1/MP4	WESTBAY MULTIPORT	4	512	510	520
AMD-2/1/WB1/MP5	WESTBAY MULTIPORT	5	659	658	668
AMD-2/1/WB1/MP6	WESTBAY MULTIPORT	6	824	820	830
AMD-2/1/WB1/MP7	WESTBAY MULTIPORT	7	1014	1012	1022
AMD-2/1/WB1/MP8	WESTBAY MULTIPORT	8	1154	1150	1160
AMD-2/1/WB1/MP9	WESTBAY MULTIPORT	9	1294	1290	1300
AMD-2/1/WB1/MP10	WESTBAY MULTIPORT	10	1444	1440	1450
AMD-3/1/WB1/MP1	WESTBAY MULTIPORT	1	65	66	76
AMD-3/1/WB1/MP2	WESTBAY MULTIPORT	2	135	134	144
AMD-3/1/WB1/MP3	WESTBAY MULTIPORT	3	210	210	220
AMD-3/1/WB1/MP4	WESTBAY MULTIPORT	4	360	360	370
AMD-3/1/WB1/MP5	WESTBAY MULTIPORT	5	480	480	490
AMD-3/1/WB1/MP6	WESTBAY MULTIPORT	6	569	570	580
AMD-3/1/WB1/MP7	WESTBAY MULTIPORT	7	823	820	830
AMD-3/1/WB1/MP8	WESTBAY MULTIPORT	8	923	920	930
AMD-3/1/WB1/MP9	WESTBAY MULTIPORT	9	1173	1170	1180
AMD-3/1/WB1/MP10	WESTBAY MULTIPORT	10	1283	1282	1292
AMD-4/1/WB1/MP1	WESTBAY MULTIPORT	1	206	204	214
AMD-4/1/WB1/MP2	WESTBAY MULTIPORT	2	296	295	305
AMD-4/1/WB1/MP3	WESTBAY MULTIPORT	3	381	380	390
AMD-4/1/WB1/MP4	WESTBAY MULTIPORT	4	561	560	570
AMD-4/1/WB1/MP5	WESTBAY MULTIPORT	5	702	700	710
AMD-4/1/WB1/MP6	WESTBAY MULTIPORT	6	794	790	800
AMD-4/1/WB1/MP7	WESTBAY MULTIPORT	7	939	935	945
AMD-4/1/WB1/MP8	WESTBAY MULTIPORT	8	1059	1055	1065
AMD-4/1/WB1/MP9	WESTBAY MULTIPORT	9	1124	1120	1130
AMD-4/1/WB1/MP10	WESTBAY MULTIPORT	10	1269	1265	1275
AMD-4/1/WB1/MP11	WESTBAY MULTIPORT	11	1409	1405	1415
AMD-5/1/WB1/MP1	WESTBAY MULTIPORT	1	101	100	110
AMD-5/1/WB1/MP2	WESTBAY MULTIPORT	2	201	200	210
AMD-5/1/WB1/MP3	WESTBAY MULTIPORT	3	301	300	310
AMD-5/1/WB1/MP4	WESTBAY MULTIPORT	4	415	414	424
AMD-5/1/WB1/MP5	WESTBAY MULTIPORT	5	497	495	505
AMD-5/1/WB1/MP6	WESTBAY MULTIPORT	6	642	640	650
AMD-5/1/WB1/MP7	WESTBAY MULTIPORT	7	754	750	760

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
AMD-5/1/WB1/MP8	WESTBAY MULTIPORT	8	924	920	930
AMD-5/1/WB1/MP9	WESTBAY MULTIPORT	9	1029	1025	1035
AMD-5/1/WB1/MP10	WESTBAY MULTIPORT	10	1214	1210	1220
AMD-5/1/WB1/MP11	WESTBAY MULTIPORT	11	1324	1320	1330
AMD-5/1/WB1/MP12	WESTBAY MULTIPORT	12	1424	1420	1430
AMD-6/1/WB1/MP1	WESTBAY MULTIPORT	1	112	110	120
AMD-6/1/WB1/MP2	WESTBAY MULTIPORT	2	152	150	160
AMD-6/1/WB1/MP3	WESTBAY MULTIPORT	3	222	220	230
AMD-6/1/WB1/MP4	WESTBAY MULTIPORT	4	277	275	285
AMD-6/1/WB1/MP5	WESTBAY MULTIPORT	5	372	370	380
AMD-6/1/WB1/MP6	WESTBAY MULTIPORT	6	497	495	505
AMD-6/1/WB1/MP7	WESTBAY MULTIPORT	7	622	620	630
AMD-6/1/WB1/MP8	WESTBAY MULTIPORT	8	714	710	720
AMD-6/1/WB1/MP9	WESTBAY MULTIPORT	9	794	790	800
AMD-6/1/WB1/MP10	WESTBAY MULTIPORT	10	904	900	910
AMD-6/1/WB1/MP11	WESTBAY MULTIPORT	11	1094	1090	1100
AMD-6/1/WB1/MP12	WESTBAY MULTIPORT	12	1264	1260	1270
AMD-6/1/WB1/MP13	WESTBAY MULTIPORT	13	1409	1405	1415
AMD-7/1/WB1/MP1	WESTBAY MULTIPORT	1	121	120	130
AMD-7/1/WB1/MP2	WESTBAY MULTIPORT	2	221	220	230
AMD-7/1/WB1/MP3	WESTBAY MULTIPORT	3	271	270	280
AMD-7/1/WB1/MP4	WESTBAY MULTIPORT	4	311	310	320
AMD-7/1/WB1/MP5	WESTBAY MULTIPORT	5	371	370	380
AMD-7/1/WB1/MP6	WESTBAY MULTIPORT	6	471	470	480
AMD-7/1/WB1/MP7	WESTBAY MULTIPORT	7	580	578	588
AMD-7/1/WB1/MP8	WESTBAY MULTIPORT	8	694	690	700
AMD-7/1/WB1/MP9	WESTBAY MULTIPORT	9	809	805	815
AMD-7/1/WB1/MP10	WESTBAY MULTIPORT	10	934	930	940
AMD-7/1/WB1/MP11	WESTBAY MULTIPORT	11	1074	1070	1080
AMD-7/1/WB1/MP12	WESTBAY MULTIPORT	12	1169	1165	1175
AMD-7/1/WB1/MP13	WESTBAY MULTIPORT	13	1299	1295	1305
AMD-7/1/WB1/MP14	WESTBAY MULTIPORT	14	1424	1420	1430
AMD-8/1/WB1/MP1	WESTBAY MULTIPORT	1	80	78	88
AMD-8/1/WB1/MP2	WESTBAY MULTIPORT	2	180	178	188
AMD-8/1/WB1/MP3	WESTBAY MULTIPORT	3	315	314	324
AMD-8/1/WB1/MP4	WESTBAY MULTIPORT	4	525	524	534
AMD-8/1/WB1/MP5	WESTBAY MULTIPORT	5	662	660	670
AMD-8/1/WB1/MP6	WESTBAY MULTIPORT	6	764	760	770
AMD-8/1/WB1/MP7	WESTBAY MULTIPORT	7	859	856	866
AMD-8/1/WB1/MP8	WESTBAY MULTIPORT	8	1004	1000	1010
AMD-8/1/WB1/MP9	WESTBAY MULTIPORT	9	1164	1160	1170
AMD-8/1/WB1/MP10	WESTBAY MULTIPORT	10	1289	1286	1296
AMD-8/1/WB1/MP11	WESTBAY MULTIPORT	11	1454	1450	1460
AMD-8/1/WB1/MP12	WESTBAY MULTIPORT	12	1569	1564	1574
AMD-8/1/WB1/MP13	WESTBAY MULTIPORT	13	1764	1760	1770
AMD-8/1/WB1/MP14	WESTBAY MULTIPORT	14	1949	1944	1954
AMD-8/1/WB1/MP15	WESTBAY MULTIPORT	15	2014	2010	2020
BPM-1/1/WB1/MP1	WESTBAY MULTIPORT	1	129	128	138
BPM-1/1/WB1/MP2	WESTBAY MULTIPORT	2	249	248	258
BPM-1/1/WB1/MP3	WESTBAY MULTIPORT	3	458	456	466
BPM-1/1/WB1/MP4	WESTBAY MULTIPORT	4	613	612	622

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
BPM-1/1/WB1/MP5	WESTBAY MULTIPORT	5	780	776	786
BPM-1/1/WB1/MP6	WESTBAY MULTIPORT	6	890	886	896
BPM-1/1/WB1/MP7	WESTBAY MULTIPORT	7	1040	1036	1046
BPM-1/1/WB1/MP8	WESTBAY MULTIPORT	8	1267	1264	1274
BPM-1/1/WB1/MP9	WESTBAY MULTIPORT	9	1392	1388	1398
BPM-1/1/WB1/MP10	WESTBAY MULTIPORT	10	1502	1498	1508
BPM-1/1/WB1/MP11	WESTBAY MULTIPORT	11	1687	1684	1694
BPM-1/1/WB1/MP12	WESTBAY MULTIPORT	12	1804	1800	1810
BPM-1/1/WB1/MP13	WESTBAY MULTIPORT	13	1934	1930	1940
BPM-1/1/WB1/MP14	WESTBAY MULTIPORT	14	2109	2105	2115
BPM-2/1/WB1/MP1	WESTBAY MULTIPORT	1	181	180	190
BPM-2/1/WB1/MP2	WESTBAY MULTIPORT	2	336	336	346
BPM-2/1/WB1/MP3	WESTBAY MULTIPORT	3	496	494	504
BPM-2/1/WB1/MP4	WESTBAY MULTIPORT	4	581	580	590
BPM-2/1/WB1/MP5	WESTBAY MULTIPORT	5	778	774	784
BPM-2/1/WB1/MP6	WESTBAY MULTIPORT	6	903	900	910
BPM-2/1/WB1/MP7	WESTBAY MULTIPORT	7	1028	1024	1034
BPM-2/1/WB1/MP8	WESTBAY MULTIPORT	8	1243	1240	1250
BPM-2/1/WB1/MP9	WESTBAY MULTIPORT	9	1367	1364	1374
BPM-2/1/WB1/MP10	WESTBAY MULTIPORT	10	1494	1490	1500
BPM-2/1/WB1/MP11	WESTBAY MULTIPORT	11	1614	1610	1620
BPM-2/1/WB1/MP12	WESTBAY MULTIPORT	12	1764	1760	1770
BPM-2/1/WB1/MP13	WESTBAY MULTIPORT	13	1931	1928	1938
BPM-2/1/WB1/MP14	WESTBAY MULTIPORT	14	2073	2070	2080
BPM-2/1/WB1/MP15	WESTBAY MULTIPORT	15	2173	2170	2180
CB-1/1/WB2/MP1	WESTBAY MULTIPORT	1	78	76	86
CB-1/1/WB2/MP2	WESTBAY MULTIPORT	2	143	140	150
CB-1/1/WB2/MP3	WESTBAY MULTIPORT	3	443	440	450
CB-1/1/WB2/MP4	WESTBAY MULTIPORT	4	663	659	669
CB-1/1/WB2/MP5	WESTBAY MULTIPORT	5	873	870	880
CB-1/1/WB2/MP6	WESTBAY MULTIPORT	6	1053	1050	1060
CB-1/1/WB2/MP7	WESTBAY MULTIPORT	7	1193	1190	1200
CB-1/1/WB2/MP8	WESTBAY MULTIPORT	8	1333	1329	1339
CB-1/1/WB2/MP9	WESTBAY MULTIPORT	9	1463	1460	1470
COSM-1/1/WB1/MP1	WESTBAY MULTIPORT	1	92	90	100
COSM-1/1/WB1/MP2	WESTBAY MULTIPORT	2	154	152	162
COSM-1/1/WB1/MP3	WESTBAY MULTIPORT	3	271	270	280
COSM-1/1/WB1/MP4	WESTBAY MULTIPORT	4	351	350	360
COSM-1/1/WB1/MP5	WESTBAY MULTIPORT	5	451	450	460
COSM-1/1/WB1/MP6	WESTBAY MULTIPORT	6	541	540	550
COSM-1/1/WB1/MP7	WESTBAY MULTIPORT	7	621	620	630
COSM-1/1/WB1/MP8	WESTBAY MULTIPORT	8	723	720	730
COSM-1/1/WB1/MP9	WESTBAY MULTIPORT	9	853	850	860
COSM-1/1/WB1/MP10	WESTBAY MULTIPORT	10	983	980	990
COSM-1/1/WB1/MP11	WESTBAY MULTIPORT	11	1103	1100	1110
COSM-1/1/WB1/MP12	WESTBAY MULTIPORT	12	1215	1212	1222
COSM-1/1/WB1/MP13	WESTBAY MULTIPORT	13	1435	1432	1442
COSM-1/1/WB1/MP14	WESTBAY MULTIPORT	14	1599	1594	1604
COSM-1/1/WB1/MP15	WESTBAY MULTIPORT	15	1764	1760	1770
COSM-2/1/WB1/MP1	WESTBAY MULTIPORT	1	60	58	68
COSM-2/1/WB1/MP2	WESTBAY MULTIPORT	2	115	113	123

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
COSM-2/1/WB1/MP3	WESTBAY MULTIPORT	3	202	198	208
COSM-2/1/WB1/MP4	WESTBAY MULTIPORT	4	309	307	317
COSM-2/1/WB1/MP5	WESTBAY MULTIPORT	5	409	406	416
COSM-2/1/WB1/MP6	WESTBAY MULTIPORT	6	541	540	550
COSM-2/1/WB1/MP7	WESTBAY MULTIPORT	7	651	649	659
COSM-2/1/WB1/MP8	WESTBAY MULTIPORT	8	763	757	767
COSM-2/1/WB1/MP9	WESTBAY MULTIPORT	9	890	886	896
COSM-2/1/WB1/MP10	WESTBAY MULTIPORT	10	1055	1051	1061
FFS-1/1/WB2/MP1	WESTBAY MULTIPORT	1	181	180	190
FFS-1/1/WB2/MP2	WESTBAY MULTIPORT	2	361	360	370
FFS-1/1/WB2/MP3	WESTBAY MULTIPORT	3	530	529	539
FFS-1/1/WB2/MP4	WESTBAY MULTIPORT	4	820	819	829
FFS-1/1/WB2/MP5	WESTBAY MULTIPORT	5	1060	1059	1069
FFS-1/1/WB2/MP6	WESTBAY MULTIPORT	6	1160	1159	1169
FFS-1/1/WB2/MP7	WESTBAY MULTIPORT	7	1300	1299	1309
FFS-1/1/WB2/MP8	WESTBAY MULTIPORT	8	1420	1419	1429
FVM-1/1/WB2/MP1	WESTBAY MULTIPORT	1	136	134	145
FVM-1/1/WB2/MP2	WESTBAY MULTIPORT	2	173	172	182
FVM-1/1/WB2/MP3	WESTBAY MULTIPORT	3	223	220	230
FVM-1/1/WB2/MP4	WESTBAY MULTIPORT	4	360	360	370
FVM-1/1/WB2/MP5	WESTBAY MULTIPORT	5	450	450	460
FVM-1/1/WB2/MP6	WESTBAY MULTIPORT	6	500	500	510
FVM-1/1/WB2/MP7	WESTBAY MULTIPORT	7	560	560	570
FVM-1/1/WB2/MP8	WESTBAY MULTIPORT	8	632	630	640
FVM-1/1/WB2/MP9	WESTBAY MULTIPORT	9	814	810	820
FVM-1/1/WB2/MP10	WESTBAY MULTIPORT	10	896	894	904
FVM-1/1/WB2/MP11	WESTBAY MULTIPORT	11	1003	1000	1010
FVM-1/1/WB2/MP12	WESTBAY MULTIPORT	12	1123	1120	1130
FVM-1/1/WB2/MP13	WESTBAY MULTIPORT	13	1178	1175	1185
FVM-1/1/WB2/MP14	WESTBAY MULTIPORT	14	1233	1230	1240
FVM-1/1/WB2/MP15	WESTBAY MULTIPORT	15	1323	1320	1330
FVM-1/1/WB2/MP16	WESTBAY MULTIPORT	16	1497	1492	1502
FVM-1/1/WB2/MP17	WESTBAY MULTIPORT	17	1587	1582	1592
FVM-1/1/WB2/MP18	WESTBAY MULTIPORT	18	1837	1834	1844
GGM-1/1/WB1/MP1	WESTBAY MULTIPORT	1	150	150	160
GGM-1/1/WB1/MP2	WESTBAY MULTIPORT	2	300	300	310
GGM-1/1/WB1/MP3	WESTBAY MULTIPORT	3	465	464	474
GGM-1/1/WB1/MP4	WESTBAY MULTIPORT	4	552	550	560
GGM-1/1/WB1/MP5	WESTBAY MULTIPORT	5	744	740	750
GGM-1/1/WB1/MP6	WESTBAY MULTIPORT	6	829	825	835
GGM-1/1/WB1/MP7	WESTBAY MULTIPORT	7	954	950	960
GGM-1/1/WB1/MP8	WESTBAY MULTIPORT	8	1074	1070	1080
GGM-1/1/WB1/MP9	WESTBAY MULTIPORT	9	1264	1260	1270
GGM-1/1/WB1/MP10	WESTBAY MULTIPORT	10	1519	1515	1525
GGM-1/1/WB1/MP11	WESTBAY MULTIPORT	11	1654	1650	1660
GGM-1/1/WB1/MP12	WESTBAY MULTIPORT	12	1771	1768	1778
GGM-1/1/WB1/MP13	WESTBAY MULTIPORT	13	2011	2008	2018
GGM-2/1/WB1/MP1	WESTBAY MULTIPORT	1	213	212	222
GGM-2/1/WB1/MP2	WESTBAY MULTIPORT	2	295	294	304
GGM-2/1/WB1/MP3	WESTBAY MULTIPORT	3	462	460	470
GGM-2/1/WB1/MP4	WESTBAY MULTIPORT	4	719	715	725

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
GGM-2/1/WB1/MP5	WESTBAY MULTIPORT	5	954	950	960
GGM-2/1/WB1/MP6	WESTBAY MULTIPORT	6	1049	1045	1055
GGM-2/1/WB1/MP7	WESTBAY MULTIPORT	7	1149	1145	1155
GGM-2/1/WB1/MP8	WESTBAY MULTIPORT	8	1254	1250	1260
GGM-2/1/WB1/MP9	WESTBAY MULTIPORT	9	1489	1485	1495
GGM-2/1/WB1/MP10	WESTBAY MULTIPORT	10	1629	1625	1635
GGM-2/1/WB1/MP11	WESTBAY MULTIPORT	11	1744	1740	1750
GGM-2/1/WB1/MP12	WESTBAY MULTIPORT	12	1904	1900	1910
GGM-2/1/WB1/MP13	WESTBAY MULTIPORT	13	1994	1990	2000
GGM-3/1/WB1/MP1	WESTBAY MULTIPORT	1	197	195	205
GGM-3/1/WB1/MP2	WESTBAY MULTIPORT	2	312	310	320
GGM-3/1/WB1/MP3	WESTBAY MULTIPORT	3	547	545	555
GGM-3/1/WB1/MP4	WESTBAY MULTIPORT	4	642	640	650
GGM-3/1/WB1/MP5	WESTBAY MULTIPORT	5	842	837	847
GGM-3/1/WB1/MP6	WESTBAY MULTIPORT	6	1007	1004	1014
GGM-3/1/WB1/MP7	WESTBAY MULTIPORT	7	1107	1104	1114
GGM-3/1/WB1/MP8	WESTBAY MULTIPORT	8	1279	1274	1284
GGM-3/1/WB1/MP9	WESTBAY MULTIPORT	9	1544	1539	1549
GGM-3/1/WB1/MP10	WESTBAY MULTIPORT	10	1684	1680	1690
GGM-3/1/WB1/MP11	WESTBAY MULTIPORT	11	1784	1780	1790
GGM-3/1/WB1/MP12	WESTBAY MULTIPORT	12	1954	1950	1960
HBM-1/1/WB1/MP1	WESTBAY MULTIPORT	1	91	90	100
HBM-1/1/WB1/MP2	WESTBAY MULTIPORT	2	191	190	200
HBM-1/1/WB1/MP3	WESTBAY MULTIPORT	3	321	320	330
HBM-1/1/WB1/MP4	WESTBAY MULTIPORT	4	483	482	492
HBM-1/1/WB1/MP5	WESTBAY MULTIPORT	5	562	560	570
HBM-1/1/WB1/MP6	WESTBAY MULTIPORT	6	702	700	710
HBM-1/1/WB1/MP7	WESTBAY MULTIPORT	7	924	920	930
HBM-1/1/WB1/MP8	WESTBAY MULTIPORT	8	1038	1034	1044
HBM-1/1/WB1/MP9	WESTBAY MULTIPORT	9	1130	1126	1136
HBM-1/1/WB1/MP10	WESTBAY MULTIPORT	10	1352	1348	1358
HBM-1/1/WB1/MP11	WESTBAY MULTIPORT	11	1464	1460	1470
HBM-1/1/WB1/MP12	WESTBAY MULTIPORT	12	1544	1540	1550
HBM-1/1/WB1/MP13	WESTBAY MULTIPORT	13	1644	1640	1650
HBM-1/1/WB1/MP14	WESTBAY MULTIPORT	14	1934	1930	1940
HBM-2/1/WB1/MP1	WESTBAY MULTIPORT	1	112	110	120
HBM-2/1/WB1/MP2	WESTBAY MULTIPORT	2	162	160	170
HBM-2/1/WB1/MP3	WESTBAY MULTIPORT	3	247	245	255
HBM-2/1/WB1/MP4	WESTBAY MULTIPORT	4	307	305	315
HBM-2/1/WB1/MP5	WESTBAY MULTIPORT	5	362	360	370
HBM-2/1/WB1/MP6	WESTBAY MULTIPORT	6	447	445	455
HBM-2/1/WB1/MP7	WESTBAY MULTIPORT	7	522	520	530
HBM-2/1/WB1/MP8	WESTBAY MULTIPORT	8	572	570	580
HBM-2/1/WB1/MP9	WESTBAY MULTIPORT	9	677	675	685
HBM-2/1/WB1/MP10	WESTBAY MULTIPORT	10	739	735	745
HBM-2/1/WB1/MP11	WESTBAY MULTIPORT	11	849	845	855
HBM-2/1/WB1/MP12	WESTBAY MULTIPORT	12	929	925	935
HBM-4/1/WB1/MP1	WESTBAY MULTIPORT	1	75	75	85
HBM-4/1/WB1/MP2	WESTBAY MULTIPORT	2	120	120	130
HBM-4/1/WB1/MP3	WESTBAY MULTIPORT	3	179	180	190
HBM-4/1/WB1/MP4	WESTBAY MULTIPORT	4	231	230	240

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
HBM-4/1/WB1/MP5	WESTBAY MULTIPORT	5	296	295	305
HBM-4/1/WB1/MP6	WESTBAY MULTIPORT	6	351	350	360
HBM-4/1/WB1/MP7	WESTBAY MULTIPORT	7	416	415	425
HBM-4/1/WB1/MP8	WESTBAY MULTIPORT	8	551	550	560
HBM-4/1/WB1/MP9	WESTBAY MULTIPORT	9	691	690	700
HBM-5/1/WB1/MP3	WESTBAY MULTIPORT	3	86	70	90
HBM-5/1/WB1/MP1	WESTBAY MULTIPORT	1	71	70	90
HBM-5/1/WB1/MP2	WESTBAY MULTIPORT	2	76	70	90
HBM-5/1/WB1/MP4	WESTBAY MULTIPORT	4	126	125	135
HBM-5/1/WB1/MP5	WESTBAY MULTIPORT	5	171	170	180
HBM-5/1/WB1/MP6	WESTBAY MULTIPORT	6	216	215	225
HBM-5/1/WB1/MP7	WESTBAY MULTIPORT	7	248	245	255
HBM-5/1/WB1/MP8	WESTBAY MULTIPORT	8	273	270	280
HBM-6/1/WB1/MP1	WESTBAY MULTIPORT	1	53	52	62
HBM-6/1/WB1/MP2	WESTBAY MULTIPORT	2	85	84	94
HBM-6/1/WB1/MP3	WESTBAY MULTIPORT	3	110	108	118
HBM-6/1/WB1/MP4	WESTBAY MULTIPORT	4	215	214	224
HBM-6/1/WB1/MP5	WESTBAY MULTIPORT	5	264	263	273
HBM-6/1/WB1/MP6	WESTBAY MULTIPORT	6	296	294	304
HBM-6/1/WB1/MP7	WESTBAY MULTIPORT	7	508	506	516
HBM-6/1/WB1/MP8	WESTBAY MULTIPORT	8	578	576	586
IDM-1/1/WB2/MP1	WESTBAY MULTIPORT	1	86	85	95
IDM-1/1/WB2/MP2	WESTBAY MULTIPORT	2	271	270	280
IDM-1/1/WB2/MP3	WESTBAY MULTIPORT	3	336	335	345
IDM-1/1/WB2/MP4	WESTBAY MULTIPORT	4	436	435	445
IDM-1/1/WB2/MP5	WESTBAY MULTIPORT	5	631	630	640
IDM-1/1/WB2/MP6	WESTBAY MULTIPORT	6	703	700	710
IDM-1/1/WB2/MP7	WESTBAY MULTIPORT	7	763	760	770
IDM-1/1/WB2/MP8	WESTBAY MULTIPORT	8	878	875	885
IDM-1/1/WB2/MP9	WESTBAY MULTIPORT	9	993	990	1000
IDM-1/1/WB2/MP10	WESTBAY MULTIPORT	10	1053	1050	1060
IDM-2/1/WB1/MP1	WESTBAY MULTIPORT	1	129	126	136
IDM-2/1/WB1/MP2	WESTBAY MULTIPORT	2	236	234	244
IDM-2/1/WB1/MP3	WESTBAY MULTIPORT	3	286	284	294
IDM-2/1/WB1/MP4	WESTBAY MULTIPORT	4	353	352	362
IDM-2/1/WB1/MP5	WESTBAY MULTIPORT	5	493	492	502
IDM-2/1/WB1/MP6	WESTBAY MULTIPORT	6	613	612	622
IDM-2/1/WB1/MP7	WESTBAY MULTIPORT	7	713	710	720
IDM-2/1/WB1/MP8	WESTBAY MULTIPORT	8	890	886	896
IDM-2/1/WB1/MP9	WESTBAY MULTIPORT	9	1055	1050	1060
IDM-2/1/WB1/MP10	WESTBAY MULTIPORT	10	1182	1178	1188
IDM-2/1/WB1/MP11	WESTBAY MULTIPORT	11	1259	1256	1266
IDM-2/1/WB1/MP12	WESTBAY MULTIPORT	12	1404	1400	1410
KBS-2/1/WB1/MP1	WESTBAY MULTIPORT	1	99	96	106
KBS-2/1/WB1/MP2	WESTBAY MULTIPORT	2	214	210	220
LAM-1/1/WB1/MP1	WESTBAY MULTIPORT	1	72	70	80
LAM-1/1/WB1/MP2	WESTBAY MULTIPORT	2	222	220	230
LAM-1/1/WB1/MP3	WESTBAY MULTIPORT	3	272	270	280
LAM-1/1/WB1/MP4	WESTBAY MULTIPORT	4	472	470	480
LAM-1/1/WB1/MP5	WESTBAY MULTIPORT	5	572	570	580
LAM-1/1/WB1/MP6	WESTBAY MULTIPORT	6	834	830	840

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
LAM-1/1/WB1/MP7	WESTBAY MULTIPORT	7	996	992	1002
LAM-1/1/WB1/MP8	WESTBAY MULTIPORT	8	1073	1070	1080
LAM-1/1/WB1/MP9	WESTBAY MULTIPORT	9	1153	1150	1160
LAM-1/1/WB1/MP10	WESTBAY MULTIPORT	10	1253	1250	1260
LAM-1/1/WB1/MP11	WESTBAY MULTIPORT	11	1498	1494	1504
LAM-1/1/WB1/MP12	WESTBAY MULTIPORT	12	1613	1610	1620
MCAS-1/1/WB2/MP1	WESTBAY MULTIPORT	1	65	60	70
MCAS-1/1/WB2/MP2	WESTBAY MULTIPORT	2	155	150	160
MCAS-1/1/WB2/MP3	WESTBAY MULTIPORT	3	215	210	220
MCAS-1/1/WB2/MP4	WESTBAY MULTIPORT	4	275	270	280
MCAS-1/1/WB2/MP5	WESTBAY MULTIPORT	5	335	330	340
MCAS-1/1/WB2/MP6	WESTBAY MULTIPORT	6	455	450	460
MCAS-1/1/WB2/MP7	WESTBAY MULTIPORT	7	545	540	550
MCAS-2/1/WB2/MP1	WESTBAY MULTIPORT	1	45	40	50
MCAS-2/1/WB2/MP2	WESTBAY MULTIPORT	2	135	130	140
MCAS-2/1/WB2/MP3	WESTBAY MULTIPORT	3	205	200	210
MCAS-2/1/WB2/MP4	WESTBAY MULTIPORT	4	375	370	380
MCAS-2/1/WB2/MP5	WESTBAY MULTIPORT	5	425	420	430
MCAS-2/1/WB2/MP6	WESTBAY MULTIPORT	6	495	490	500
MCAS-2/1/WB2/MP7	WESTBAY MULTIPORT	7	555	550	560
MCAS-2/1/WB2/MP8	WESTBAY MULTIPORT	8	625	620	630
MCAS-3/1/WB2/MP1	WESTBAY MULTIPORT	1	91	80	90
MCAS-3/1/WB2/MP2	WESTBAY MULTIPORT	2	166	160	170
MCAS-3/1/WB2/MP3	WESTBAY MULTIPORT	3	226	220	230
MCAS-3/1/WB2/MP4	WESTBAY MULTIPORT	4	346	340	350
MCAS-3/1/WB2/MP5	WESTBAY MULTIPORT	5	426	420	430
MCAS-3/1/WB2/MP6	WESTBAY MULTIPORT	6	496	490	500
MCAS-7/1/WB3/MP1	WESTBAY MULTIPORT	1	92	90	100
MCAS-7/1/WB3/MP2	WESTBAY MULTIPORT	2	192	190	200
MCAS-7/1/WB3/MP3	WESTBAY MULTIPORT	3	352	350	360
MCAS-7/1/WB3/MP4	WESTBAY MULTIPORT	4	442	440	450
MCAS-7/1/WB3/MP5	WESTBAY MULTIPORT	5	512	510	520
MCAS-7/1/WB3/MP6	WESTBAY MULTIPORT	6	802	800	810
MCAS-7/1/WB3/MP7	WESTBAY MULTIPORT	7	912	910	920
MCAS-7/1/WB3/MP8	WESTBAY MULTIPORT	8	982	980	990
MCAS-7/1/WB3/MP9	WESTBAY MULTIPORT	9	1082	1100	1110
SAR-1/1/WB2/MP1	WESTBAY MULTIPORT	1	162	150	170
SAR-1/1/WB2/MP2	WESTBAY MULTIPORT	2	297	290	300
SAR-1/1/WB2/MP3	WESTBAY MULTIPORT	3	327	320	330
SAR-1/1/WB2/MP4	WESTBAY MULTIPORT	4	367	360	370
SAR-1/1/WB2/MP5	WESTBAY MULTIPORT	5	519	510	530
SAR-1/1/WB2/MP6	WESTBAY MULTIPORT	6	584	580	590
SAR-1/1/WB2/MP7	WESTBAY MULTIPORT	7	829	820	840
SAR-1/1/WB2/MP8	WESTBAY MULTIPORT	8	894	890	900
SAR-1/1/WB2/MP9	WESTBAY MULTIPORT	9	914	910	920
SAR-1/1/WB2/MP10	WESTBAY MULTIPORT	10	1014	1010	1020
SAR-1/1/WB2/MP11	WESTBAY MULTIPORT	11	1114	1110	1120
SAR-1/1/WB2/MP12	WESTBAY MULTIPORT	12	1284	1280	1290
SAR-1/1/WB2/MP13	WESTBAY MULTIPORT	13	1374	1370	1380
SAR-1/1/WB2/MP14	WESTBAY MULTIPORT	14	1446	1441	1451
SAR-2/1/WB2/MP1	WESTBAY MULTIPORT	1	141	140	150

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
SAR-2/1/WB2/MP2	WESTBAY MULTIPORT	2	271	270	280
SAR-2/1/WB2/MP3	WESTBAY MULTIPORT	3	311	310	320
SAR-2/1/WB2/MP4	WESTBAY MULTIPORT	4	417	470	480
SAR-2/1/WB2/MP5	WESTBAY MULTIPORT	5	611	610	620
SAR-2/1/WB2/MP6	WESTBAY MULTIPORT	6	741	740	750
SAR-2/1/WB2/MP7	WESTBAY MULTIPORT	7	881	880	890
SAR-2/1/WB2/MP8	WESTBAY MULTIPORT	8	981	980	990
SAR-2/1/WB2/MP9	WESTBAY MULTIPORT	9	1021	1020	1030
SAR-2/1/WB2/MP10	WESTBAY MULTIPORT	10	1101	1100	1110
SAR-2/1/WB2/MP11	WESTBAY MULTIPORT	11	1231	1230	1240
SAR-2/1/WB2/MP12	WESTBAY MULTIPORT	12	1351	1350	1360
SAR-3/1/WB2/MP1	WESTBAY MULTIPORT	1	164	160	170
SAR-3/1/WB2/MP2	WESTBAY MULTIPORT	2	234	230	240
SAR-3/1/WB2/MP3	WESTBAY MULTIPORT	3	414	410	420
SAR-3/1/WB2/MP4	WESTBAY MULTIPORT	4	514	510	520
SAR-3/1/WB2/MP5	WESTBAY MULTIPORT	5	644	640	650
SAR-3/1/WB2/MP6	WESTBAY MULTIPORT	6	774	770	780
SAR-3/1/WB2/MP7	WESTBAY MULTIPORT	7	954	950	960
SAR-3/1/WB2/MP8	WESTBAY MULTIPORT	8	1074	1070	1080
SAR-3/1/WB2/MP9	WESTBAY MULTIPORT	9	1199	1195	1205
SAR-3/1/WB2/MP10	WESTBAY MULTIPORT	10	1269	1265	1275
SAR-3/1/WB2/MP11	WESTBAY MULTIPORT	11	1393	1390	1400
SAR-4/1/WB2/MP1	WESTBAY MULTIPORT	1	123	115	125
SAR-4/1/WB2/MP2	WESTBAY MULTIPORT	2	328	320	330
SAR-4/1/WB2/MP3	WESTBAY MULTIPORT	3	478	470	480
SAR-4/1/WB2/MP4	WESTBAY MULTIPORT	4	598	590	600
SAR-4/1/WB2/MP5	WESTBAY MULTIPORT	5	738	730	740
SAR-4/1/WB2/MP6	WESTBAY MULTIPORT	6	868	860	870
SAR-4/1/WB2/MP7	WESTBAY MULTIPORT	7	978	970	980
SAR-4/1/WB2/MP8	WESTBAY MULTIPORT	8	1068	1060	1070
SAR-4/1/WB2/MP9	WESTBAY MULTIPORT	9	1168	1160	1170
SAR-4/1/WB2/MP10	WESTBAY MULTIPORT	10	1398	1395	1405
SAR-5/1/WB2/MP1	WESTBAY MULTIPORT	1	80	80	90
SAR-5/1/WB2/MP2	WESTBAY MULTIPORT	2	170	170	180
SAR-5/1/WB2/MP3	WESTBAY MULTIPORT	3	360	360	370
SAR-5/1/WB2/MP4	WESTBAY MULTIPORT	4	617	616	626
SAR-5/1/WB2/MP5	WESTBAY MULTIPORT	5	764	760	770
SAR-5/1/WB2/MP6	WESTBAY MULTIPORT	6	944	940	950
SAR-5/1/WB2/MP7	WESTBAY MULTIPORT	7	1084	1080	1090
SAR-5/1/WB2/MP8	WESTBAY MULTIPORT	8	1193	1190	1200
SAR-5/1/WB2/MP9	WESTBAY MULTIPORT	9	1293	1290	1300
SAR-5/1/WB2/MP10	WESTBAY MULTIPORT	10	1543	1540	1550
SAR-5/1/WB2/MP11	WESTBAY MULTIPORT	11	1733	1730	1740
SAR-5/1/WB2/MP12	WESTBAY MULTIPORT	12	1823	1820	1830
SAR-6/1/WB2/MP1	WESTBAY MULTIPORT	1	206	200	210
SAR-6/1/WB2/MP2	WESTBAY MULTIPORT	2	366	360	370
SAR-6/1/WB2/MP3	WESTBAY MULTIPORT	3	476	470	480
SAR-6/1/WB2/MP4	WESTBAY MULTIPORT	4	581	574	584
SAR-6/1/WB2/MP5	WESTBAY MULTIPORT	5	706	700	710
SAR-6/1/WB2/MP6	WESTBAY MULTIPORT	6	786	780	790
SAR-6/1/WB2/MP7	WESTBAY MULTIPORT	7	1086	1080	1090

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
SAR-6/1/WB2/MP8	WESTBAY MULTIPORT	8	1186	1180	1190
SAR-6/1/WB2/MP9	WESTBAY MULTIPORT	9	1276	1270	1280
SAR-6/1/WB2/MP10	WESTBAY MULTIPORT	10	1501	1500	1510
SAR-7/1/WB2/MP1	WESTBAY MULTIPORT	1	111	110	120
SAR-7/1/WB2/MP2	WESTBAY MULTIPORT	2	171	170	180
SAR-7/1/WB2/MP3	WESTBAY MULTIPORT	3	310	310	320
SAR-7/1/WB2/MP4	WESTBAY MULTIPORT	4	440	440	450
SAR-7/1/WB2/MP5	WESTBAY MULTIPORT	5	605	604	614
SAR-7/1/WB2/MP6	WESTBAY MULTIPORT	6	742	740	750
SAR-7/1/WB2/MP7	WESTBAY MULTIPORT	7	862	856	866
SAR-7/1/WB2/MP8	WESTBAY MULTIPORT	8	1194	1190	1200
SAR-7/1/WB2/MP9	WESTBAY MULTIPORT	9	1354	1350	1360
SAR-8/1/WB1/MP1	WESTBAY MULTIPORT	1	44	34	44
SAR-8/1/WB1/MP2	WESTBAY MULTIPORT	2	94	84	94
SAR-8/1/WB1/MP3	WESTBAY MULTIPORT	3	159	150	160
SAR-9/1/WB1/MP1	WESTBAY MULTIPORT	1	150	148	160
SAR-9/1/WB1/MP2	WESTBAY MULTIPORT	2	239	236	248
SAR-9/1/WB1/MP3	WESTBAY MULTIPORT	3	409	406	418
SAR-9/1/WB1/MP4	WESTBAY MULTIPORT	4	491	488	500
SAR-9/1/WB1/MP5	WESTBAY MULTIPORT	5	606	604	616
SAR-9/1/WB1/MP6	WESTBAY MULTIPORT	6	730	724	736
SAR-9/1/WB1/MP7	WESTBAY MULTIPORT	7	877	872	884
SAR-9/1/WB1/MP8	WESTBAY MULTIPORT	8	1072	1068	1080
SAR-9/1/WB1/MP9	WESTBAY MULTIPORT	9	1262	1258	1270
SAR-9/1/WB1/MP10	WESTBAY MULTIPORT	10	1477	1473	1484
SAR-9/1/WB1/MP11	WESTBAY MULTIPORT	11	1572	1567	1578
SAR-9/1/WB1/MP12	WESTBAY MULTIPORT	12	1724	1719	1730
SAR-9/1/WB1/MP13	WESTBAY MULTIPORT	13	1821	1815	1826
SAR-9/1/WB1/MP14	WESTBAY MULTIPORT	14	1893	1889	1900
SBM-1/1/WB1/MP1	WESTBAY MULTIPORT	1	79	74	84
SBM-1/1/WB1/MP2	WESTBAY MULTIPORT	2	149	144	154
SBM-1/1/WB1/MP3	WESTBAY MULTIPORT	3	244	240	250
SBM-1/1/WB1/MP4	WESTBAY MULTIPORT	4	374	370	380
SBM-1/1/WB1/MP5	WESTBAY MULTIPORT	5	514	510	520
SBM-1/1/WB1/MP6	WESTBAY MULTIPORT	6	706	696	706
SBM-1/1/WB1/MP7	WESTBAY MULTIPORT	7	916	910	920
SBM-1/1/WB1/MP8	WESTBAY MULTIPORT	8	1256	1250	1260
SC-1/1/WB1/MP1	WESTBAY MULTIPORT	1	48	44	54
SC-1/1/WB1/MP2	WESTBAY MULTIPORT	2	93	90	100
SC-1/1/WB1/MP3	WESTBAY MULTIPORT	3	153	150	160
SC-1/1/WB1/MP4	WESTBAY MULTIPORT	4	197	194	204
SC-1/1/WB1/MP5	WESTBAY MULTIPORT	5	299	294	304
SC-1/1/WB1/MP6	WESTBAY MULTIPORT	6	394	390	400
SC-2/1/WB2/MP1	WESTBAY MULTIPORT	1	49	46	56
SC-2/1/WB2/MP2	WESTBAY MULTIPORT	2	96	94	104
SC-2/1/WB2/MP3	WESTBAY MULTIPORT	3	148	146	156
SC-2/1/WB2/MP4	WESTBAY MULTIPORT	4	192	190	200
SC-2/1/WB2/MP5	WESTBAY MULTIPORT	5	251	248	258
SC-2/1/WB2/MP6	WESTBAY MULTIPORT	6	303	300	310
SC-3/1/WB2/MP1	WESTBAY MULTIPORT	1	227	224	234
SC-3/1/WB2/MP2	WESTBAY MULTIPORT	2	412	410	420

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
SC-3/1/WB2/MP3	WESTBAY MULTIPORT	3	577	576	586
SC-3/1/WB2/MP4	WESTBAY MULTIPORT	4	712	710	720
SC-3/1/WB2/MP5	WESTBAY MULTIPORT	5	1022	1018	1028
SC-3/1/WB2/MP6	WESTBAY MULTIPORT	6	1154	1150	1160
SC-3/1/WB2/MP7	WESTBAY MULTIPORT	7	1234	1230	1240
SC-3/1/WB2/MP8	WESTBAY MULTIPORT	8	1374	1370	1380
SC-3/1/WB2/MP9	WESTBAY MULTIPORT	9	1459	1460	1470
SC-4/1/WB1/MP1	WESTBAY MULTIPORT	1	102	100	111
SC-4/1/WB1/MP2	WESTBAY MULTIPORT	2	201	198	209
SC-4/1/WB1/MP3	WESTBAY MULTIPORT	3	271	268	279
SC-4/1/WB1/MP4	WESTBAY MULTIPORT	4	393	391	402
SC-4/1/WB1/MP5	WESTBAY MULTIPORT	5	483	482	493
SC-4/1/WB1/MP6	WESTBAY MULTIPORT	6	573	572	583
SC-4/1/WB1/MP7	WESTBAY MULTIPORT	7	660	658	669
SC-4/1/WB1/MP8	WESTBAY MULTIPORT	8	830	827	838
SC-4/1/WB1/MP9	WESTBAY MULTIPORT	9	1082	1078	1089
SC-5/1/WB1/MP1	WESTBAY MULTIPORT	1	124	123	133
SC-5/1/WB1/MP2	WESTBAY MULTIPORT	2	196	196	206
SC-5/1/WB1/MP3	WESTBAY MULTIPORT	3	291	290	300
SC-5/1/WB1/MP4	WESTBAY MULTIPORT	4	470	468	478
SC-5/1/WB1/MP5	WESTBAY MULTIPORT	5	670	667	677
SC-5/1/WB1/MP6	WESTBAY MULTIPORT	6	807	804	814
SC-5/1/WB1/MP7	WESTBAY MULTIPORT	7	937	932	942
SC-5/1/WB1/MP8	WESTBAY MULTIPORT	8	1024	1020	1030
SC-5/1/WB1/MP9	WESTBAY MULTIPORT	9	1238	1234	1244
SC-5/1/WB1/MP10	WESTBAY MULTIPORT	10	1430	1426	1436
SC-6/1/WB1/MP1	WESTBAY MULTIPORT	1	92	90	100
SC-6/1/WB1/MP2	WESTBAY MULTIPORT	2	202	200	210
SC-6/1/WB1/MP3	WESTBAY MULTIPORT	3	302	300	310
SC-6/1/WB1/MP4	WESTBAY MULTIPORT	4	542	540	550
SC-6/1/WB1/MP5	WESTBAY MULTIPORT	5	789	785	795
SC-6/1/WB1/MP6	WESTBAY MULTIPORT	6	964	960	970
SC-6/1/WB1/MP7	WESTBAY MULTIPORT	7	1124	1120	1130
SC-6/1/WB1/MP8	WESTBAY MULTIPORT	8	1329	1325	1335
SC-6/1/WB1/MP9	WESTBAY MULTIPORT	9	1464	1460	1470
SC-6/1/WB1/MP10	WESTBAY MULTIPORT	10	1544	1540	1550
SC-6/1/WB1/MP11	WESTBAY MULTIPORT	11	1684	1680	1690
SC-6/1/WB1/MP12	WESTBAY MULTIPORT	12	1894	1890	1900
SC-6/1/WB1/MP13	WESTBAY MULTIPORT	13	2029	2025	2035
SC-6/1/WB1/MP14	WESTBAY MULTIPORT	14	2119	2115	2125
SCS-1/1/WB1/MP1	WESTBAY MULTIPORT	1	29	24	34
SCS-1/1/WB1/MP2	WESTBAY MULTIPORT	2	94	90	100
SCS-1/1/WB1/MP3	WESTBAY MULTIPORT	3	146	142	152
SCS-1/1/WB1/MP4	WESTBAY MULTIPORT	4	183	178	188
SCS-1/1/WB1/MP5	WESTBAY MULTIPORT	5	223	220	230
SCS-1/1/WB1/MP6	WESTBAY MULTIPORT	6	298	295	305
SCS-2/1/WB1/MP1	WESTBAY MULTIPORT	1	139	134	145
SCS-2/1/WB1/MP2	WESTBAY MULTIPORT	2	179	174	185
SCS-2/1/WB1/MP3	WESTBAY MULTIPORT	3	218	212	223
SCS-2/1/WB1/MP4	WESTBAY MULTIPORT	4	265	260	270
SCS-2/1/WB1/MP5	WESTBAY MULTIPORT	5	330	325	335

APPENDIX E - OCWD WESTBAY GROUNDWATER MONITORING WELLS
MONITORING PORT INFORMATION

Westbay Monitoring Port Name	Well Type	Monitoring Port No.	Westbay Port Depth (ft.)	Top of Zone (ft.)	Bottom of Zone (ft.)
WBS-2A/1/WB1/MP1	WESTBAY MULTIPORT	1	54	50	60
WBS-2A/1/WB1/MP2	WESTBAY MULTIPORT	2	94	90	100
WBS-2A/1/WB1/MP3	WESTBAY MULTIPORT	3	139	135	145
WBS-3/1/WB1/MP1	WESTBAY MULTIPORT	1	79	75	85
WBS-3/1/WB1/MP2	WESTBAY MULTIPORT	2	219	215	225
WMM-1/1/WB2/MP1	WESTBAY MULTIPORT	1	111	109	119
WMM-1/1/WB2/MP2	WESTBAY MULTIPORT	2	361	359	369
WMM-1/1/WB2/MP3	WESTBAY MULTIPORT	3	483	480	490
WMM-1/1/WB2/MP4	WESTBAY MULTIPORT	4	603	600	610
WMM-1/1/WB2/MP5	WESTBAY MULTIPORT	5	745	740	750
WMM-1/1/WB2/MP6	WESTBAY MULTIPORT	6	815	810	820
WMM-1/1/WB2/MP7	WESTBAY MULTIPORT	7	895	889	899
WMM-1/1/WB2/MP8	WESTBAY MULTIPORT	8	985	980	990
WMM-1/1/WB2/MP9	WESTBAY MULTIPORT	9	1065	1060	1070
WMM-1/1/WB2/MP10	WESTBAY MULTIPORT	10	1215	1210	1220
WMM-1/1/WB2/MP11	WESTBAY MULTIPORT	11	1315	1309	1319
WMM-1/1/WB2/MP12	WESTBAY MULTIPORT	12	1370	1364	1374
WMM-1/1/WB2/MP13	WESTBAY MULTIPORT	13	1435	1430	1440
WMM-1/1/WB2/MP14	WESTBAY MULTIPORT	14	1570	1565	1575
WMM-1/1/WB2/MP15	WESTBAY MULTIPORT	15	1625	1619	1629
WMM-1/1/WB2/MP16	WESTBAY MULTIPORT	16	1745	1740	1750
WMM-1/1/WB2/MP17	WESTBAY MULTIPORT	17	1805	1800	1810
WMM-1/1/WB2/MP18	WESTBAY MULTIPORT	18	1945	1940	1950

APPENDIX F

ACRONYMS AND ABBREVIATIONS

Abbreviations and Acronyms

The following abbreviations and acronyms are used in this report:

ACOE	U.S. Army Corps of Engineers
af	acre-feet
afy	acre-feet per year
AOC	assimiable organic carbon
AOP	advanced oxidation processes
AWT	advanced water treatment
basin	Orange County groundwater basin
Basin Model	OCWD groundwater model
BEA	Basin Equity Assessment
BPP	Basin Production Percentage
CDFG	California Department of Fish & Game
CDPH	California Department of Public Health
cfs	cubic feet per second
CWTF	Colored Water Treatment Facility
DATS	Deep Aquifer Treatment System
District	Orange County Water District
DOC	dissolved organic compound
DWR	Department of Water Resources
DWSAP	Drinking Water Source Assessment and Protection
EDCs	Endocrine Disrupting Compounds
EIR	Environmental Impact Report
EPA	U.S. Environmental Protection Agency
FY	fiscal year
GAC	granular activated carbon
GIS	geographic information system
GWR	Groundwater Replenishment
H_2O_2	hydrogen peroxide
IEUA	Inland Empire Utilities Agency
IRWD	Irvine Ranch Water District
K	model layer hydraulic conductivity
LACDWP	Los Angeles County Department of Power & Water
maf	million acre feet
MCAS	Marine Corps Air Station
MCL	maximum contaminant level
MCWD	Mesa Consolidated Water District
MWDOC	Municipal Water District of Orange County
MF	microfiltration
MODFLOW	Computer program developed by USGS
mgd	million gallons per day
mg/L	milligrams per liter
MTBE	methyl tertiary-butylether
Metropolitan	Metropolitan Water District of Southern California

MWDOC	Municipal Water District of Orange County
NDMA	n-Nitrosodimethylamine
NF	nanofiltration
ng/L	nanograms per liter
NBGPP	North Basin Groundwater Protection Program
NO_2	nitrite
NO_3^-	Nitrate
NPDES	National Pollution Discharge Elimination System
NWRI	National Water Research Institute
O&M	operations and maintenance
OCHCA	Orange County Health Care Agency
OCSD	Orange County Sanitation District
OCWD	Orange County Water District
PCE	perchloroethylene
Plan	Groundwater Management Plan
ppb	less than one microgram per liter
PPCPs	pharmaceuticals and personal care products
Producers	Orange County groundwater producers
RA	replenishment assessment
REWG	Recharge Enhancement Working Group
RO	reverse osmosis
RWQCB	Regional Water Quality Control Board
SARI	Santa Ana River Interceptor
SARWQH	Santa Ana Regional Water Quality and Health
SAWA	Santa Ana Watershed Association
SAWPA	Santa Ana Watershed Project Authority
SBGPP	South Basin Groundwater Protection Project
SDWA	Safe Drinking Water Act
SOCs	synthetic organic chemicals
SWP	State Water Project
SWRCB	State Water Resource Control Board
TCE	trichloroethylene
TDS	total dissolved solids
TIN	total inorganic nitrogen
µg/L	micrograms per liter
USFWS	U.S. Fish & Wildlife Service
USGS	U.S. Geological Survey
UV	ultraviolet light
VOCs	volatile organic compounds
WACO	Water Advisory Committee of Orange County
WF-21	Water Factory 21
WRD	Water Replenishment District of Southern California
WRMS	Water Resources Management System