FORECASTED WATER RESOURCE IMPACTS FROM CHANGES IN OPERATION OF FREEMAN DIVERSION

United Water Conservation District
Open-File Report 2016-03

PREPARED BY

GROUNDWATER RESOURCES DEPARTMENT
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THIS REPORT IS PRELIMINARY AND IS SUBJECT TO MODIFICATION

BASED UPON FUTURE ANALYSIS AND EVALUATION

Cover Photo: Freeman Diversion

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FORECASTED WATER RESOURCE IMPACTS FROM CHANGES IN OPERATION OF FREEMAN DIVERSION

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EXECUTIVE SUMMARY

United Water Conservation District (United) is preparing a Multiple Species Habitat Conservation Plan (MSHCP) as part of its application packages for incidental take permits (ITP) under section 10(a)(1)(B) of the federal Endangered Species Act (FESA) and 2081(b) of the California Fish and Game Code, or a consistency determination under section 2080.1, as appropriate. United seeks ITPs for activities that may incidentally result in take of covered species. These activities are referred to in the MSHCP as “covered activities.” Southern California steelhead is one of the covered species, and these fish require river flow for both upstream and downstream migration opportunities. The purpose of the underlying, covered activity of surface-water diversion at the Freeman Diversion is to sustain the reliable supply of water over the long-term based on known and foreseeable community demand for irrigation and municipal and industrial purposes. This includes maintenance of groundwater levels, prevention of groundwater quality degradation and surface deliveries in lieu of pumping in certain areas on the Oxnard coastal plain. United’s Freeman Diversion and other associated facilities directly and indirectly provide irrigation supplies as well as drinking water to municipal customers, including the City of Oxnard, the Port Hueneme Water Agency, and the Naval Base Ventura County, in-lieu of coastal groundwater extractions. United’s facilities are also vital to groundwater recharge, providing replenishment water to the aquifers for use during drought years, and reducing and reversing seawater intrusion in the aquifers of the Oxnard Plain.

United has developed a number of surface water diversion operational scenarios that provide various instream flows for fish migration in the Santa Clara River downstream of the Freeman Diversion. These scenarios range from use of United’s full water right for diversions as licensed by the (CA) State Water Resources Control Board (which itself includes instream flow requirements), to scenarios proposed by the NMFS in a biological opinion issued to the U.S Bureau of Reclamation in 2008, to no diversion of water. This report evaluates the impacts of various diversion scenarios on conditions in aquifers underlying the Oxnard coastal plain.

Despite long-term efforts to conserve water, import more water to the District and optimize the use of local resources, water deficits exist in a number of areas throughout the District, most notably on the southern Oxnard Plain basin and in the Pleasant Valley basin. In some places, the depletion of groundwater reserves has to date simply resulted in lowered water tables. In other areas, significant water quality problems have developed in response to conditions of overdraft. The California Department of Water Resources recently revised the list of basins “subject to critical overdraft.” Southern California has six basins designated as subject to critical overdraft, and the Oxnard Plain and Pleasant Valley basins have been assigned this designation. The Oxnard Plan and Pleasant Valley basins are the only two coastal basins on the list.

United staff used a surface water routing model to prescribe the distribution of available surface water under various surface-water diversion scenarios, and a groundwater flow model to forecast

future aquifer conditions associated with the various scenarios. The diversion scenarios evaluated include:

- **Scenario 1 (No Diversion)** – United diverts no river flow at the Freeman Diversion other than water released from Santa Felicia Dam during the summer-fall conservation release.
- **Scenario 2 (Water Right Operations)** – United conducts operations at the Freeman Diversion in accordance with SWRCB Permit 18908.
- **Scenario 3 (Interim Bypass Operations 2010-2016)** – United conducts operations at the Freeman Diversion largely in accordance with the 2009/2010 bypass flow plans.
- **Scenario 4 (2008 Biological Opinion)** – United conducts diversion operations in accordance with reasonable and prudent alternative 2 (RPA 2(a) and 2(b)), as contained in the 2008 Biological Opinion issued by NMFS.
- **Scenario 6 (Mimic Flow Recession)** – United conducts diversion operations at the Freeman Diversion in a manner that attempts to balance mimicking the natural flow recession to benefit steelhead trout, while minimizing net yield loss compared to scenario 3.
- **Scenario 6A** – This scenario assumes the existing diversion capabilities. Diversions in this scenario are limited to suspended sediment levels in the river of 2,580 mg/l or lower, which is the current limit on diversions for sediment concentrations in the river. Potential diversions are also rejected when the groundwater mounding occurs during wet conditions.
- **Scenario 6B** – As described in scenario 2, United is currently limited in its capabilities of diverting its full water right due to high levels of sediment and infrastructure capabilities. This scenario includes major infrastructure changes to the diversion system, conveyance system, and percolation basins, in order to regain yield that would be lost by extending the duration of bypass flows. The additional yield would result from diverting water with higher turbidity levels (TSS up to 10,000 mg/l) during the peaks of the storms, and percolating additional water in new facilities (e.g. Ferro Basin) during wet years when groundwater mounding is expected to occur.
- **Scenario 7 (Increased Diversion Rate Operations)** – Under this scenario, United increases its instantaneous diversion rate to a maximum of 750 cfs and the total annual diversion limit to 188,000 AF, as a means to offset yield losses to benefit steelhead trout. Importantly, this operational scenario is not covered under United's current water right and permit. Therefore, to implement this scenario, United would need to obtain additional water rights. Additionally, the existing infrastructure of the Freeman Diversion facility and associated downstream facilities cannot accommodate operations under this scenario and would need to be modified.

The modeling results indicate significant adverse groundwater conditions in the Lower Aquifer System (LAS) and the Upper Aquifer System (UAS) in the Oxnard Plain, Forebay, Pleasant Valley, and the Mound groundwater basins under all diversion scenarios. Maintaining groundwater elevations above sea level is key to preventing further seawater intrusion and other groundwater quality problems from occurring in the aquifers underlying the Oxnard coastal plain, and for achieving sustainable management of the Oxnard Plain, Forebay, and Pleasant Valley basins, as required by the State of California under the Sustainable Groundwater Management Act. Key results of this evaluation include:

- There is a direct relationship between average annual diversions and the area where groundwater elevations are forecasted to be below sea level below the Oxnard coastal plain.

- In both the UAS and the LAS, groundwater elevations under diversion scenario 1 are forecasted to be substantially lower than under the other diversion scenarios, remaining below sea level across most of the Oxnard coastal plain throughout the simulation period. This illustrates the importance of United's artificial recharge and surface-water deliveries in lieu of pumping for preventing or mitigating undesirable results (e.g. seawater intrusion) of groundwater-level declines in the aquifers underlying the Oxnard coastal plain.
- Forecasted UAS groundwater elevations in areas of the southeastern part of the Oxnard Plain basin, southern Pleasant Valley basin, Mound basin, and northern Pleasant Valley basin remain below sea level under all diversion scenarios evaluated. The southern Oxnard Plain and Pleasant Valley basin area has historically been the site of seawater intrusion, and is of particular concern for achieving sustainable groundwater management. The area of the UAS below sea level is smallest under diversion scenarios 2 and 7, are slightly larger under scenarios 3, 6A, and 6B (1,400 to 4,900 acres greater than under scenario 2), and are substantially larger (19,000 acres, encompassing most of the remaining farmland in the eastern Oxnard coastal plain east of Oxnard and south of Camarillo) under scenario 4.
- In the LAS, groundwater elevations below most of the Oxnard coastal plain are forecasted to remain well below sea level throughout the simulation period under all diversion scenarios. Similar to the UAS, the forecasted areas below sea level for scenarios 2 and 7 are roughly equal, are somewhat larger under scenarios 3, 6A, and 6B (2,600 to 4,900 acres greater than under scenario 2), and are substantially larger (21,000 acres) under scenario 4. This will almost certainly increase the rate and areal extent of seawater intrusion into the LAS in the Oxnard Plain and Pleasant Valley basins, and could prevent the FCGMA from achieving sustainable management as required under the SGMA.

Historically, the Freeman Diversion (and United's previous diversion structures near Saticoy) have been the single most effective project providing groundwater recharge to the Oxnard Forebay and the Oxnard Plain. Any reduction in United's ability to divert water from the Santa Clara River has a direct impact on the sustainable yield of these groundwater basins and the protection and continued viability of the dependent water uses and associated economies and communities. Considering the forecasted impacts on groundwater levels described above for each diversion scenario evaluated in this analysis, Scenario 2, which reflects operations consistent with United's surface-water right, would accomplish the purposes of the Freeman Diversion better than any alternative flow operations that do not rely on additional infrastructure or new water rights. The forecasted negative impacts to groundwater levels of scenarios 1 and 4 are substantially greater than all other scenarios, increasing the potential for seawater intrusion and other undesirable results. United developed Scenario 6 to address conservation objectives for steelhead migration. However, Scenario 6A would have a larger impact to groundwater levels compared to Scenario 2. This report does not evaluate the feasibility of those actions needed to take water at higher flows.

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1 INTRODUCTION

United Water Conservation District (United) is preparing a Multiple Species Habitat Conservation Plan (MSHCP) as part of its application packages for incidental take permits (ITP) under section 10(a)(1)(B) of the federal Endangered Species Act (FESA) and 2081(b) of the California Fish and Game Code, or a consistency determination under section 2080.1, as appropriate. United owns, operates, and maintains water facilities in a number of locations in the Santa Clara River Watershed and Oxnard Plain, some of which have the potential to result in take of federally and state protected species. The federal ITPs would authorize incidental take of 11 species listed as threatened or endangered under the FESA or the California Endangered Species Act (CESA) or both, referred to in the MSHCP as “covered species.” Among other issuance criteria, ITPs will be issued based on the determination by US Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) that the MSHCP minimizes and mitigates the effects of incidental take of the covered species authorized by the ITPs will be minimized and mitigated consistent with the standards in FESA and CESA.

United seeks ITPs for activities that may incidentally result in take of covered species. Southern California steelhead is one of the covered species, and these fish require river flow for both upstream and downstream migration opportunities. The purpose of the underlying, “covered” activities is to sustain the reliable supply of water over the long-term based on known and foreseeable community demand for irrigation and municipal and industrial purposes. This includes maintenance of groundwater levels, prevention of groundwater quality degradation and surface deliveries in lieu of pumping in certain areas on the Oxnard coastal plain. United’s Freeman Diversion and other associated facilities directly and indirectly provide irrigation supplies as well as drinking water to municipal customers, including the City of Oxnard, the Port Hueneme Water Agency, and the Naval Base Ventura County, in-lieu of coastal groundwater extractions. United’s facilities are also vital to groundwater recharge, providing replenishment water to the aquifers for use during drought years, and reducing and reversing seawater intrusion in the aquifers of the Oxnard Plain.

United has developed a number of surface water diversion scenarios that provide various instream flows for fish migration in the Santa Clara River downstream of the Freeman Diversion. These scenarios range from use of United’s full water right for diversions as licensed by the (CA) State Water Resources Control Board (which itself includes instream flow requirements), to scenarios proposed by the NMFS in a biological opinion issued to the U.S Bureau of Reclamation in 2008, to no diversion of water. This report evaluates the impacts of various diversion scenarios on conditions in aquifers underlying the Oxnard coastal plain.

United is proposing a conservation program, including instream flows, in the MSHCP intended to minimize and mitigate the effects of incidental take to the maximum extent practicable. For purposes of assessing impacts to groundwater-resources United has completed technical evaluations and comparisons in this report.

United staff used a surface water routing model to prescribe the distribution of available surface water under the various scenarios, and a groundwater flow model to forecast future aquifer conditions associated with the various scenarios. The modeling results indicate significant adverse groundwater conditions in the Lower Aquifer System (LAS) on the Oxnard coastal plain under all diversion scenarios, and to the Upper Aquifer System (UAS) under some diversion scenarios.

Despite existing water conservation programs and extensive investments in water resource infrastructure, the existing water deficit is significant and without improvement of this situation there would be detrimental impacts to existing users reliant on groundwater supplies. Large supplemental sources of water are not readily available, and the development of supplemental sources could have negative impacts on habitat and species at other locations. Therefore, reduced surface water diversions from the Santa Clara River are impractical as part of an effective water management strategy. United is developing an MSHCP intended to meet the issuance criteria for ITPs, including instream flows for fish migration, while also ensuring that it meets the need to benefit regional aquifers by balancing the use of surface water from the Santa Clara River and groundwater in a conjunctive manner to meet the needs of existing and foreseeable urban and agricultural water users in the community.

1.1 UNITED WATER CONSERVATION DISTRICT

United Water Conservation District (also “United” or “District”) is a public agency that encompasses nearly 213,000 acres of central and southern Ventura County. The District covers the downstream (Ventura County) portion of the valley of the Santa Clara River, as well as the Oxnard Plain. The District serves as a steward for managing the surface water and groundwater resources for all or portions of eight interconnected groundwater subbasins (Figure 1.1-1). It is governed by a seven-person board of directors elected by division, and receives revenue from property taxes, groundwater extraction (pump) charges, recreation fees, and water delivery charges. The developed areas of the District are a mix of agriculture and urban areas, with prime agricultural land supporting high-dollar crops such as avocados, berries, row crops, tomatoes, lemons, oranges, flowers, ornamental nursery stock and sod. Approximately 370,000 people live within the District boundaries, including those living in the cities of Oxnard, Port Hueneme, Santa Paula, Fillmore and eastern Ventura.

The District is authorized under its principal act (California Water Code Section 74000 et seq) to exercise multiple powers. These powers include the authority to conduct water resource investigations, acquire water rights, build facilities to store and recharge water, construct wells and pipelines for water deliveries, commence actions involving water rights and water use, prevent interference with or diminution of stream/river flows and their associated natural subterranean supply of water, and to acquire and operate recreational facilities in connection with dams, reservoirs or other District works.

1.1.1 UWCD MISSION STATEMENT AND GOALS

The District's mission statement is:

> *United Water Conservation District shall manage, protect, conserve, and enhance the water resources of the Santa Clara River, its tributaries and associated aquifers, in the most cost-effective and environmentally balanced manner.*

In order to accomplish this mission, United Water Conservation District follows these guiding principles:

- Construct, operate, and maintain facilities needed now and in the future to put local and imported water resources to optimum beneficial use;
- Deliver safe and reliable drinking water that meets current and future health standards to cities and urban areas;
- Provide an adequate and economical water supply to support a viable and productive agricultural sector;
- Fight overdraft and seawater intrusion and enhance the water quality of the aquifers through the use of District programs;
- Monitor water conditions to detect and guard against problems and to report those conditions to the public;
- Seek opportunities to develop cooperative programs with other agencies in order to maximize use of District resources and promote mutually beneficial projects;
- Acquire and operate high-quality public recreational facilities that are financially self-supporting;
- Balance District operations with environmental needs to maximize use of the region's water resources; and
- Conduct District affairs in a business-like manner that promotes safe investment policy, sound financial audits and the utmost in professional and financial integrity.

The District recognizes that many of the projects and activities required to implement these guiding principles have long timelines for development and initiation, and the positive impacts of these projects and activities may be realized over many years. This is consistent with the District's mission to provide for the long-term health of the water resources within the District. To fulfill its mission, the District retains technical experts in the fields of engineering, hydrogeology, surface water hydrology, environmental science, ecology, and regulatory compliance, as well as administrative personnel with specialties in accounting and finance.

1.1.2 UWCD HISTORY

The original predecessor entity for United Water Conservation District was called the Santa Clara River Protective Association. It was formed in 1925 to protect the runoff of the Santa Clara River from being appropriated and exported outside the watershed. The Santa Clara Water Conservation District (Santa Clara District) was formed in 1927 to further the goals of the Association by protecting water rights and conserving the waters of the Santa Clara River and its tributaries. The Santa Clara District began a systematic program of groundwater recharge in 1928, primarily through constructing recharge basins along the Santa Clara River. Sand dikes were constructed on the Santa Clara River near Saticoy to divert river water into recharge basins in nearby upland areas.

The demand and need for groundwater for agricultural irrigation and municipal use exceeded natural recharge, resulting in overdraft conditions. As groundwater overdraft and seawater intrusion on the Oxnard Plain were recognized in the 1940s, it was clear that the Santa Clara District did not have the financial ability to raise money to construct the facilities necessary to combat the problem. Proposed facilities included dams on both Sespe Creek and Piru Creek. With the help of the City of Oxnard, a new district was organized in 1950 under the Water Conservation District Law of 1931. The new district was called United Water Conservation District for its unification of urban and agricultural concerns. Substantial bond measures were approved by the constituents of the District, allowing United to construct a number of water conservation projects, including:

- Santa Felicia Dam (1955) to capture and store winter runoff on Piru Creek to release in controlled amounts during the dry season. The 200-foot high dam was designed to store up to 100,000 acre-feet (AF) in Lake Piru, but sediment accumulation in the reservoir has reduced storage capacity to about 81,000 AF. The reservoir is now located downstream of a State Water Project reservoir, enabling the District to receive Northern California water via flows down middle Piru Creek without the construction of expensive delivery pipelines;
- A pipeline to new recharge basins at El Rio; and
- Municipal wells at the El Rio recharge facility to produce water for the Oxnard-Hueneme (O-H) pipeline (1954) that supplies drinking water to the City of Oxnard, the Port Hueneme Water Agency (City of Port Hueneme, Naval Base Ventura County, Channel Islands Beach Community Services District), and a number of small mutual water companies. The O-H system supplies water from the Oxnard Forebay basin (the recharge area for the Oxnard Plain basin), rather than pumping individual wells in coastal areas of the Oxnard Plain that could accelerate seawater intrusion.

Overdraft conditions and increasing intrusion of seawater generally persisted during the drought period that existed from the late 1940s through the mid-1960s, and United constructed additional facilities to increase recharge to the aquifers and to decrease groundwater pumping in areas affected by the intrusion. In 1958 a pipeline and terminal reservoir was completed to deliver diverted surface water to Pleasant Valley County Water District, which serves agricultural water to the Pleasant Valley basin. The Pleasant Valley basin, like the neighboring Oxnard Plain, had significant overdraft issues by that time.

Despite the construction of Santa Felicia Dam that allowed storage of water from the Piru Creek watershed, United recognized the need for additional water to support a growing population and industry within its district boundaries. United continued its effort to construct two reservoirs on Sespe Creek. The original bond measure funding both a dam on Sespe Creek and a dam on Piru Creek was narrowly defeated in the polls in 1952 (but a smaller bond measure of nearly $11 million passed in 1953 and funded construction of the Santa Felicia Dam on Piru Creek and the various facilities in the Oxnard Forebay described above). In 1957, United renewed its efforts to construct dams on the Sespe, but there were now claims by others to appropriate water from Sespe Creek for export to the Calleguas Creek watershed area. Lengthy legal proceedings were finally resolved in 1963. United then partnered with the U.S. Bureau of Reclamation for a feasibility study for the Sespe Creek Project, a proposal which included the Cold Spring and Topatopa dams on Sespe Creek, along with a diversion facility near Fillmore and a pipeline to distribute (high quality) Sespe water to a number of downstream cities and growers. This proposal failed at the polls in March 1966 by a very narrow margin. In the mid-1970s, United was still proposing the “Oat Mountain Diversion” near Fillmore to divert water from Sespe Creek and the “Quality Management Pipeline” to distribute diverted water, but this project was never funded or constructed.

1.1.3 POTENTIAL STATE ADJUDICATION

Above-average rainfall conditions prevailed in the later years of the 1960s, but water levels on the Oxnard Plain fell below sea level again in the early 1970s and there was a new episode of saline intrusion. In March 1979, the California State Water Resources Control Board (State Board) Division of Water Rights issued a staff report detailing groundwater conditions on the Oxnard Plain (SWRCB, 1979). The State Board threatened to initiate an adjudication of water rights on the Oxnard Plain unless local entities could demonstrate credible plans to address overdraft conditions in the aquifers of the UAS. Of particular concern was in the inland migration of saline water in the Oxnard aquifer, and the recognition that there are a number of areas where the major aquifers of the Oxnard Plain are merged (vertically), creating the potential for vertical flow between aquifers and water quality degradation in the deeper aquifers. It was envisioned by the State Board that any effective solution would include a combination of regulatory measures to reduce pumping demand and physical projects to increase recharge to the aquifers, allowing the re-establishment of seaward groundwater gradients in the Oxnard Aquifer.

Ventura County interests responded to the State Board’s demand for action, with the County of Ventura and United being the most active agencies involved with the planning and implementation of programs and projects to align groundwater demand and supply over the long term. A new agency was envisioned to regulate pumping in the coastal basins: creation of the Fox Canyon Groundwater Management Agency (FCGMA) was authorized by the California legislature in 1982, and the new agency came into existence in January 1983. The FCGMA conducted studies to determine the safe yield of the groundwater basins within its jurisdiction, and following a period to determine baseline pumping allocations, implemented a program of systematic cuts to reduce pumping by as much as 25% and attempt to bring the basins into balance.

In 1979, United already had a proposal in hand for the Freeman Diversion structure. Community support was realized, presumably in part because an adjudication likely would have had adverse consequences for existing uses. United's engineers estimated the permanent Freeman Diversion structure, including the Pumping Trough Pipeline (PTP) project, would increase the average annual yield of the existing Saticoy Diversion by some 15,500 AF, given the ability to divert water soon after large flow events when the existing earthen berms would have been washed out (and could not be repaired until flows subsided in the Santa Clara River) (United Water Conservation District, 1983). United eventually received a construction loan of $18.73M from the U.S. Bureau of Reclamation, and a loan of $5.0M from the State of California Department of Water Resources, which allowed the project to be built. Construction of the Freeman Diversion, associated canals, and the desilting basin was initiated in 1988 and completed in 1991. A major additional benefit of the Freeman Diversion was the stabilization of riverbed elevations upstream of the facility, correcting the long-term incision of the river related to decades of in-channel gravel mining in the Saticoy area.

Other physical projects to reduce overdraft on the Oxnard Plain did not take as long to design, fund and construct. United partnered with the County of Ventura to construct the PTP in 1986. This pipeline was designed to convey diverted river water to agricultural pumpers in the east-central area of the Oxnard Plain, thus reducing the amount of groundwater pumping in this critical area. The chronic pumping depression in the Oxnard aquifer in this vicinity was a major concern, and cited specifically in the State Board's call for action, as these low water levels would eventually draw saline water from the coastal areas to the center of the basin. Surface water diverted by the Freeman Diversion and delivered to the PTP is supplemented by five wells that produce from the LAS. Although pumping the deep wells would exacerbate overdraft in the Fox Canyon aquifer, the project was designed to address the more immediate concern of severe overdraft and extensive saline intrusion in the UAS. The project has been successful in eliminating the Oxnard aquifer pumping depression in the area.

1.1.4 RECENT GROUNDWATER MANAGEMENT ACTIONS AND DIRECTIVES

Following the construction of the Freeman Diversion, United constructed the Noble recharge basins (1995) to recharge additional water diverted from the river, particularly during wet periods. United then constructed the Saticoy well field in 2003 to pump down the groundwater mound that develops beneath the Saticoy recharge facility during periods of heavy recharge water deliveries. Water pumped from the Saticoy well field is distributed to agricultural users on the Pleasant Valley and Pumping Trough Pipelines, in order to reduce pumping in those areas. A grant from the California Department of Water Resources (DWR) funded about 75% of the Saticoy well field, as DWR is supportive of conjunctive use projects that maximize the use of surface water when it is available. In December 2009, United acquired the Ferro and Rose basins, former mining pits located in the Oxnard Forebay that will be used for future groundwater recharge activities. In 2015, United completed a short connection pipeline between the Noble and Rose basins, and the Rose basin can now be used for surface water recharge. Currently there is no infrastructure to convey water to the Ferro basin. The District is developing plans for the connection and associated in-basin improvements.

As mentioned in the previous section, the Fox Canyon Groundwater Management Agency has been the agency with primary groundwater use regulatory authority in the Oxnard Plain, Forebay and Pleasant Valley basins since 1983. Following the allocation base period in the late 1980s, the FCGMA required a series of 5% pumping reductions, approximately every five years, to reduce pumping demands within its area of jurisdiction. Agricultural water users had the option of demonstrating efficient irrigation practices, thereby avoiding the specified pumping reductions mandated for the municipal pumpers. The original goal of a 25% pumping reduction from baseline allocation was achieved in 2012, but this reduction was largely limited to municipal pumpers, as many agricultural pumpers were demonstrating irrigation efficiency. Despite the implementation of these various measures to reduce pumping from the coastal basins, chronic overdraft conditions persist in the aquifers of both the UAS and the LAS (FCGMA, 2015).

More recently, the FCGMA Board adopted Emergency Ordinance E in April 2014 (*www.fcgma.org*). This ordinance was crafted in response to the severely depleted groundwater conditions in the coastal basins, following the lack of substantial rainfall since spring 2011. Temporary extraction allocations were applied to wells within the FCGMA, effecting additional pumping restrictions to area wells. Additionally, in February 2015, the County of Ventura (County) passed a well ordinance prohibiting the construction of new wells in the overdrafted basins of Ventura County, including the basins within the jurisdiction of the FCGMA (*http://vcpublicworks.org/pwa/groundwater-resources*). Replacement wells can still be installed, as the ordinance was more intended to limit the expansion of groundwater use than to limit existing use. The County intends that this ordinance remain in effect until Groundwater Sustainability Agencies are formed within the various medium and high-priority basins, as per the Sustainable Groundwater Management Act (SGMA).

The SGMA requires the formation of Groundwater Sustainability Agencies (GSAs) for all California groundwater basins. SGMA became law in January 2015 and requires that Groundwater Sustainability Plans (GSPs) be developed for all significant groundwater basins in the state. The GSPs are required to demonstrate how sustainable conditions will be achieved within the next twenty years. Basins considered to be subject to critical overdraft must recover to sustainable conditions by the year 2040. Basins designated as high and medium priority basins must be managed sustainably by 2042. The Oxnard Plain and Pleasant Valley basins are designated as subject to critical overdraft, and the other groundwater basins of the Oxnard coastal plain are either high or medium priority basins. The FCGMA is the GSA for the groundwater basins within its jurisdiction, and has retained a team of consultants to draft a GSP. A draft GSP is expected to be completed by summer 2017.

The future GSP may include some level of additional pumping restrictions, but even if so efforts to bring the Oxnard Plain to long-term groundwater sustainability will likely also require new water projects. Historically, the Freeman Diversion (and United's previous diversion structures near Saticoy) have been the single most effective project providing groundwater recharge to the Oxnard

Forebay and the Oxnard Plain. Any reduction in United's ability to divert water from the Santa Clara River has a direct impact on the sustainable yield of these groundwater basins and the protection and continued viability of the dependent water uses and associated economies and communities.

1.2 FREEMAN DIVERSION AND SATICOY RECHARGE FACILITY

The Freeman Diversion is located on the Santa Clara River about 10 miles upstream from its mouth at the Pacific Ocean. The concrete diversion structure was completed in 1991 and replaced the previous diversion method of building temporary sand and gravel diversion dikes, levees, and canals. The prior method of diverting water from the Santa Clara River near Saticoy had been in practice since the 1920s. With each high flow in the river the dikes were washed out, eliminating the ability to divert water until construction crews were able to work in the riverbed with bulldozers to restore the diversion levees. Construction of the Freeman Diversion has increased the conservation of flood flows by increasing the District's ability to more reliably divert a portion of the flood flows immediately following storm events. The current facility consists of the following structures: diversion structure, fish passage facilities, headworks, canal, flocculation building, and desilting basin.

The diversion is operated to redirect surface water from the Santa Clara River to United's Saticoy recharge facility (Saticoy, Noble, and Rose basins) and El Rio recharge facility, for the purpose of recharging the aquifers underlying the Oxnard Forebay and Oxnard Plain. The remainder of the diverted water is delivered directly to agricultural users to satisfy irrigation demands "in lieu" of the users pumping groundwater. These deliveries are designed to reduce groundwater pumping in areas where overdraft conditions and related water quality issues exist, such as where aquifers are most susceptible to saline water intrusion and the upwelling of saline waters. Water releases from Lake Piru and a portion of the natural runoff from the Santa Clara River are diverted by the Freeman Diversion.

1.2.1 EXISTING WATER RIGHTS

Diversions at the Freeman are permitted under California State Water Resources Control Board License 10173 (issued in 1972) and Permit 18908 (originally issued in 1982 and updated in 1987). The permit was issued for the anticipated increase in diversions due to the new Freeman Diversion and the PTP system. Details of these permitted activities include the following:

- License 10173
    - Maximum diversion rate = 375 cubic feet per second (cfs)
    - Annual groundwater recharge volume = 89,000 AF
    - Annual surface water recharge volume = 15,630 AF
    - No required fish bypass flows

- Permit 18908
  - Maximum diversion rate = 375 cfs to groundwater recharge and 38 cfs to surface water direct deliveries
  - Annual groundwater recharge volume = 30,000 AF
  - Annual surface water recharge volume = 10,000 AF
  - Between February 15 and May 15, 40 cfs should be bypassed through the fish ladder whenever the flow in the river subsides to 415 cfs. The total amount of water bypassed in this manner should not exceed 5,000 AF over a ten-year period.

1.2.2 PURPOSE OF FREEMAN DIVERSION AND UNITED'S ARTIFICIAL RECHARGE FACILITIES

As noted above, the Freeman Diversion diverts water from the Santa Clara River for groundwater recharge and direct delivery to support agricultural and municipal and industrial uses of water, and was intended specifically to provide yield increases over prior operations. The construction of the Freeman Diversion structure created a diversion structure highly resistant to storm damage, and stabilized the elevation from which surface water is diverted from the river. Following extensive mining of aggregate from the channel of the Santa Clara River in the Forebay area, riverbed elevations near Saticoy had dropped by about twenty feet by the late 1980s. Scour associated with large flow events in the river allowed the riverbed degradation to propagate ever farther upstream, and United was repeatedly required to move its Saticoy diversion location farther upstream. The completed structure has prevented further down-cutting of the river upstream of the facility as expected, and some recovery of channel elevations between Santa Paula Creek and the Freeman Diversion has been documented (Stillwater Sciences, 2007). Since completion in 1991, the elevation of the Freeman diversion point has been stable at 162 feet, and the facility has enabled the diversion of river flow soon after large storm events.

When the Freeman Diversion was constructed, the riverbed elevation upstream of the structure was elevated about ten feet, and materials excavated during construction were used to raise floodplain elevations in an area extending approximately 2,000 feet upstream of the facility. The dam structure extends about 40 feet into the subsurface and rests on a bench of low-permeability Pico Formation. Groundwater elevations at an upstream location near the diversion structure vary little from the crest elevation of 162 feet, as groundwater moving through shallow river alluvium stages up behind the Freeman structure. Construction of the Freeman Diversion has benefited groundwater elevations in the Santa Paula basin, as the earlier incision of the river that was lowering the discharge elevation for shallow groundwater in the basin was arrested and partially restored in the area upstream of the diversion structure (Santa Paula Basin Experts Group, 2003).

The Freeman Diversion was completed at the end of the 1990 drought and has proven itself during the 1990s and 2000s wet period. The average diversions from 1991 to 2015 are 68,100 AF per year. In 1998 the district almost reached its license and permit limit by diverting 142,300 AF for recharge and surface water delivery. Since the Freeman Diversion was built in 1991, over 1.7

million AF have been diverted at the diversion with 1.3 million AF being recharged in the Oxnard Forebay. The remainder of the 0.3 million AF went to the surface water delivery systems. Overall since 1927 diversions from this location have exceeded 3.8 million AF.

1.2.2.1 SATICOY RECHARGE FACILITY

The Saticoy Recharge Facility is located approximately 2 miles downstream of the Freeman Diversion. The facility contains several recharge basins that are interconnected with a canal system and gates. United's predecessor agency built recharge facilities in this general area in the late 1920s. They have been reconfigured several times in the past 90 years to accommodate the addition of additional basins.

1.2.2.1.1.1 SATICOY BASINS

The Saticoy basins include 12 individual sub-basins, covering a wetted area of 116 acres. This facility was built much like it is today in 1945. Percolation rates in some of these basins have been observed at over 15 feet per day due to the favorable geology and operational practices to preserve the basins. Average annual deliveries to this facility for the period 1991 to 2015 have been 21,800 AF. These basins have percolated up to 54,000 AF in one year during a very wet period. The Saticoy Basins' capability to percolate water diminishes when groundwater mounds under the facility during periods of intense recharge. Four wells known as the Saticoy well field were added to pump down the mound under these basins as part of a conjunctive use strategy to get more yield from the Oxnard Forebay.

1.2.2.1.1.2 NOBLE BASINS

The Noble basins are old gravel mining pits that have been reconfigured to into three recharge basins. The Noble basins were built in 1993 and cover an area of 120 acres. These basins are approximately 20 feet deep, much deeper than most other recharge basins operated by the District. Due to their depth, during sustained recharge activities and resulting mounded groundwater conditions, these basins become much less effective than the other basins that are above the high groundwater levels, as District staff is unable to access them with heavy equipment to perform maintenance. During wet conditions the ponds that are maintained will attain an increased percolation rate. Due to the maintenance issues of the Noble basins, they are normally the last place that the District will send water. An exception to this is when the desilting basin is not able to effectively remove all the sediment from the water it has diverted. The most turbid water goes to this facility to preserve the high performance of the other basins. From 1995 to 2015, the Noble basin system has recharged an average of 4,750 AF per year.

1.2.2.1.1.3 ROSE BASIN

The Rose basin is an adjacent gravel mine next to the Noble basins. A pipeline connecting it to the Noble basins was built in 2015. Due to the dry year in 2016, this system has not been used. The basin has the potential to provide an additional 121 acres of surface area for recharging after adding berms that will allow water to stage in the entire basin. Like the Noble basins, the Rose basin is a deep basin and the opportunity to maintain this basin is limited to years when significant groundwater mounding does not exist beneath the Saticoy Recharge Facility.

1.2.2.1.1.4 FERRO BASIN

The Ferro basin is a 183-acre reclaimed gravel mining site. This basin is an important facility as it provides an opportunity for future District operations diverting water at relatively high flows if the District can secure a permit to divert more than 375 cfs under high flow conditions in the Santa Clara River. These basins would provide a location for the water diverted at a higher diversion rate, as the large sediment load associated with these high flows cannot be managed in the other recharge basins the District operates. Extensive new canal works would need to be constructed to bring this facility online.

1.2.2.2 EL RIO FACILITY (RECHARGE BASINS AND OXNARD-HUENEME WELLFIELD)

The El Rio recharge facility is located at the terminus of the El Rio branch of the main supply line, approximately two miles southwest of the Saticoy recharge facility. Surface water diverted from the Santa Clara River is distributed to a series of basins totaling approximately 80 acres for the purpose of groundwater recharge. United built the Oxnard-Hueneme system in 1954 to move municipal groundwater extraction on the Oxnard Plain away from coastal areas subject to seawater intrusion. The well field for the O-H system surrounds the El Rio recharge basins, and water produced by the well field is a blend of recharge water that has filtered down through the aquifer, and water drawn laterally from surrounding areas. The El Rio well field includes both upper and lower aquifer wells, allowing a blending of sources for water quality purposes. In practice, the LAS wells are used less frequently, as they are primarily used as alternative wells when others have high nitrate concentrations.

When water levels in the Oxnard Forebay are low, nitrate levels tend to be high, as discussed in section 1.4.4. As a result, during dryer climatic periods, water diverted from the Freeman Diversion is preferentially sent to this facility. During wetter periods, this facility will receive as much water as the conveyance system will allow, as it is typically the least susceptible to groundwater mounding which can reduce the District's potential diversions and recharge. The conveyance pipeline to this system is limited to 120 cfs. Average deliveries for groundwater recharge to this facility from 1991 through 2015 have been 26,400 AF per year.

1.2.3 SURFACE WATER DELIVERIES

Deliveries to El Rio basins shares a portion of the same pipeline as the supplemental surface water deliveries to the Pumping Trough Pipeline System and the Pleasant Valley Delivery System for agricultural irrigation. These systems are discussed separately in the following two subsections. The surface water deliveries are considered one of the most effective ways to improving groundwater conditions in the Oxnard coastal plain. Deliveries to this system reduce the amount of pumping in this area, thereby improving groundwater conditions.

1.2.3.1 PTP DELIVERY SYSTEM

The Pumping Trough Pipeline delivery system was designed to serve surface water from the Santa Clara River to a portion of the Oxnard Plain basin where the UAS was determined to be in severe overdraft. Five LAS wells were constructed along the pipeline to balance pipeline pressures and provide additional water to the system when surface water supplies are inadequate to meet demands. The four UAS wells of the Saticoy well field, completed in 2004, can also provide groundwater to the agricultural pipelines when groundwater elevations are high near the Saticoy recharge facility. The average deliveries to the PTP system from 1991 to 2015 are about 5,800 AF of surface water per year. The demands on this system depend on the demands of the crops it delivers to. Typically, irrigation demands are down during and shortly after rain events, and the peak demand is during the establishment of the strawberries and other fall crops in October. Demands in October can exceed 1,300 AF per month. The PTP delivers water to about 4,400 acres.

1.2.3.2 PLEASANT VALLEY DELIVERY SYSTEM

Water diverted from the Santa Clara River is delivered to the Pleasant Valley County Water District (PVCWD) via the Pleasant Valley Pipeline. The pipeline terminates at United’s Pleasant Valley Reservoir, located east of the Camarillo Airport near the City of Camarillo. PVCWD uses the water from the reservoir and eleven LAS wells in the western Pleasant Valley basin, to supply water to agricultural customers via a delivery system linking the wells and the reservoir. The delivery of diverted river water to PVCWD offsets pumping of irrigation wells in the area. United is obligated by contract to supply, on an annual basis, 12.22 percent of the water diverted at the Freeman Diversion to PVCWD. United has delivered an average of 9,600 AF of surface water per year to PVCWD, from 1991 to 2015. Since 2002, PVCWD has also received surface water from the Conejo Creek Diversion, operated by the Camrosa Water District. Starting in 2016, PVCWD has also received a small amount of recycled water from the City of Oxnard.

1.3 GROUNDWATER BASINS

The groundwater basins within the District vary in their water production and ability to be recharged rapidly. The groundwater basins detailed here are sub-basins of the larger basin of the Santa Clara River Valley (CA DWR, 2003). Hydraulic connection exists between all basins within the District boundaries. The Fillmore basin receives recharge as underflow from the Piru basin, and the Santa Paula basin receives significant recharge from the Fillmore basin. Often, a component of the flow between basins occurs as surface water around the basin boundaries. The Mound basin receives recharge from the Santa Paula basin as well as from the Oxnard Plain and Oxnard Forebay basins, although head differentials across the western Santa Paula basin boundary are greater than those between the other sub-basins of the Santa Clara River valley. The Oxnard Forebay basin is widely recognized as the primary recharge area for aquifers in the Oxnard coastal plain. Many of the confining clays present in the aquifer systems of the Oxnard Plain are absent or discontinuous in the Oxnard Forebay basin, creating a window for recharge to other down-gradient aquifers. High groundwater elevations in and near the Oxnard Forebay promote groundwater flow to the nearby Mound and West Las Posas basins. The Pleasant Valley basin is more distant from the Oxnard Forebay but still receives direct benefit from United's recharge operations, and pipelines have been constructed to convey irrigation water directly to water users in Pleasant Valley and on the southern Oxnard Plain.

1.3.1 OXNARD FOREBAY

Both UAS and LAS aquifers are present in the Oxnard Forebay and Oxnard Plain basins. The Oxnard Forebay maintains direct hydraulic connection with confined aquifers of the Oxnard Plain basin, which extends several miles offshore beneath the marine shelf where outer edges of the aquifer are in direct contact with seawater. In areas near Port Hueneme and Pt. Mugu where submarine canyons extend nearly to the coastline, the fresh-water aquifers may be in direct contact with seawater a short distance offshore.

The Forebay is the main source of recharge to the Oxnard Plain basin. Recharge to the Forebay benefits other coastal basins (Mound, West Las Posas, Pleasant Valley), but a majority of the water recharged to the Forebay flows down-gradient to the confined aquifers of the Oxnard Plain. The shallow sediments of the basin are dominated by coarse alluvial deposits of the ancestral Santa Clara River. The absence of low-permeability confining layers between surface recharge sources and the underlying aquifers in the Forebay allow rapid groundwater recharge in the Forebay. The recharge to the Forebay comes from percolation of Santa Clara River flows, artificial recharge from United's recharge facilities, irrigation return flows, percolation of rainfall, and likely lesser amounts of underflow from the Santa Paula basin and mountain-front recharge from South Mountain. In the area of the Oxnard Forebay between the El Rio and Saticoy recharge facilities, the LAS has been uplifted and truncated along its contact with the UAS. In this area, recharge from surface sources may enter both the UAS and the underlying LAS. The U.S. Geological Survey estimates that about 20% of the water recharged to this area reaches the LAS, with the remainder recharging the UAS. In some areas of the Forebay, significant clays are present among the deposits of the LAS.

1.3.2 OXNARD PLAIN

The Oxnard Forebay is hydraulically connected with the aquifers of the Oxnard Plain basin, which is overlain by an extensive confining clay layer. Thus, the primary recharge to the Oxnard Plain basin is from underflow from the Oxnard Forebay rather than the deep percolation of water from surface sources on the Oxnard Plain. Natural and artificial recharge to the Oxnard Forebay serves to raise groundwater elevations in this up-gradient area of the groundwater flow system for the Oxnard coastal plain. Changes in the volume of groundwater in storage in the Oxnard Forebay changes the hydrostatic pressure in the confined aquifers extending from the margins of the Forebay to the coastal and offshore portions of these continuous aquifer units. High water levels in the Oxnard Forebay are desirable, as they are required to maintain offshore pressure gradients from the Oxnard Forebay to coastal areas. While the physical movement of groundwater out of the Oxnard Forebay is fairly slow, the pressure response in the confined aquifers distant from the Oxnard Forebay responds more rapidly to significant recharge events in the Forebay. When groundwater levels are below sea level along the coastline, there can be significant groundwater recharge by seawater flowing into the aquifers.

Vertical gradients also commonly exist between aquifer units on the Oxnard Plain, resulting in some degree of water movement through low-permeability units that occur between most of the major aquifers. When LAS water levels are substantially lower than UAS water levels (creating a downward gradient), there can be substantial leakage of UAS water into the LAS through the various aquitards that generally separate the aquifer units. This movement of water can be significant in areas where the UAS is in direct contact with the LAS. Likewise, a downward pressure gradient can exist between the Semi-perched aquifer and the Oxnard aquifer when heads in the shallow confined Oxnard aquifer are lowered (either regionally by drought conditions or locally by pumping wells). The movement of poor quality water from the Semi-perched aquifer to the Oxnard aquifer has been documented in some locations, with abandoned or improperly constructed wells being a notable pathway for this downward flow (Izbicki, 1992; Stamos et al, 1992).

The highly-permeable deposits of the UAS are relatively flat, lying across approximately the upper 400 feet of the Oxnard Plain. In the northern Oxnard Plain, heads are often similar in the Oxnard and Mugu aquifers, but heads in the Mugu aquifer are considerably deeper in the greater area surrounding Mugu Lagoon. Deposits of the LAS are generally finer-grained and have been deformed by folding and faulting in many areas. An uneven distribution of pumping, along with structural and stratigraphic changes within the deposits of the LAS result in varied heads among the deep wells across the Oxnard Plain and Pleasant Valley basins. As a result of faulting and uplift of the underlying marine deposits near Mugu Lagoon, the LAS is not hydraulically connected to the Pacific Ocean in this area (Izbicki, 1996a; Hanson et al., 2003). Near Port Hueneme, both the UAS and the LAS are exposed to the ocean by the near-shore Hueneme submarine canyon.

1.3.3 PLEASANT VALLEY

The Pleasant Valley basin is bounded to the south by the Santa Monica Mountains, to the north by the Camarillo Hills, and to the west by the Oxnard Plain. The Bailey fault runs along the base of the Santa Monica Mountains, and the Camarillo fault along the Camarillo Hills to the north.

The Pleasant Valley basin is differentiated from the Oxnard Plain basin by a general lack of productive UAS aquifers (Turner, 1975). The UAS is composed of alluvial deposits about 400 feet thick. In Pleasant Valley much of the UAS is fine grained and not extensively pumped for water supply (Turner, 1975; Hanson et al, 2003). UAS deposits in the Pleasant Valley basin are comprised of sediments sourcing from the Calleguas Creek watershed, a much smaller drainage than that of the Santa Clara River which deposited the UAS deposits on the Oxnard Plain.

The LAS is composed of the Hueneme, Fox Canyon, and Grimes Canyon aquifers to a depth of about 1,400 feet. The Hueneme aquifer is composed of alternating layers of sand and finer grained deposits. The Fox Canyon and Grimes Canyon aquifers are composed of thick sequences of relatively uniform marine sand. The Fox Canyon aquifer is the major water-bearing unit in the basin.

In Pleasant Valley the LAS is surrounded and underlain by partly consolidated marine deposits and volcanic rocks. Marine deposits are present in the Camarillo Hills and in the western edge of the Santa Monica Mountains near the coast. Volcanic rocks consisting of basalts, submarine volcanic flows, and debris flows are present in the Santa Monica Mountains along the southern edge of the valley (Weber et al., 1976). The underlying marine deposits and volcanic rocks both contain high-chloride water.

High-chloride concentrations are present in water from wells throughout the Pleasant Valley basin, especially along the southern edge of the basin near the Bailey Fault. Wells yielding high-chloride water in this area may have been drilled too deep and directly penetrate deposits having high-chloride water, or brines may have invaded deep freshwater aquifers from surrounding and underlying deposits as a result of pumping. Regardless of the source, changing hydraulic pressure as water levels within the Lower Aquifer System decline as a result of pumping wells, especially during dry periods, may increase chloride concentrations in water produced from deeper wells if the proportion of high-chloride water yielded to the wells from underlying deposits increases (Izbicki et al., 2005a). Chloride concentrations in water from deep wells in the Pleasant Valley basin tend to increase during dry periods when groundwater pumping increases. Conversely, chloride concentrations generally decrease during wetter periods when alternative sources of irrigation water are available from surface supplies and groundwater pumping decreases. In addition to water from surrounding and underlying rocks, irrigation return flow also may contribute to high chloride concentrations in deep wells that are partly screened in the UAS. More recently, groundwater recharge from Arroyo Las Posas in the northern portion of the basin has been recognized as an additional source of salt in the basin.

1.3.4 WEST LAS POSAS

The West Las Posas basin lies adjacent the northeast Oxnard Plain in the area south of South Mountain and north of the Camarillo Hills. The basin generally consists of a broad alluvial plain sloping to the south, and is drained by Beardsley Wash which flows west around the Camarillo Hills. Only the western portion of the West Las Posas basin lies within United's District boundary. Tree crops are the dominant land use in this agricultural area. Much of this area is served by groundwater imports from the Oxnard Plain basin, but some agricultural pumping is reported from deep wells near Beardsley Wash and other wells along the South Mountain foothills.

Most groundwater production in the West Las Posas basin is from deposits of the San Pedro Formation. Beneath most of the Las Posas Valley, the upper San Pedro Formation consists of low permeability sediments with lenses of permeable sediments which are age-equivalent to Hueneme Aquifer on the Oxnard Plain (DWR, 1975). The permeable lenses form isolated, yet, locally important water sources. The water-bearing zones in the upper San Pedro Formation are not well connected. Some recharge to the deeper Fox Canyon aquifer may source from downward leakage from the upper San Pedro Formation. Many wells in the Las Posas Basin are perforated in the Fox Canyon aquifer, making it the principal water-bearing unit (Mukae, 1988). The Fox Canyon aquifer is exposed almost continuously along the southern flank of South Mountain. South of the outcrop, beds of the Fox Canyon aquifer dip below the valley and are folded into a series of anticlines and synclines. Groundwater in the Fox Canyon aquifer exists under confined conditions beneath the valley and unconfined conditions at the valley margins where the aquifer is folded upward and exposed at the surface. Much of the groundwater recharge to the western portion of the West Las Posas basin is believed to source from the Oxnard Plain. Minor amounts of recharge are derived likely from infiltration of precipitation and runoff in the outcrop areas.

1.3.5 MOUND BASIN

The principal fresh water-bearing strata of the Mound basin are the upper units of the San Pedro Formation and overlying Pleistocene deposits that are interpreted to be correlative with the Mugu aquifer of the Oxnard Plain basin. There is an upper confining layer of Pleistocene clay approximately 300 feet in thickness. The basin extends several miles into the offshore.

The sediments of the basin have been warped into a syncline that is oriented in an east-west direction that roughly follows Highway 126. Structural disruption along the Oak Ridge fault in the southern portion of the basin has resulted in considerable uplift and erosion of the San Pedro and younger sediments. This disruption is the cause of the topographic “mounds” near the intersection of Victoria Avenue and U.S. 101, for which the basin is named. The Montalvo anticline has traditionally been used to define the southern extent of the basin. These structural features generally offset only the deeper LAS units of the adjacent Oxnard Plain. The deposits of the UAS overlie the faults and folds along the southern margins of the basin, but the character of the deposits change as they extend to the north, becoming more finely bedded and fine-grained (UWCD, 2012).

The limited number of wells in the Mound basin, especially in the northern half of the basin, complicates efforts to ascertain the primary sources of recharge to the basin. There likely is some component of recharge from precipitation falling on aquifer units that outcrop in the hills along the northern margin of the Mound basin (Figure 1.3-1), but no wells exist to provide evidence of this occurrence. There is general agreement that the basin benefits from recharge from the Oxnard

Forebay and Oxnard Plain to the south, especially during periods of high water level on the Plain (GTC, 1972; Fugro, 1996; UWCD 2012). The hydrogeologic boundaries of the Mound basin are not coincident with the structural boundaries of the basin, so there is hydrologic connection between the Mound basin and adjoining groundwater basins (UWCD, 2012). The amount of recharge from the Santa Paula basin to the east is also unclear, but high heads in some wells in the eastern Mound basin suggests some degree of connection and recharge. Mann (1959) suggested that there is little underflow from the Santa Paula basin to the Mound basin, although more recent studies suggest it may be significant (Fugro, 1996; UWCD, 2012).

Groundwater flow in the Mound basin is generally to the west and southwest with modest to weak gradients, especially in times of drought. The poor distribution and limited number of wells with water level records complicates efforts to contour groundwater elevations in the basin. During periods of drought and increased pumping, a pumping trough forms along the southern portion of the basin that significantly modifies groundwater gradients. Groundwater elevations fall below sea level in dry periods, but saline intrusion has not been observed in the Mound basin.

1.4 CURRENT GROUNDWATER CONDITIONS

Despite long-term efforts to conserve water, import more water to the District and optimize the use of local resources, water deficits exist in a number of areas throughout the District, most notably on the southern Oxnard Plain and in the Pleasant Valley basin. In some places, the depletion of groundwater reserves has simply resulted in lowered water tables. In other areas, significant water quality problems have developed in response to conditions of overdraft. Following construction of the Freeman Diversion and the Pumping Trough Pipeline, United's increased ability to divert water from the Santa Clara River for recharge and direct delivery restored the aquifers of the UAS to healthy conditions in the late 1990s and mid-2000s. Overdraft conditions have however continued in the LAS since construction of the Freeman Diversion. In recent years, United has modified diversion operations in order to be more protective of steelhead trout, resulting in a loss of water available for in-lieu deliveries and artificial recharge.

The following sections summarize current groundwater conditions on the Oxnard coastal plan within United's district boundaries. The onset of drought conditions in 2012 exacerbated the long-term overdraft issues that exist on the Oxnard coastal plain. The California Department of Water Resources recently revised the list of basins "subject to critical overdraft." Southern California has six basins designated as subject to critical overdraft, and the Oxnard Plain and Pleasant Valley basins have been assigned this designation. The Oxnard Plan and Pleasant Valley basins are the only two coastal basins on the list.

1.4.1 UAS GROUNDWATER ELEVATIONS, SPRING AND FALL 2015

A continuous potentiometric surface extends from the (unconfined) Oxnard Forebay basin to the confined Oxnard Plain and Pleasant Valley basins. Staff from United, the County of Ventura, cities and other agencies routinely measure water levels in more than 250 wells in the greater Oxnard Plain area. United compiles available records and queries measurements for individual wells in the spring and fall of the year, then draws potentiometric-surface (groundwater-elevation) contours for the Oxnard coastal plain. Groundwater levels are severely depressed and are currently at or near record lows in both the UAS and LAS, the result of diminished rainfall and recharge and ongoing groundwater extractions since 2012.

Groundwater elevation contours for the UAS in spring 2015 are shown for the Forebay and Oxnard Plain in Figure 1.4-1. These conditions are far from typical, with heads in much of the Forebay and virtually all of the Oxnard Plain below sea level. In the northern portion of the Forebay, water levels were above sea level and gradients were steeper than usual (and groundwater flow direction is interpreted to be more southerly than usual). The -10 foot contour is drawn within about a mile of the coast across the entire Oxnard Plain coastline, indicating landward gradients at all locations. The potentiometric surface in the interior portions of the basin is nearly flat, with a few minor pumping depressions indicated. Between spring 2012 and spring 2015, the zero elevation contour moved about ten miles inland, from near Mugu lagoon to the northern portion of the Forebay. In 2015, the lowest groundwater elevations were recorded in the middle of the basin, and not at the southern margin as is typical.

By fall 2015, UAS groundwater elevations were lower than in the spring, with the -20 foot contour drawn near the coast all along the margin of the basin (Figure 1.4-2). The hydraulic gradient in the interior of the basin was still nearly flat, and the lowest Oxnard aquifer water levels were recorded in the Forebay near United's El Rio spreading grounds where the O-H well field is in operation. Steep groundwater gradients exist between this location and the northern extent of the Forebay, where heads as high as 56 feet were recorded.

In many areas of the Forebay and Oxnard Plain, groundwater elevations in the Mugu aquifer are similar to or a few feet lower than those in the Oxnard aquifer. On the southern Oxnard Plain, and most notably in the area surrounding Mugu lagoon, water levels in the Mugu aquifer may be as much as 30 feet lower than in the Oxnard aquifer. Mugu aquifer heads in some wells south of Hueneme Road are nearly as deep as LAS heads. United contours Oxnard aquifer heads (to represent the UAS) by convention, despite the lower Mugu aquifer heads at some well sites.

1.4.2 LAS GROUNDWATER ELEVATIONS, SPRING AND FALL 2015

Figure 1.4-3 displays groundwater elevations from Lower Aquifer System wells in the Oxnard Forebay, Oxnard Plain and Pleasant Valley basin from spring 2015. LAS water levels were below sea level for the entire Oxnard Plain, most of the Forebay, and much of the Pleasant Valley basin. The highest water levels were recorded in the northern Forebay and the northern Pleasant Valley basins, which are recognized areas of recharge. Although LAS water levels are lower than in preceding years, the overall pattern of the contours remains similar. A persistent broad pumping depression is centered on the Oxnard Plain/Pleasant Valley basin boundary, where several wells recorded spring 2015 water levels at least 110 feet below sea level. This pumping depression extends to the coast near the Mugu submarine canyon, where the spring 2015 water level in well CM1A-565 was measured at 58 feet below sea level.

Figure 1.4-4 displays contours of groundwater elevations recorded in LAS wells in fall 2015. Water levels in the Forebay fell about 10 feet since the spring, but the main pumping depression shifted eastward into the Pleasant Valley basin. An area of more than three square miles had groundwater elevations deeper than 150 feet below sea level, located between the Bailey fault near Round Mountain and the Pleasant Valley basin boundary to the west. The broader pumping trough with groundwater elevations deeper than 100 feet below sea level is centered beneath the Oxnard Plain/Pleasant Valley basin boundary, extending from the Camarillo Hills to near Mugu Lagoon. The water level at the coast near Mugu Lagoon was measured at 98 feet below sea level. LAS piezometers surrounding Port Hueneme recorded water levels ranging from -19 to -40 feet below sea level in fall 2015.

Figures 1.4-3 and 1.4-4 show steep groundwater gradients in the northeast Oxnard Plain near the West Las Posas basin boundary. Along the northern portion of the West Las Posas basin boundary, the production wells used for water level monitoring tend to be screened in the Hueneme aquifer. To the south in the area west of the Camarillo Hills, the Hueneme aquifer is more fine-grained and interbedded, and most wells are completed in deeper beds of the Fox Canyon aquifer where heads are lower. There are steep LAS gradients in this area as the character of the Hueneme aquifer changes, but the apparent gradient displayed in the contouring is also influenced by the shift to deeper well completions to the south. The deep LAS monitoring wells at the El Rio spreading grounds record water levels similar to the Fox Canyon wells near the Camarillo hills, so contouring water levels from the deeper LAS wells in the Forebay would extend the eastern Oxnard Plain/Pleasant Valley pumping depression into the Forebay. United's modeling of groundwater flow in the coastal basins shows the LAS aquifers of the Oxnard Plain do receive significant recharge from the Forebay, but much of the groundwater leaves the Forebay as flow in the UAS. Across the Oxnard Plain there is significant downward groundwater flow from the UAS to the LAS, especially in areas where large vertical gradients exist and aquitards between the aquifers are thin or discontinuous.

1.4.3 SALINE WATER INTRUSION

High chloride levels were first detected on the Oxnard Plain in the vicinity of the Hueneme and Mugu submarine canyons in the early 1930s (CA DWR, 1965) and became a serious concern in the 1950s. Drought conditions in the mid-1970s resulted in depleted basins conditions that resulted in another episode of saline intrusion. The State Water Resources Control Board was concerned enough to threaten adjudication of water rights on the Oxnard coastal plain, as discussed in Section 1.1.3 above. This threat spurred the construction of the Pumping Trough Pipeline and the Freeman Diversion, and the creation of the Fox Canyon Groundwater Management Agency.

Early monitoring programs used only existing production wells and abandoned wells as monitoring points; sampling of these wells indicated that there was a widespread area of elevated chloride concentrations in the Hueneme to Mugu areas. In 1989, the U.S. Geological Survey initiated their Regional Aquifer-System Analysis (RASA) study and other cooperative studies with local water agencies. United, Calleguas Municipal Water District and the FCGMA provided significant funding for various USGS studies within the greater Santa Clara-Calleguas groundwater basin. As part of these studies, a series of 14 nested well sites, with three or more wells installed at each site, were drilled and completed at specific depths in the Oxnard Plain basin (Densmore, 1996). Water quality samples from this new network of coastal monitoring wells provided significant new insight into the both the extent of saline intrusion in coastal areas and the various processes by which saline intrusion occurs (United, 2016a).

The installation of a dedicated monitoring network and detailed chemical analysis of water samples from the new wells and other wells yielded new interpretations on the extent of seawater intrusion on the Oxnard Plain. It is now known that some areas of the Oxnard Plain are not intruded by seawater, and instead may be subsurface brine intruding into adjacent fresh water supply aquifers from surrounding and underlying formations (Izbicki, 1992; Stamos and others, 1992; Izbicki and others, 1995; U.S. Geological Survey, 1996). Historic assessments of saline intrusion focused largely on chloride and total dissolved solids (TDS) or electrical conductivity (EC) as indicators of water quality degradation. The evaluation of major and minor-ion chemistry, trace element analysis and specific isotope chemistry from samples collected during and since the USGS RASA study has led to the conclusion that chloride degradation in the Oxnard Plain and Pleasant Valley basins is related to four sources and processes (Izbicki, 1991, Izbicki et al, 2005a). Lateral intrusion of seawater is most common near the Hueneme and Mugu submarine canyons where seawater enters confined production aquifers in response to landward hydraulic gradients. Near-shore submarine canyons can shorten the flow path of seawater into onshore coastal aquifers, enhancing the potential for seawater intrusion (Hanson et al., 2009).

Another source of saline intrusion is subsurface brine intruding into adjacent fresh water aquifers from surrounding and underlying formations. Clay beds are common both between and within the aquifers of the Oxnard Plain, and saline connate waters may be expelled from these clays as they compact in response to prolonged periods of low pressure within the surrounding aquifer units. Saline water (also referred to here as brine) can also originate from older geologic formations, which may be displaced by faulting to a position adjacent fresh water aquifers, or may move upwards from greater depths, along fault traces in response to low pressures in production aquifers (Izbicki et al, 2005a).

Cross contamination through corroded or improperly constructed wells also may be a source of saline water detected in aquifers underlying the Oxnard coastal plain. Heads are commonly higher in the Semi-perched aquifer than in deeper confined aquifers. Saline or brackish groundwater has been documented in the Semi-perched aquifer, and may result from a combination of 1) seawater that recharged the aquifer through offshore outcrops or infiltrated into the aquifer through coastal wetlands or during coastal flooding, 2) elevated concentrations of dissolved minerals resulting from the evaporative discharge of groundwater at land surface, or 3) the infiltration of irrigation return flows (Izbicki, 1996c). Large differences in head can also exist between production aquifers at a single location. When long-screen production wells are screened across several aquifers with differential heads, passive flow within these wells can be significant (Alvarado et al, 2009), allowing poor-quality groundwater from one aquifer to migrate to other (underlying or overlying) aquifers.

In summary, detailed chemical analysis of samples from the coastal monitoring wells has revealed that the source of the elevated chloride levels varies among wells on the Oxnard Plain (Izbicki, 1991, 1992). Four major processes of chloride degradation have been documented in this area:

- **Lateral Seawater Intrusion -** the inland movement of seawater (under the influence of a landward hydraulic gradient) from areas where aquifers crop out in the Hueneme and Mugu submarine canyons.
- **Cross Contamination** - the introduction of poor quality water into fresh water aquifer zones via existing wellbores that were improperly constructed, improperly destroyed, or have been corroded by poor quality water in the Semi-perched zone.
- **Compaction of Salt-Laden Marine Clays** - the dewatering of marine clays, interbedded within the sand and gravel rich aquifers, yields high concentrations of chloride enriched water. This dewatering is the result of decreased pressure in the aquifers, caused by regional pumping stresses.
- **Lateral Movement of Brines from Tertiary formations** - the lateral movement of saline water from older geologic formations that have been uplifted by faulting to positions adjacent to younger freshwater-bearing formations. The lateral movement occurs across a buried fault face near Pt. Mugu where Tertiary rocks are in contact with the younger aquifers.

Chloride degradation from each of the processes listed above is directly related to water levels in the basin. The water balance of the Oxnard Plain and the offshore component of the aquifer units is a dynamic relationship between groundwater recharge, groundwater extraction and change in aquifer storage. The primary source of groundwater recharge for the Oxnard Plain groundwater basin is the Oxnard Forebay, where United’s recharge basins are located. High water levels in the Forebay exert a positive pressure on the confined aquifers of the Oxnard Plain, and water flows from the recharge areas toward the coast. The pressure (piezometric) surface of the confined aquifer is diminished by the extraction of water from the system. If pressure heads at the coast fall below sea level, the lateral intrusion of seawater will occur, resulting in aquifers being recharged with seawater due to landward pressure gradients. The dewatering of marine clays will occur if heads in the surrounding sediments remain below their historic levels for prolonged periods, allowing formerly immobile salts to be expelled into surrounding aquifer material. Brine migration into fresh aquifers also results from low pressure in the aquifers compared to historic conditions. United’s recharge activities and delivery of surface water to the southern regions of the Oxnard coastal plain serves to diminish pumping stress on the aquifers and mitigate all forms of saline intrusion.

In addition to drilling coastal monitoring wells, in 1990 the USGS conducted a time domain electromagnetic (TDEM) geophysical survey to determine the general extent of the high-saline areas (Stamos and others, 1992; Zohdy and others, 1993). This work indicated that the high-saline areas consisted of two distinct lobes (near Port Hueneme and Mugu Lagoon), with relatively fresh water separating the lobes (U.S. Geological Survey, 1996). The survey also revealed that areas of aquifer degradation by saline water varies with depth. The greater Mugu area was again surveyed with TDEM geophysics in 2010 (UWCD, 2010). Wire line conductivity surveys were conducted by the USGS in a number of the well bores for the coastal monitoring wells, and these surveys were also later repeated by United. Results from the wire line surveys indicate that the edges of the observed saline lobes are relatively distinct, with the first saline intrusion occurring in thin individual beds of permeable sand and gravel. As intrusion continues, more individual beds are impacted, resulting in increasing chloride levels.

Figures 1.4-5 through 1.4-10 plot recent chloride concentrations from the coastal monitoring wells sampled by United, and use results from United’s 2010 geophysical survey as a base image. The density and distribution of available monitoring wells is fairly poor for the large area of the southern Oxnard Plain, but the TDEM findings of high salinity are substantiated in a number of wells. In other areas there is poor agreement between sampled chloride concentrations and areas of impact modeled by the TDEM geophysical methods. Without additional monitoring well installations it is difficult to ascertain whether high salinity exists in beds not screened by the short screened intervals of the monitoring wells, or if the geophysical survey results are inaccurate. The maps include an interpreted line suggesting the current inland extent of saline intrusion based on measured concentrations from monitoring wells, United’s 2010 geophysical survey, and other prior studies detailing the extent of the intrusion front. Saline impacts associated with the compaction of sediments or brine migration have a more random distribution, however, and are not necessarily represented by a frontal boundary.

An additional source of saline water, the upwelling brines from deeper formations, has been documented in a number of production wells in the Pleasant Valley basin. Advancements in the tools used in sampling pumping production wells has allowed for the documentation of flow and water quality profiles in long-screen production wells (Izbicki et al, 2005a, 2005b). Data from some area wells indicate that poor water quality at the wellhead results from saline water entering the well from specific aquifer zones rather than thick portions of the aquifer. High chloride concentrations most commonly observed in the deepest portion of a well may be indicative of brines migrating from deeper zones towards a water level depression (low pressure area) created by long-term conditions where demand and pumping exceed recharge. This upwelling of brines is another form of saline intrusion, and like the compaction of marine clays, where occurrence is not limited to coastal areas (Izbicki, 1992). An increase in the number of LAS wells recording increases in chloride concentrations suggest areas impacted by brine intrusion are increasing, most notably in the Pleasant Valley basin.

The shallow groundwater of the Semi-perched aquifer is rarely used for supply purposes, and relatively little water quality data exists for this zone. Water quality of the Semi-perched zone can vary dramatically with time and location, ranging from fresh to saline. United’s fall 2015 sampling event documented chloride concentrations in Semi-perched wells ranging from 77 milligrams per liter (mg/l) to 13,000 mg/l (Figure 1.4-5). Near Port Hueneme, groundwater of this unit is consistently saline, with chloride concentration recorded at 13,000 mg/l in well A2-70. Chloride concentrations are much lower east of Port Hueneme, with well SW recording 398 mg/l chloride, and fresh water observed in the SWIFT well (77 mg/l chloride). Farther inland between Port Hueneme and Point Mugu, chloride concentrations are variable in the SCE well, with higher chloride concentrations observed during dry periods (Figure 1.4-5). Elevated chloride of 1,950 mg/l was recorded in well SCE-38 in fall 2015. The leakage of poor-quality water from the Semi-perched aquifer can degrade water quality in the deeper confined aquifers. Corroded and improperly constructed wells can provide a pathway for this downward leakage.

The Oxnard aquifer is the shallowest confined aquifer of the UAS. There are two distinct areas of known saline intrusion in the Oxnard aquifer, generally occurring near and southeast of Port Hueneme, and in the area surrounding Mugu Lagoon (Figure 1.4-6). Near Port Hueneme, chloride concentrations have been increasing since 2013 in the area west of the harbor, with 1,080 mg/l recorded in well A2-170 in fall 2015. This is new saline intrusion associated with the current drought conditions. Concentrations in well A1-195 located to the east of the harbor have remained stable, and were measured at 159 mg/l in 2015. Southeast of Port Hueneme, an area of elevated chloride is observed and includes the locations of coastal wells CM4 and CM7, and the more inland wells SW and SWIFT. The highest fall 2015 chloride concentrations are found near the coast, with 5,520 mg/l recorded in well CM4-275 and 1,890 mg/l in well CM7-190. Well CM7-110 has had nearly a ten-fold increase in chloride, rising from 2,470 mg/l in 2013 to a peak of 22,500 mg/l in March 2015. It is interesting to note that nearby coastal well clusters CM4 and CM7 both have two wells screened in the Oxnard aquifer. Each of these four wells have significantly different chloride concentrations in 2015, and the lesser chloride is recorded in the shallower well at CM4 and the deeper well at CM7. To the southeast of well CM7, the coastal well CM5 records relatively low and fairly stable chloride. The more inland wells SW and SWIFT recorded 2015 chloride concentrations of 462 and 1,100 mg/l, respectively.

Located on the coast south of Mugu Lagoon and near the Mugu submarine canyon, Oxnard aquifer well CM1A-220 has historically had chloride levels approaching that of seawater, recorded at 16,700 mg/l in fall 2015 (Figure 1.4-6). Northwest of that location, water quality in well CM6-200 remains moderately degraded, measuring 2,060 mg/l chloride in 2015. At the DP and Q2 well sites, Oxnard aquifer chloride was measured at 374 and 402 mg/l, respectively, in fall 2015.

The Mugu aquifer is the deeper aquifer of the UAS. Chloride impacts are less widespread in the Mugu aquifer than in the Oxnard aquifer. Well CM2-280, located west of Port Hueneme and on the coast near the Hueneme submarine canyon, recorded a slight increase in chloride in recent years, measuring 117 mg/l in 2015 (Figure 1.4-7). Wells A1-320 and A2-320, also located near Port Hueneme, record chloride concentrations common to unimpaired areas of the Mugu aquifer. The Mugu aquifer wells located north and northwest of Mugu Lagoon record high chloride values that have increased fairly consistently since the wells were installed. Fall 2015 chloride concentrations in wells CM6-300, Q2-285 and Q2-370 ranged from 2,590 to 2,900 mg/l (Figure 1.4-7). These elevated chloride concentrations are believed to be associated with brines and not direct lateral seawater intrusion. The remaining piezometers completed in the Mugu aquifer and located in both the coastal and more inland areas between Port Hueneme and Point Mugu consistently have low chloride concentrations ranging from about 30 to 40 mg/l.

The Lower Aquifer System is comprised of the Hueneme, Fox Canyon and Grimes Canyon aquifers. Relatively few coastal monitoring wells are completed in the Hueneme aquifer, and all of those are located in the area surrounding Port Hueneme. Wells A1-680 and CM4-760, located east of the port, do not indicate any recent or historic chloride impacts (Figure 1.4-8). Three of the four Hueneme aquifer wells located west of Port Hueneme, however, have recorded elevated chloride concentrations. The highest chloride concentrations are recorded in well CM2-760, and have generally measured greater than 10,000 mg/l since fall 2003. An increase in chloride has also been observed since 2014 in well CM2-520, recently reaching 365 mg/l. Chloride concentrations in this well reached 2,800 mg/l in 1993, but this peak concentration was followed by a long period of decreasing chloride lasting until 2014. The A2 well cluster is located north of the CM2 site, and chloride impacts have not been observed in well A2-560. Chloride concentrations have however increased in well A2-740 since 2004, reaching a high of 208 mg/l in fall 2015. No Hueneme aquifer monitoring wells exist in the area surrounding Mugu Lagoon, as the sediments that make up the Hueneme aquifer are interpreted to have been uplifted and eroded in this vicinity.

Evidence of saline water intrusion has not detected by the sampling of existing monitoring wells screened in the Fox Canyon aquifer near Port Hueneme and nearby coastal areas to the east. The Fox Canyon aquifer wells surrounding Mugu Lagoon, however, document significant water quality degradation (Figure 1.4-9). Well Q2-640 is located north of Mugu Lagoon, and samples show steady degradation since the well was constructed. In fall 2015 sampling of this well recorded 5,140 mg/l chloride. Northwest of Mugu Lagoon, chloride concentrations in well CM6-400 have had an increasing trend since 1999, measuring 1,430 mg/l in a recent sampling event. Well CM6-550 has shown a decreasing trend in chloride concentrations since a significant peak in 2004, most recently measuring 205 mg/l chloride. The Fox Canyon aquifer wells of the DP cluster, located north of CM6 well cluster, have differing trends. Well DP-580 has recorded an increasing chloride trend, rising from 460 to 1,790 mg/l throughout the period of record, while well DP-450 has had a more stable chloride trend (average concentration of approximately 1,000 mg/L) since 2007. Further inland and north of Mugu Lagoon a slightly elevated chloride concentration of 99 mg/l was recorded in fall 2015, which is consistent with the ten-year record for well GP1-740. Fox Canyon aquifer well GP1-460 does not show chloride impacts, nor does well SCE-414 located farther to the north.

There are no Grimes Canyon aquifer monitoring wells at Port Hueneme, and wells CM4-1395 and CM5-1200, located near the coast to the southeast of the port do not show evidence of saline intrusion (Figure 1.4-10). Grimes Canyon wells surrounding Mugu Lagoon do show significant chloride impacts. At the coast near the Mugu submarine canyon, well CM1A-565 has become steadily more saline since its installation in 1989, with 5,820 mg/l chloride recorded in fall 2015. North and northwest of Mugu Lagoon, deterioration of water quality is documented at the Q2 and DP well locations. Chloride concentrations of 14,300 and 4,050 mg/l were recently observed in wells Q2-840 and Q2-970, respectively. Northwest of that location, chloride was measured at 6,060 mg/l in well DP-720 in fall 2015. The rising chloride concentrations in these deep wells in the Mugu Lagoon area is thought to be associated with brines and not the directed lateral intrusion of seawater.

1.4.4 NITRATE IN THE OXNARD FOREBAY

The Oxnard Forebay is vulnerable to nitrate contamination for some of the same reasons the basin is valued for water resource projects. The coarse alluvial sediments common to the area allow the rapid vertical transport of water from the near-surface to the water table. During wet periods, the regional water table is often only tens of feet below the land surface in the Forebay. Nitrate is highly soluble and very mobile, making it susceptible to leaching from soils and transport to groundwater. United monitors water quality in 43 monitoring wells in the Oxnard Forebay, in its public supply wells, and in 11 privately-owned production wells. Nitrate concentrations tend to be low in wells near the Santa Clara River and near the Saticoy Recharge Facility, as Santa Clara River water consistently has low nitrate concentrations (UWCD, 2008). Wells completed in the LAS also tend to have low nitrate concentrations. Measured nitrate concentrations are more variable in the down-gradient portions of the basin. Figure 1.4-11 shows the maximum-recorded nitrate concentrations for Forebay wells in calendar year 2015.

United's El Rio facility was developed in the early 1954 as part of a groundwater management strategy to move groundwater pumping associated with growing coastal populations away from the coastal areas that were increasingly impacted by saline intrusion. The El Rio Recharge Facility and well field are located in the down-gradient portion of the Oxnard Forebay, and the Oxnard-Hueneme (O-H) Pipeline was constructed to convey potable groundwater from the Forebay to the City of Oxnard and the Port Hueneme Water Agency (City of Port Hueneme, Naval Base Ventura County, Channel Islands Beach Community Services District), and several small mutual water districts. This strategy remain)s effective in mitigating pumping impacts in coastal areas subject to saline intrusion. Nitrate concentrations are however quite variable in United's El Rio wells, and at times United has to monitor production wells frequently and blend water from various wells to maintain nitrate concentrations below regulatory standards. A primary health standard exists for nitrate, and the maximum contamination level (MCL) for nitrate of 45 mg/l nitrate (or 10 mg/l for nitrate as N). Adherence to this standard is enforced by the California State Water Resources Control Board's Division of Drinking Water (DDW), as high nitrate concentrations can result in methemoglobinemia (or "blue baby syndrome"), a condition where ingested nitrogen interferes with the blood's ability to carry oxygen.

Water produced by United's El Rio wells is a mixture of groundwater that enters the well at various depths along the screened interval of the well. Santa Clara River water that is spread in the El Rio recharge basins located adjacent the wells migrates downward fairly rapidly, and this high-quality water often makes up a large percentage of the water produced by the UAS wells during periods of active recharge operations. When recharge at the El Rio facility ceases or is significantly reduced, groundwater flow paths from up-gradient areas become the dominant source of water produced by the wells. Groundwater travel times are difficult to determine, but nitrate can remain in the groundwater of the basin for years or decades before arriving at well screens, even in relatively shallow wells (Boyle et al, 2012).

Nitrate levels in the El Rio area have fluctuated widely through time, with highest nitrate levels commonly observed during and following drought periods, and relatively low nitrate levels are often recorded during wet periods (UWCD, 1998, UWCD, 2008). Nitrate levels tend to stay relatively low during wet periods when low-nitrate Santa Clara River water is spread by United in the El Rio recharge basins and natural recharge to the basin is abundant. However, when there is not sufficient river water to spread at El Rio, nitrate levels in the O-H wells sometimes rise, particularly in the northeastern (up-gradient) portion of the recharge facility.

Monthly recharge totals and recorded nitrate concentrations from the El Rio UAS wells, from 2011 to present, are shown in Figure 1.4-12. The figure shows a clear inverse relationship between recharge volumes and nitrate concentrations in many of the wells. Nitrate concentrations were consistently low from January 2011 through May 2012, when surface water was available for recharge at El Rio. Nitrate concentrations increased in some wells in summer 2012, but recharge in fall 2012 and in early 2013 reduced nitrate concentrations to below the MCL in all but one well. Nitrate concentrations in all the wells increased in the summer and fall when there was no recharge activity. Since that time, nitrate concentrations more than twice the MCL have become common in some of the wells, and the wells with the lowest nitrate concentrations commonly range from about 20 to 40 mg/l.

Beginning in spring 2013, United began operating its deeper El Rio (LAS) wells in the Forebay as a source of blending water to mitigate high nitrate concentrations in the UAS wells. While low in nitrate, the LAS wells have iron and manganese concentrations that pose water quality treatment challenges for some of the O-H customers. It is a particular problem for the Port Hueneme Water Agency, as the iron and manganese interferes with the reverse osmosis system it operates. Because of this, United and its O-H customers are contemplating construction of an iron and manganese treatment system at El Rio. Construction of the facility would cost approximately $4.5 million, and cost about $200 per acre-foot to treat water produced by the LAS wells.

2 ANALYSIS

To inform the MSHCP, United has developed a set of instream flow/diversion operational scenarios. They included proposed facilities modifications. Below is a description of the operational scenarios:

Scenario 1 (No Diversion) – United diverts no river flow at the Freeman Diversion other than water released from Santa Felicia Dam during the summer-fall conservation release.[1]

Scenario 2 (Water Right Operations) – United conducts operations at the Freeman Diversion in accordance with SWRCB Permit 18908. Under this scenario, United diverts up to 375 cfs on a daily basis for distribution to groundwater recharge percolation basins and an additional 38 cfs for consumptive use within its service area. The maximum annual diversion volume on a calendar year basis is 144,630 AF. During the period February 15 to May 15, each time the Santa Clara River flows recede to 415 cfs, United must provide a minimum bypass flow of 40 cfs for 48 hours. Due to various limitations such as excessively high total suspended solid (TSS) levels (TSS greater than 2,580 mg/l) and limited recharge facilities during high groundwater conditions, United cannot always divert what is allowed under the water right. The calculated diversions included from the Hydrologic Operations Simulation System (HOSS) model (discussed in the section below) incorporated the existing facilities' limitations in the model to estimate the diversions and bypass flows under this water right at the facilities' current capabilities.

Scenario 3 (Interim Bypass Operations 2010-2016) – Between 2010 and 2016, United conducted operations at Freeman Diversion largely in accordance with the 2009/2010 bypass flow plan. This scenario includes a 160 cfs bypass target within an 18-day ramp-down schedule for migration of steelhead adults between January 1 and May 31st. Additional restrictions on diversions depend upon turn-in procedures. Smolt bypass flows are implemented from March 15th to May 31st. The District reserves the right to divert the first 40 cfs of the river after the upstream migration releases have ceased and the smolt flows are being released. The target flow at the critical riffle during this period is 120 cfs. The critical riffle is the point in the river downstream of the diversion that is the most difficult riffle for an upstream migrant. This point can move within the river although has always been located in the Forebay. The critical riffle is the compliance point for many of the bypass flows downstream of the diversion. Bypass flows are to remain at 120 cfs until all the water in the river less the critical diversions is unable to maintain the targeted flow. The critical diversions are the flows that are needed to maintain the surface water deliveries to the PTP and PVCWD. Bypass flows will then continue until all the

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[1] United releases water at the Santa Felicia Dam from Lake Piru during the fall months to recharge the Piru, Fillmore and Santa Paula groundwater basins and divert remaining flows at the Freeman Diversion.

water in the river less the critical divisions is unable to maintain 80 cfs at the critical riffle. At this time a 3-day ramp down may commence to divert the remaining river.

Scenario 4 (2008 Biological Opinion) – United conducts diversion operations in accordance with reasonable and prudent alternative 2 (RPA 2(a) and 2(b)), as contained in the 2008 Biological Opinion issued by NMFS. Under this scenario, United must bypass a flow magnitude that maintains a minimum 160 cfs over the critical riffle. After 160 cfs is maintained at the critical riffle, the remaining provisions apply. When United initiates the turn-in procedure, and when total river flows are higher than 750 cfs, United may divert up to 100 percent of the remaining flows (total flow minus minimum bypass flow) up to its full diversion limit of 375 cfs. At total river flows from 635 to 750 cfs United may divert up to 30 percent of the remaining flow up to its full diversion limit, and at total river flows less than 635 cfs United may divert up to 20 percent of the remaining flow up to its full diversion limit. Bypass flows are to be implemented until flows at the critical riffle go below 160 cfs with all the water in the river and none being diverted. From March 1 through May 31, when total river discharge immediately upstream of the Freeman Diversion is sufficient to maintain connectivity with the Santa Clara River estuary during the emigration season for juvenile steelhead, United extends the 18-day bypass flows to ensure volitional emigration of juvenile steelhead to the estuary. When total river discharge immediately upstream of the Freeman Diversion recedes to a magnitude no longer capable of maintaining connectivity with the Santa Clara River estuary (80 cfs), even with all water in the river passing downstream and none being diverted, United ceases bypass flows. The 2008 Biological Opinion was based on United's existing facilities, therefore the limitations to diversions in this scenario were based on the existing facilities' capabilities, as were scenarios 2 and 3.

Scenario 5 (Yield Neutral – Mimic Flow Recession) – This scenario is not included in the analysis.

Scenario 6 (Mimic Flow Recession) – United conducts diversion operations at the Freeman Diversion in a manner that attempts to balance mimicking the natural flow recession while minimizing net yield loss compared to scenario 3. This scenario guarantees, at a minimum, all the bypass flows in scenario 3 as well as additional flows to mimic the receding limb of the hydrograph and extend the operations of the fish passage facility from 18 to 30 days. The mimicking of the receding limb will bypass, if possible, 650, 450, 350, 280, 235, 205, 185, and 170 cfs for each consecutive day after the peak of the storm. If there is insufficient flow in the river to maintain the targeted bypass, then United returns to operations described in scenario 3. Bypass flows continue at a minimum of 160 cfs at the critical riffle for 30 days after the peak of a migration storm, available flows permitting. United implements scenario 3 flows if there is not sufficient water in the river to meet the targeted additional flows that mimic the receding limb of the hydrograph.

- **Scenario 6A** - This scenario assumes the existing diversion capabilities. Diversions in this scenario are limited to suspended sediment levels in the river of 2,580 mg/l or lower, which is the current limit on diversions for sediment concentrations in the river. Potential diversions are also rejected when the groundwater mounding occurs during wet conditions. If this scenario becomes the accepted alternative, then it will most likely be closest to actual operations until improvement have been made to reflect scenario 6B.

- **Scenario 6B** - As described in scenario 2, United is currently limited in its capabilities of diverting its full water right due to high levels of sediment and infrastructure capabilities. This scenario includes major infrastructure changes to the diversion system, conveyance system, and percolation basins, in order to regain yield that would be lost by extending the duration of bypass flows. The additional yield would result from diverting water with higher turbidity levels (TSS up to 10,000 mg/l) during the peaks of the storms, and percolating additional water in new facilities (e.g. Ferro Basin) during wet years when groundwater mounding is expected to occur.

Scenario 7 (Increased Diversion Rate Operations) – Under this scenario, United increases its instantaneous diversion rate to a maximum of 750 cfs and the total annual diversion limit to 188,000 AF. Under this scenario, United diverts water with TSS levels as high as 10,000 mg/l (current maximum levels are around 2,580 mg/l). United also implements all bypass flows as described in scenario 6. When suspended sediment and the bed load sediments reach levels that would overwhelm the system, United turns out and stops diverting water. Diversions resume when the TSS levels in the river fall below 10,000 mg/l. United diverts up to 750 cfs if the bypass flows detailed in scenario 6 are met. Upon turning-in, diversions are limited by the ramping rate schedules as detailed in Appendix A of the MSHCP (United, 2016b). Importantly, this operational scenario is not covered under United's current water right and permit. Therefore, to implement this scenario, United would need to obtain additional water rights. Additionally, the existing infrastructure of the Freeman Diversion facility and associated downstream facilities cannot accommodate operations under this scenario and would need to be modified. In many normal and wet years, storm water runoff in the Santa Clara River often is over 1,000 cfs for several days. New infrastructure at the Freeman Diversion headwork's would allow for diversions of 750 cfs during these higher flow events while providing sufficient bypass flows for the migration of steelhead and lamprey. Most of the additional yield would be accrued when there is enough water in the river to maintain both bypass flows and diversions, helping to make up for the water dedicated to bypass flows for fish migration.

The following subsections describe the models used to develop and evaluate forecasted effects of each simulated diversion scenario on groundwater conditions.

2.1.1 HYDROLOGICAL OPERATIONS SIMULATION SYSTEM (HOSS)

The HOSS is a hydrology-based operations model that simulates flow magnitudes in the Santa Clara River downstream of the Freeman Diversion. The HOSS is based upon the earlier hydrology-based Freeman Operations Model (FOM), developed by United to simulate the Freeman Diversion operations' effects upon Santa Clara River flows downstream of the Diversion, and based upon several decades of historical flow gage data, groundwater conditions in the aquifer, and diversion flow rates. The HOSS is a more user-friendly operations model with a graphical user interface

(GUI), but still incorporates United's original hydrology-based model (FOM) (R2 2016). The HOSS calculates the magnitude of flow at five locations using operational rules defined in the various scenarios. The main outputs from the model are the magnitude of diversion flows, and the magnitude of flows within the "critical reach." The critical reach is the section of the Santa Clara River extending from approximately the Highway 118 bridge downstream to the Highway 101 bridge, and includes transects to measure flow characteristics at a series of critical riffles. Since the 1990s, the HOSS has been expanded to include additional operational rule sets and refined to better represent surface and ground water interactions within the critical reach. In general, the HOSS processes total river flow entering the Freeman Diversion facility and the operational rules determine the amount of water that is diverted, the amount of water that continues to flow downstream of the facility, and the amount of water that is lost or gained to/from groundwater in the critical reach.

2.1.2 OXNARD PLAIN SURFACE WATER DISTRIBUTION MODEL

The Oxnard Plain Surface Water Distribution model is essentially a water routing model that simulates amounts of groundwater recharge in United's recharge basins and supply to surface water delivery systems, based on a series of adjustable hydrologic inputs (e.g. total river flow, diversions) and operational assumptions. All model calculations are performed in daily time steps in Excel software, using hydrologic inputs from the period of record between January 3, 1944 and December 31, 2015. The surface water distribution model was used in the current report to calculate recharge and surface water deliveries for seven operational scenarios, which are required as inputs for the groundwater model described in Section 2.1.3. In order to match the groundwater model stress periods, Oxnard Plain Surface Water Distribution model outputs were converted to monthly totals for the period between January 1, 1985 and December 31, 2015. The water distribution model was also used to calculate pumping demands for the groundwater modeling period, based on the difference between surface water deliveries and total agricultural demands within United's service area.

Water resource inputs to the model include diversion amounts, pumping from Saticoy wells and Conejo Creek diversions. Operational assumptions determine how the distribution of water resources is prioritized among recharge basins and surface water deliveries, and change based on seasons and hydrologic conditions (dry or wet years). For operational scenarios 2 to 7 (with diversions), it is assumed that diverted water can supply all recharge basins and surface water delivery systems, while supplies from the Saticoy wells are restricted to surface water delivery pipelines, and supplies from Conejo Creek diversions are restricted to the Pleasant Valley (PV) surface water delivery pipeline. For scenario 1 (no diversions), only conservations releases are diverted, and delivered to the El Rio recharge basin. Infrastructure limitations restrict maximum daily recharge in each basin and surface water deliveries, and additionally infiltration rates in the Saticoy and El Rio basins are gradually decreased, based on cumulative recharge volumes. Infiltration rates in the latter basins become limiting only when basins are filled to capacity.

2.1.2.1 INPUTS AND ASSUMPTIONS

Water resource inputs include:

- Diversions at Freeman Diversion: Daily average diversions (cfs) for all operational scenarios. Diversions were calculated in the HOSS (described in Section 2.1.2), but reduced by 10% for days when bypass flows were provided to account for inefficiencies in diversion operations due to flushing, maintenance and other reasons. For scenario 1, 100% efficiency was assumed.
- Saticoy Well Field: Daily average supply from Saticoy well field (cfs). The Saticoy well field is used to pump down the groundwater mound that develops beneath the Saticoy recharge basins, with the capacity of the Saticoy well field dependent upon groundwater elevation. The well field does not supply water during periods of heavy spreading in the recharge basins. Water pumped from the Saticoy well field is distributed to the PTP and PV pipelines. Supply input was calculated as potential supply (i.e. without considering demand) based on a correlation between the actual water levels near the pumps to the observed production rate. The Saticoy well field will only be utilized for scenarios 2 to 7, when the demands for surface water deliveries exceed the potential supply of the surface water. The Saticoy well field is not operational under scenario 1.
- Conejo Creek Diversions: Daily average diversions from Conejo Creek by Camrosa Water District and delivered to Pleasant Valley County Water District. These diversions exclusively supply the PV surface water delivery system. Diversions were assumed constant at 6.1 cfs, based on data from 2012.

Water routing prioritization indicates the order in which recharge basins and surface water delivery systems receive available water. Facilities assigned a priority of 3 or higher often receive no water, as all water has been used by higher priority facilities. Prioritization rules for water routing are summarized in Table 2.1-1, and depend on the following factors:

- Water year hydrology is defined as low, moderate or high, based on stream flow magnitude (R2 Resource Consultants, 2016).
- Season: summer is defined as July 1st to first significant storm event of the winter (equal to first turn-out of season); winter is the remaining period. During summer dry and normal conditions, the highest priorities for surface water routing are El Rio, PTP and PV (percentages to each facility are detailed in Table 2.1-1). During winter season and wet summers, the highest priority is surface water deliveries (equally divided between PTP and PV), followed by El Rio and then other recharge basins.
- Forebay available storage (AF) is the volume of groundwater that is able to be stored in the Forebay and is calculated based on water elevation in 2 key wells. Conditions with available storage > 70,000 AF indicate dry conditions with a high priority for recharge in El Rio.
- Suspended sediment concentrations. When sediment levels in the river exceed 3,000 NTUs, diversions are routed to Noble Basin first, to avoid clogging of the surface layer in the Saticoy basins due to accumulation of sediment. Sediment levels in the river were estimated based on correlation between average daily streamflow and sediment concentration.

Table 2.1-1. Prioritization order for water resources supply to United's facilities.

Facility	Scenarios 2 to 7 Summer (low – moderate)	Summer (high), winter	Forebay storage > 70,000 AF	NTU > 3,000	Scenario 1
El Rio basin	1 (50%)	2	1	5	1
PTP system	1 (25%)	1 (50%)	2 (50%)	6 (50%)	n/a
PV system	1 (25%)	1 (50%)	2 (50%)	6 (50%)	n/a
Saticoy basin	2	3	3	4	n/a
Noble basin	3	4	4	1	n/a
Rose basin	4	5	5	2	n/a
Ferro basin	5	6	6	3	n/a

Notes: "1" is the highest priority; when facilities are assigned identical priorities, the percentages of supply received for each facility are included in parentheses.

Instantaneous conveyance capacity limits for the facilities were the following: 225 cfs for Saticoy, 80 cfs for Noble, 30 cfs for Rose, 100 cfs for Ferro (increased to 375 cfs for scenario 7), 120 cfs for El Rio (increased to 405 cfs for scenario 1), 65 cfs for PTP and PV systems individually, and 75 cfs for PTP and PV systems combined. In addition, cumulative restrictions on supply to the Saticoy and El Rio basins were applied for scenarios 2 to 7 to reflect reduced infiltration rates during period of high recharge (Table 2.1-2). These rates only applied when the storage capacities for Saticoy (576 AF) or El Rio (700 AF) were exceeded. Note that the model applied no additional restrictions on supplies to Ferro basin under scenarios 2 to 6A, while in reality Ferro basin is not in use for these scenarios and any supplies should be applied to the nearby Noble basin. However, modeled supplies to Ferro basin are low for scenarios 2 to 6A, and implications for groundwater elevations in the Forebay are negligible.

Table 2.1-2. Maximum infiltration rates for scenarios 2 to 7 for Saticoy and El Rio basins.

Cumulative diversions to basin (AF)	Saticoy (cfs)	El Rio (cfs)
< 35,000	375	100
35,000 – 45,000	320	90
45,000 – 50,000	300/280*	80
50,000 – 55,000	275/240*	70
> 55,000	240	60

* Rates marked with asterisk apply when available storage in the Forebay remained below 20,000 AF during the 100 days prior. The correlation was developed by observed percolation rates in both facilities.

Pumping demands for the PTP and PV service areas were calculated as the difference between total irrigation demands and surface water deliveries within each service area. Total demands were set at the 2013 level, but adjusted monthly throughout the modeling period, based on growing season and rainfall. Total demands for periods 1 (January - June) and 2 (July – August) were 5,597 and 6,112 AF for the PTP System, and 13,947 and 16,411 AF, for the PV System, respectively. An example of monthly adjustments in demand for the PV system for 1985 is shown in Figure 2.1-1. For scenarios 2 to 7, pumping in the PTP service area was distributed between the PTP LAS and UAS wells based on historic ratios of pumping between the systems. For scenario 1, the ratios of pumping for the year 2014 (with minimal surface water deliveries) were used for this purpose.

2.1.2.2 VALIDATION

Comparison of modeled (for scenario 3) and actual (measured) monthly supplies to recharge basins and the PTP and PV systems for the period 1998-2001 indicated good accuracy of the model (Figure 2.1-2). The validation serves as a rough check of the model, because important differences exist between actual operations at the time and model inputs and assumptions: actual diversions did not fully match scenario 3 diversions, water routing to recharge basins was somewhat different than assumed in the model, and Rose and Ferro basins were not yet in service.

2.1.3 GROUNDWATER MODEL

United has developed a numerical groundwater flow model (the United model) for the aquifers underlying the Oxnard coastal plain, adapted from a USGS model for the region (Hanson and others, 2003). The United model was originally planned as an update of the USGS model, but evolved into a distinct, new model, with revised grid, layering system, and boundary conditions. The United model is still being tested and updated as new data become available; however, based on calibration results to date and initial review by an expert panel, it is a significant improvement over past groundwater models of the region, and is a suitable tool for evaluating changes to groundwater conditions under the Oxnard coastal plain resulting from potential changes in operation of the Freeman Diversion.

2.1.3.1 DEVELOPMENT

Development of the United model began with considerable effort to review and update the hydrostratigraphic conceptual model for the Oxnard Plain, Oxnard Forebay, Pleasant Valley, and Mound groundwater basins, with the goal of explicitly representing each aquifer and aquitard present in the study area. The hydrostratigraphic conceptual model for the basins was updated based on review of geophysical and lithologic logs from hundreds of gas, petroleum, and water wells in the study area, resulting in significant adjustment to aquifer top and bottom elevations in key areas compared to the USGS model, which contained only two model layers representing the UAS and the LAS. In addition, the geometry of some faults and folds was adjusted in the conceptual model during construction of multiple new cross sections developed for the model area.

Following completion of the hydrostratigraphic conceptual model, a numerical model grid was developed using MODFLOW-NWT (USGS, 2011), with 2,000-foot uniform grid spacing and 13 layers representing the seven recognized aquifers and six aquitards present in the model area. The current active domain of the UWCD model includes the Oxnard Forebay, Mound, Oxnard Plain, Pleasant Valley, and West Las Posas basins, part of the Santa Paula basin, and the submarine (offshore) outcrop areas of the principal aquifers that underlie these basins. The active model domain spans approximately 282 square miles, of which 60% (169 square miles) is onshore and 40% (113 square miles) is offshore.

Boundary conditions vary around the active model domain, as follows:

- The eastern edge of the active model domain in the West Las Posas basin adopts a no-flow boundary coincident with the East Las Posas basin boundary and the Central Las Posas Fault.
- The eastern edge of the active model domain in the Pleasant Valley basin adopts a no-flow boundary assuming negligible groundwater flux from the Santa Rosa basin.
- The northeastern boundary of the active model domain currently terminates just inside Santa Paula basin. This boundary is simulated as a general-head boundary.
- The northern edge of the active model domain coincides with the contact of Pleistocene and Holocene alluvial deposits with the San Pedro Formation near the northern edge of the Mound basin. Recharge into the San Pedro Formation (Hueneme and Fox Canyon aquifers) is simulated from the San Pedro outcrop north of the model boundary.
- The southeastern edge of the active model domain is a no-flow boundary coincident with the contact between Holocene alluvial fill deposits and bedrock of the Conejo Volcanics along the foothills of the Santa Monica Mountains. Mountain-front recharge to the semi-perched aquifer is implemented in the model adjacent to this boundary.
- The southwestern edge of the active model domain extends offshore to the submarine outcrop areas of the aquifers of the Oxnard Plain basin. This boundary is implemented as a general-head boundary to simulate the interaction of seawater with freshwater in aquifers that outcrop under the sea floor and submarine canyons.

The simulation period of the UWCD model for calibration was January 1985 through December 2012, with 336 monthly stress periods with variable recharge and pumping rates. The simulation period was selected based on the following considerations:

- The timeframe for model historical calibration was selected to span several cycles of dry and wet years so that the model can be demonstrated to simulate a wide range of climatic conditions. This calibration period included several dry periods, including the severe drought that culminated in 1990, and record-low rainfall in 2007.
- The model calibration period also was a time of major changes in groundwater management in Ventura County, including the establishment of Fox Canyon Groundwater Management Agency and construction of a pipeline to deliver water to farmers to limit groundwater pumping from UAS wells in 1986.
- Reporting of various data, including groundwater level measurements and pumping records, became more detailed and extensive starting in the early- to mid-1980s.

- At the time the current modeling effort commenced (2013), groundwater-level, pumping, and other hydrogeologic data through 2012 were reported and available in databases. Therefore, December 2012 was selected as the end-point of the model's historical calibration period. The simulation period was subsequently extended through December 2015.

A number of aquifer tests and slug tests have been performed in aquifers underlying the Oxnard coastal plain by United and the USGS. Review of the aquifer test results indicate that the hydraulic conductivities for the aquifers of the UAS typically range from 100 to 300 feet per day. The hydraulic conductivity of the aquifers in the LAS generally range from 10 to 50 feet per day. The inferred hydraulic conductivity values from the aquifer tests, together with other available information regarding hydraulic parameters for aquifers in the region, were used to set the range of initial aquifer parameters in the model. The aquifer parameters were adjusted during calibration, as described below.

2.1.3.2 CALIBRATION

The groundwater flow model was calibrated by adjusting input parameters, including:

- hydraulic conductivity
- specific yield
- storage coefficient
- stream-channel conductance
- general head boundary head and conductance
- horizontal flow barrier conductance
- recharge rates
- multi-node well conductance.

By comparing simulated groundwater levels with measured groundwater levels, and adjusting model input parameters to minimize differences between the two, a set of calibrated model parameters was determined to yield an optimal fit based on manual and automated calibration simulations. The most sensitive parameter influencing calibration of simulated to measured heads was hydraulic conductivity; this parameter is typically also subject to the greatest variability and uncertainty. Therefore, hydraulic conductivity commonly receives the greatest degree of adjustment during model calibration. The vertical to horizontal anisotropy ratio is generally set to 0.1 through most of the United model. However, the vertical anisotropy ratio in the layers representing the aquifers of the UAS in the Oxnard Forebay basin is 0.5, to represent improved hydraulic communication between layers in this area.

Results of calibration indicate that the model is well calibrated throughout most of the Oxnard Forebay, Oxnard Plain, and Pleasant Valley basins. The model is not as well calibrated yet in the Mound basin and the northeast margin of the Pleasant Valley basin; however, these areas are of minor relevance for modeling the effects of potential changes to Freeman Diversion operations on groundwater levels across most of the Oxnard Coastal Plain. Figures 2.1-3 and 2.1-4 show model calibration hydrographs, comparing measured to simulated groundwater elevations, for several UAS and LAS wells in the Oxnard Plain, Oxnard Forebay, and Pleasant Valley basins. These are just a few examples from the hundreds of calibration hydrographs used to calibrate the model, and are provided in this report simply to illustrate the degree to which the modeled groundwater elevations agree with measured groundwater elevations.

2.1.3.3 REVIEW

Following initial calibration, the model was peer-reviewed by an expert panel, including:

- Dr. Sorab Panday, of GSI Environmental, Inc., co-author of the two most recent versions of MODFLOW: MODFLOW-NWT and MODFLOW-USG;
- Jim Rumbaugh, of Environmental Simulations Inc., creator of GW Vistas, a widely used MODFLOW pre- and post-processor; and,
- John Porcello, of GSI Water, Inc., a consultant with extensive experience in groundwater modeling in general, and specific experience with hydrogeologic conditions in Ventura County.

The expert panel provided “the following key observations regarding the model’s significant and most substantive simulation capabilities” in a preliminary review memorandum (Porcello and others, 2016):

- “The model’s layering and choice of boundary conditions is appropriate for simulation of the very complex geologic and hydrostratigraphic conditions that exist in the Oxnard and Pleasant Valley groundwater basins – specifically the discrete multiple layered aquifers and aquitards; the moderate to strong compartmentalization of certain aquifers by faults; the significant well-to-well variability in the depths and aquifers which are furnishing groundwater to production wells in each groundwater basin; the strong influence of UWCD’s managed aquifer recharge programs (recharge basins) on groundwater elevations and flow directions; and the complex three-dimensional nature of the ocean interface and its interaction with each shallow and deep aquifer zone along the coast and offshore.
- The model provides an accounting of groundwater budgets and flow conditions for current land use and water use conditions. This includes the conditions that have been observed during the current drought, which began during the end of the calibration period and has continued through the period being used for model verification (2013 through 2015).
- The model is well-calibrated to changes in groundwater levels over time, including through multiple series of drought years (1985 through 1991; 1999 through 2003; 2012 to present) and above-normal rainfall years (1992-1993, 1997-1998, 2004-2005) which together comprise a hydrologic cycle composed of highly variable rainfall and streamflow conditions. Additionally, the calibration time period accounts for the gradual historical increase in dry-weather baseflows that occurred in Arroyo Las Posas from the late 1980s through the 1990s, which has substantially increased the annual volume of groundwater recharge to the Pleasant Valley basin.
- UWCD has invested considerable time and resources in updating and refining the hydrostratigraphic model, creating a new model with discrete representation of each aquifer and aquitard, and estimating the detailed recharge processes of a nearly 3-decade time period. This effort has had a direct beneficial effect on the ability of the model to simulate

> the historical fluctuations in groundwater levels that have occurred in the past. Model-simulated hydrographs of water level changes and scatter plots of the water-level-change residuals (the differences between modeled and measured changes) indicate that the model is simulating the month-by-month and year-by-year aquifer system responses to fluctuating natural hydrologic conditions (rainfall and streamflows), groundwater pumping, and managed aquifer recharge quite well, though in a few areas it was noted that water level recovery during high-rainfall years is under-predicted."

Several modifications were made to the model following the review, and model documentation is currently in preparation, in response to recommendations provided by the expert panel. United is planning to complete the model documentation by January 2017, and can share the documentation with interested parties at that time.

2.1.3.4 APPLICATION

The overall approach for applying the United model to evaluate potential effects of various operations of the Freeman Diversion was to simulate a 31-year future period with alternating cycles of above- and below-average natural and artificial recharge to the groundwater system, similar to the large fluctuations in hydrologic conditions observed during the past 31 years (January 1985 through December 2015). This was a period of greater climatic variability than has generally been observed in the historical record and is likely to be representative of the range of future climatic conditions, even if the average precipitation during the forecasting period increases or decreases to some degree as a result of long-term regional climate cycles (e.g. the Pacific Decadal Oscillation) or global climate change. The groundwater model was then used to forecast the magnitude and extent of groundwater elevation changes resulting from the different Freeman Diversion operational scenarios described in at the beginning of this Section 2. Results from simulation of each diversion scenario were evaluated by comparing the extent of the areas where groundwater elevations are forecasted to be below sea level during a representative future water year. The differences between simulation results of each diversion scenario are key to this evaluation, as the magnitude of groundwater elevations forecasted by any one scenario are partly dependent on climate and other factors that are subject to substantial uncertainty. Therefore, the analysis of groundwater modeling results (in Section 3.2) focuses on comparison of the modeled effects of the diversion scenarios (e.g. "Groundwater elevations under scenario 2 are forecasted to be higher than those under scenario 4") instead of the specific forecasts of each scenario (e.g. "groundwater elevations under scenario 3 are forecasted to be 6 feet above mean sea level at well X").

For each diversion scenario simulated, it was assumed that extractions for municipal and agricultural use from the coastal groundwater basins will continue at current rates, with some variation from year to year in response to changes in precipitation rates. It is understood that under the SGMA, a Groundwater Sustainability Plan (GSP) must be developed for most groundwater basins in the state. Because the "Oxnard basin" (defined by the DWR as consisting of both the Oxnard Plain and Forebay basins as described previously in this report) and Pleasant Valley basin are considered to be in critical overdraft, they must be managed under a GSP by January 31, 2020; the FCGMA has taken the lead role for developing GSPs for these basins. This evaluation does not incorporate assumptions regarding future water-supply changes that may be implemented as a result of GSPs for the Oxnard Plain and Pleasant Valley basins. It is recognized that the GSPs being developed by the FCGMA for the Oxnard Plain and Pleasant Valley basins could propose reductions in pumping from the UAS and/or LAS in the near future in order to avoid multiple “undesirable results” related to declining groundwater levels.

2.1.3.5 ASSUMPTIONS AND LIMITATIONS

Each of the Freeman Diversion operational scenarios described in this section was simulated assuming:

- a repeat of 1985 through 2015 climatic and boundary conditions (hydrologic-cycle inputs),
- artificial recharge rates at the Saticoy and El Rio spreading grounds and surface water deliveries to the PTP, Pleasant Valley, and Oxnard-Hueneme pipelines consistent with each diversion scenario,
- corresponding changes in pumping rates at wells that provide groundwater to agricultural lands that historically received a portion of their water supply from the Freeman Diversion via the PTP, Pleasant Valley, and Oxnard-Hueneme pipelines (e.g. more pumping from wells when a diversion scenario results in reduced surface water delivered from the Freeman Diversion),
- municipal and industrial pumping rates proportional to 1985 to 2015 rates from each well (municipal and industrial pumping in the area have remained relatively stable over time), and
- agricultural irrigation proportional to 2015 rates, adjusted upwards or downwards depending on rainfall and surface-water delivery rates.

A limitation of this approach is that it assumes a repeat pattern of climatic conditions in the study area during the period from 1985 through 2015, which included two severe droughts only 25 years apart, separated by several of the wettest years on record in the region during the 1990s. However, the extreme climatic conditions occurring during this period are potentially representative of the range of future climatic conditions when considering global climate change, which is anticipated to cause an increase in variability of precipitation amounts in southern California. Another limitation is that this approach assumes no significant land use changes during the forecasting period. Forecasting of future long-term average rainfall amounts and land-use changes in the study area were beyond the scope of this effort, but are not expected to have a large impact on the *relative* effects of each diversion scenario on future groundwater conditions (comparing one forecast to another).

3 RESULTS

This section summarizes results of the surface-water and groundwater modeling conducted to evaluate water-resource impacts forecasted to result from each diversion scenario described in Section 2.

3.1 SURFACE WATER DISTRIBUTION ON OXNARD PLAIN

Annual average Freeman diversions for the model forecasting period are presented in Figure 3.1-1. Scenario 6A presents a significant loss of yield over scenario 2 (over 8,000 AF per year). However, the infrastructure improvement projects proposed under scenarios 6B and 7 would make up for most or all of the yield loss. Scenario 4 includes by far the lowest amount of average annual diversions among scenarios with diversions (excluding scenario 1), approximately 20,000 AF less than scenario 1, which represents operations without any conservation measures for steelhead between the restrictions in the state water rights. Diversions under scenario 1 are limited to the conservation releases, and are approximately 38,000 AF less than scenario 4. Note that the climate conditions under the 31-year model forecasting period were relatively wet, and average annual diversions are between 4,500 and 8,500 AF higher compared to those using climate conditions for the 72-year period of record (1944-2015). However, relative differences between scenarios are mostly similar for the two periods.

A comparison of modeled surface water distribution to recharge basins and surface water delivery systems for scenarios 4, 6B, and 7 is provided for 2010 (a representative year with close to average rainfall) on Figure 3.1-2(a-c). During 2010, priorities for surface water distribution for normal years were in effect, specifically, the highest priorities were surface water deliveries and El Rio recharge, except during high turbidity events (see Table 2.1-1). Surface water deliveries were roughly equal for all scenarios, but under scenario 4, recharge to El Rio was significantly reduced during the January to September period due to limited diversions. Improvements in yield under scenario 7 compared to scenario 6B include more recharge to Noble, Rose and Ferro basins when higher flows can be diverted. Surface water distribution in the fall was associated with United's conservation releases from Santa Felicia Dam, and amounts were equal between scenarios.

Results modeled for 2010 agree well with those for the entire model forecasting period. Average annual recharge to El Rio and Saticoy basins was significantly lower under scenario 4 compared to all other scenarios with diversions (Figure 3.1-3, Table 3.1-1). Surface water deliveries to the PTP and PV systems were roughly equal among scenarios 2 through 7, except for a small decrease under scenario 4. Under scenario 7, significantly higher amounts of water were directed towards the Noble, Rose and Ferro basins, compared to the other scenarios. Under scenario 1, all diversions were directed toward the El Rio basins.

Table 3.1-1. Distribution of surface water on Oxnard Plain for scenarios 2 to 7.

Facility	Scenarios						
	2	**3**	**4**	**5**	**6A**	**6B**	**7**
El Rio	30,012	28,406	22,775	28,374	28,021	27,928	27,475
Saticoy	20,324	16,754	12,632	16,563	15,688	16,505	16,267
Noble	4,419	3,324	2,016	3,241	2,989	4,872	6,171
Rose	443	355	258	356	344	1,144	1,721
Ferro	380*	322*	196*	320*	317*	1,841	6,140
PTP	5,369	5,342	4,684	5,330	5,329	5,339	5,340
PV	8,848	8,749	7,437	8,735	8,722	8,735	8,738
Total	**69,795**	**63,252**	**49,998**	**62,919**	**61,410**	**66,364**	**71,852**

Notes:

Values indicated are average annual rates, in AF per year.

Deliveries to the PTP and PV systems only include surface water diverted at the Freeman Diversion.

* Under diversion scenarios 2, 3, 4, 5, and 6A, the surface-water distribution model transferred small quantities of surface water from Noble basin to Ferro basin. Such transfers are not realistic given the assumptions for each scenario; however, the transferred quantities are negligible and do not significantly affect the results of the water-resources evaluation presented herein.

A more detailed comparison of recharge to El Rio and surface water deliveries for scenarios 7 and 4 indicate that for many years, total annual recharge to El Rio is between approximately 3,500 and 13,000 AF less for scenario 4, because of reduced recharge during the winter season (Figure 3.1-4a and 3.1-4b). During most dry years, when total diversions are low, recharge is similar between the two scenarios. Surface water deliveries are between 500 and 2,200 AF higher for scenario 7 during half of the forecasting period. For the other years, the difference is less than 500 AF. Scenarios 6A and 6B compare similarly to scenario 4 with respect to recharge to El Rio and surface water deliveries.

3.2 GROUNDWATER MODEL

The United groundwater model was used to forecast groundwater elevations in each of the aquifers underlying the Oxnard coastal plain in response to changes in pumping and recharge assumed during the next 30 years under each diversion scenario described in Section 2. For each diversion scenario, time-series hydrographs were prepared for representative wells to illustrate forecasted changes in groundwater elevation over time. In addition, the forecasted 0 ft msl (sea level) groundwater contour was mapped in the Oxnard aquifer (representing the UAS) and Fox Canyon (main) aquifer (representing the LAS) during a model stress period considered representative of groundwater conditions in the region during a typical year, when groundwater elevations are not forecasted to be anomalously high or low as a result of extended wet periods or droughts. The "typical" year selected for contouring of groundwater levels was year 17 of the simulation. Forecasted groundwater elevations in the Mugu (UAS) and Hueneme (LAS) aquifers were also inspected by United, and were very similar to those in the Oxnard and Fox Canyon aquifers, respectively. Therefore, forecasted results are only shown in this report for the Oxnard and Fox Canyon (main) aquifers. Review of the time-series hydrographs shown on Figures 3.2-1 and 3.2-2 indicates that forecasted groundwater elevations during year 17 of the simulation approximately represent typical long-term conditions during average to wet years, rather than the two severe droughts culminating in years 7 and 31 of the simulation period. For this evaluation, groundwater elevations during average- to wet-year hydrologic conditions are considered most relevant; both measured and simulated groundwater elevations during severe droughts decline significantly and rapidly, but are not as representative of long-term average conditions.

Figures 3.2-1 and 3.2-2 show groundwater elevations forecasted to occur under each diversion scenario, at representative UAS and LAS wells (01N21W17D02S and 01N21W07J02S, respectively, with locations shown on Figures 3.2-3 and 3.2-4) in the eastern Oxnard Plain basin near the boundary with the Pleasant Valley basin. The percentage of time during the 31-year simulation period that groundwater elevations at the representative UAS well is forecasted to be below sea level under each diversions scenario is summarized below each hydrograph on Figure 3.2-1. Groundwater elevations are consistently below sea level at the representative LAS well; therefore, the percentage of time that groundwater levels are below sea level under each scenario is not shown on Figure 3.2-2.

Figure 3.2-1 indicates that under most diversion scenarios, groundwater elevations in the UAS at well 01N21W17D02S are forecasted to typically fluctuate between -10 to +10 ft msl, except during severe droughts near the beginning and end of the simulation. Maintaining groundwater elevations above sea level in the Oxnard Plain and Pleasant Valley basins will likely be key to preventing further seawater intrusion and other groundwater quality problems from occurring in the aquifers underlying the Oxnard coastal plain. Groundwater elevations are forecasted to be below sea level slightly more than 50 percent of the simulation period under diversion scenarios 2 and 7, and 59 to 76 percent under scenarios 3, 6A, and 6B. It is notable that under diversion scenarios 1 and 4, groundwater elevations at this well are forecasted to remain below sea level throughout the duration of the simulation, indicating a strong potential for increased seawater intrusion into the UAS in the central Oxnard Plain.

Figure 3.2-2 indicates that forecasted groundwater elevations in the LAS at well 01N21W07J02S typically fluctuate from -40 to -100 ft msl, and deeper during the simulated severe droughts. If groundwater elevations were to actually remain at these depths below sea level for a decade or longer, seawater intrusion would likely advance at a rapid pace, potentially causing some water-supply wells to be shut down due to poor water quality. The model simulations assume that all existing wells will continue pumping throughout the simulation period; however, continued pumping from parts of the LAS may not actually be feasible if water quality declines further due to seawater intrusion.

In both the UAS and the LAS, groundwater elevations under diversion scenario 1 are forecasted to be substantially lower compared to the other diversion scenarios, indicating the importance of surface-water diversions (which are the primary source of artificial recharge and deliveries of surface water in lieu of pumping) in preventing or mitigating undesirable results of groundwater-level declines in the aquifers underlying the Oxnard coastal plain.

Scenario 1 was modeled for the sole purpose of illustrating the importance of surface-water diversions from the Santa Clara River on groundwater conditions in the region. Therefore, subsequent discussion of forecasted effects of the various diversion scenarios generally does not include scenario 1—if included, scenario 1 would always result in the greatest declines in groundwater levels and resultant negative effects on groundwater quality (e.g. seawater intrusion). The large differences in the forecasted groundwater impacts resulting from scenario 1 versus all of the other diversion scenarios illustrates how successful the operation of the Freeman Diversion is at sustaining UAS groundwater elevations across the Oxnard coastal plain. Forecasted UAS groundwater elevations in a typical year under scenario 1 are similar to the current basin conditions following five years of sustained drought. Water levels are currently at or near record lows for many wells in both the UAS and LAS as a result of drought conditions since 2012, which have greatly reduced United's artificial recharge operations.

Across the Oxnard coastal plain, forecasted groundwater elevations are typically highest in both the UAS and LAS under diversion scenarios 2 and 7, with somewhat lower groundwater elevations under diversion scenarios 3, 6A, and 6B. Forecasted groundwater elevations under diversion scenario 4 are significantly lower than groundwater elevations under all other scenarios (except scenario 1), typically 5 feet deeper in the UAS and 10 feet deeper in the LAS compared to scenarios 2, 3, 6A, 6B, and 7.

The purpose of including the hydrographs shown on Figures 3.2-1 and 3.2-2 is to illustrate the general temporal trends in forecasted groundwater elevations under each diversion scenario. Although the timing of the upward and downward trends in groundwater elevation shown on these figures would be consistent throughout the Oxnard Plain and Pleasant Valley basins, the specific groundwater elevation for a given time would depend on location. Forecasted groundwater elevations at locations near the coast and in areas with a relatively high density of pumping wells are typically lower than groundwater elevations at the inland margins of the basins, particularly in areas with few pumping wells.

Figures 3.2-3 and 3.2-4 show the areas where groundwater elevations in the Oxnard aquifer (selected to represent the UAS) and the Fox Canyon aquifer (selected to represent the LAS) are forecasted to be below sea level under each diversion scenario during a typical water year (year 17 of the simulation period). Areas where groundwater levels remain below sea level during average to wet years would be most prone to lateral seawater intrusion and other related groundwater quality problems, with the potential for chloride concentrations to increase to levels that could make the aquifer unusable for years to decades. Detailed modeling of seawater intrusion rates and extents was beyond the scope of this evaluation; however, seawater intrusion in the region has historically been directly correlated with groundwater-level decline below sea level in the aquifers of the Oxnard Plain and Pleasant Valley basins. Under diversion scenarios 1 and 4, the areas where groundwater elevations are forecasted to be below sea level extend offshore under the Pacific Ocean seafloor near Hueneme Submarine Canyon (scenario 1) and Mugu Submarine Canyon (scenarios 1 and 4). Such an occurrence would likely exacerbate seawater intrusion in the region, as these submarine canyons are considered to be the primary locations for seawater to enter the aquifers underlying the Oxnard coastal plain.

Inspection of Figures 3.2-3 and 3.2-4 indicates the following:

- All of the modeled diversion scenarios are forecasted to have negative impacts on groundwater elevations in the UAS and LAS in the Oxnard Plain, Forebay, Pleasant Valley, and the Mound basins.
- Diversion scenarios 2 and 7 result in the smallest areas where groundwater elevations in the UAS and LAS are forecasted to be below sea level. In the UAS, groundwater elevations are forecasted to be below sea level in a circular area that includes the southeastern Oxnard Plain basin and in the southern Pleasant Valley basin, and in smaller areas in the southwestern Mound and northern Pleasant Valley basins. In the LAS, groundwater elevations are forecasted to be below sea level across nearly the entire extent of the coastal plain. The forecasted occurrence of groundwater elevations below sea level across large areas during average to wet years would be expected to result in further seawater intrusion relative to the current extent, shown with black dotted lines on Figures 3.2-3 and 3.2-4.
- The areas where groundwater elevations in the UAS and the LAS are forecasted to be below sea level under diversion scenarios 3, 6A, and 6B are somewhat larger than under diversion scenarios 2 and 7.
- The areas where groundwater elevations in the UAS and LAS are forecasted to be below sea level under diversion scenario 4 are substantially larger than all other diversion scenarios (except scenario 1). In particular, the area where forecasted groundwater elevations are below sea level in the UAS includes most of the remaining farmland (and associated water-supply wells) in the eastern portion of the Oxnard coastal plain, south of Camarillo and east of Oxnard.

The areas of forecasted UAS and LAS groundwater elevations below sea level under each diversion scenario (during a typical year) are summarized on Figures 3.2-5 and 3.2-6. These graphs indicate areas of the UAS and the LAS forecasted to be below sea level under diversion scenarios 3, 4, 6A, 6B, and 7 relative to scenario 2, quantifying the differences in impact that are qualitatively apparent on Figures 3.2-3 and 3.2-4. Figures 3.2-5 and 3.2-6 indicate that:

- There is a direct relationship between average annual diversions and the area where groundwater elevations are below sea level below the Oxnard coastal plain.
- The forecasted areas of the UAS and LAS below sea level under scenario 7 are approximately equal to those under scenario 2.
- The forecasted areas below sea level under scenarios 3, 6A, and 6B range from approximately 1,400 to 4,900 acres (2.2 to 7.7 square miles) greater than under scenario 2 in the UAS, and from 2,600 to 7,900 acres (4.1 to 12.4 square miles) greater than under scenario 2 in the LAS.

- The forecasted area below sea level under scenario 4 is approximately 19,000 acres (30 square miles) greater than under scenario 2 in the UAS, and 21,000 acres (33 square miles) greater in the LAS.

Table 3.2-1 compares modeled surface water diversion scenarios based on the annual average volume of surface water available for diversion. The table also contains notes with additional information and other considerations.

Table 3.2-1. Comparison of diversion scenarios.

Scenario	Average Annual Estimated Surface Water Diversions (AF per year)[1]	Total Area Where Groundwater Elevations Are Forecasted to be Below Sea Level During a Typical Year (acres)[1]	Comments
1 – No Diversion	0	UAS: 104,300 LAS: 124,800	Modeled solely to illustrate the importance of surface-water diversions from the Santa Clara River on groundwater conditions in the region and generally is not compared to the other scenarios. Scenario 1 always results in the greatest declines in groundwater levels and likely negative effects on groundwater quality (e.g. seawater intrusion).
2 – Water Rights Operation	69,800	UAS: 12,000 LAS: 85,300	Represents operation allowed under current surface-water rights and without any infrastructure modification. Similar in effects on groundwater resources to scenario 7.
3 – Interim Bypass Operations 2010-2016	63,200	UAS: 15,400 LAS: 91,300	Would not require additional water rights or substantial infrastructure modification; however, forecasted impacts to groundwater resources are significantly greater than scenarios 2, 6B, or 7.
4 – 2008 Biological Opinion	49,900	UAS: 31,500 LAS: 106,200	Much greater impacts to groundwater resources than all other scenarios (except scenario 1).
6a – Mimic Flow Recession	61,400	UAS: 16,900 LAS: 93,200	This scenario assumes the existing diversion capabilities. It does not require a modification of the District's existing water right. However, forecasted impacts to groundwater resources are significantly greater than scenarios 2, 3, 6B, or 7.

Table 3.2-1. Comparison of diversion scenarios.

Scenario	Average Annual Estimated Surface Water Diversions (AF per year)[1]	Total Area Where Groundwater Elevations Are Forecasted to be Below Sea Level During a Typical Year (acres)[1]	Comments
6b – Mimic Flow Recession	66,300	UAS: 13,400 LAS: 87,900	This scenario involves infrastructure modifications required to capture storm flows with higher turbidity, but does not include an expansion of the District's surface-water right from the State Water Resources Control Board. Although final infrastructure design parameters are not yet available, it is estimated that construction costs for these infrastructure changes will be in the range of $5-10 million[2] and the maintenance of that infrastructure will have significant, but as yet unquantified, operational costs.
7 – Increased Diversion Rate Operations	71,800	UAS: 11,200 LAS: 84,500	Requires extensive infrastructure modifications and also a new water right from State Water Resources Control Board to allow higher instantaneous surface water diversion rates and higher annual diversion quantities (feasibility not addressed in this report). Although final infrastructure design parameters are not yet available, it is estimated that construction costs for these infrastructure changes will be in the range of $25-30 million[2] and the infrastructure will have significant, but as yet unquantified, operational costs.

[1] Rounded to the nearest 100 acre-feet.

[2] These costs are in addition to funds that may be required for construction of a new fish passage structure and associated infrastructure.

The modeling results also provide an indication of the relative benefit of delivering surface water in lieu of pumping groundwater from the UAS and/or LAS in the Oxnard Plain and Pleasant Valley basins. The major differences in groundwater elevation between the UAS (most commonly above sea level) and the LAS (most commonly below sea level) under each diversion scenario are largely a result of the rate of groundwater extraction from the LAS, and how readily natural and artificial recharge (which occur primarily in the UAS in the Forebay) reaches those areas of pumping. Natural and artificial recharge entering the UAS in the Forebay basin has a substantial and immediate effect on groundwater levels in adjacent areas of the Oxnard Plain, particularly in the UAS. Recharge entering the UAS in the Forebay basin also migrates radially outward and downward to more distal locations, and thus has a substantial influence on groundwater levels in the LAS in the eastern Oxnard Plain and Pleasant Valley basins. However, delivering surface water to these areas and reducing pumping from the LAS by a corresponding amount is a more direct, expedient, and effective approach to limiting groundwater elevation decline in the LAS in much of the Oxnard Plain and Pleasant Valley basins.

As noted previously in this section, GSPs being developed by the FCGMA may include pumping reductions in portions of the UAS and/or LAS most susceptible to seawater intrusion, which would maintain groundwater elevations above sea level as a potential approach to achieve sustainable yield in the Oxnard Plain and Pleasant Valley basins. It is currently unknown specifically how such pumping reductions would be achieved, but likely options include: increased surface water imports to replace groundwater withdrawals, new sources of locally derived water, more pumping from the UAS, reduction in irrigated farmland, or increased conservation in cities. Regardless of how such pumping reductions would be achieved, the differences in forecasted effects of each diversion scenario would tend to be accentuated by the resultant higher average groundwater elevations. For example, Figure 3.2-4 indicates that without pumping reductions, all of the simulated diversion scenarios result in groundwater elevations in the LAS that are below sea level across most of the Oxnard coastal plain, even during average to wet years. If pumping reductions were implemented that raised groundwater elevations across most of the LAS to near-sea-level, then the differences in artificial recharge and surface-water deliveries (in-lieu of pumping) that are inherent in each diversion scenario would result in greater differentiation between scenarios in measurable objectives such as area and duration of groundwater elevations above sea level, and frequency of seaward versus landward hydraulic gradients. United will consider updating this analysis when sufficient information is released by FCGMA during its groundwater sustainability planning efforts to simulate the likely locations and magnitudes of LAS (or UAS) pumping reductions if included in the GSPs.

Also, it is beyond the scope of this analysis to evaluate economic or other impacts to water users and the region of curtailments of groundwater pumping or surface water delivery.

4 CONCLUSIONS

Despite long-term efforts to conserve water, import more water to the District and optimize the use of local resources, water deficits exist in a number of areas throughout the District, most notably on the southern Oxnard Plain and in the Pleasant Valley basin. In some places, the depletion of groundwater reserves has to date simply resulted in lowered water tables. In other areas, significant water quality problems have developed in response to conditions of overdraft. The California Department of Water Resources recently revised the list of basins "subject to critical overdraft." Southern California has six basins designated as subject to critical overdraft, and the Oxnard Plain and Pleasant Valley basins have been assigned this designation. The Oxnard Plan and Pleasant Valley basins are the only two coastal basins on the list.

Using a combination of surface water and groundwater models, United compared diversion amounts at the Freeman Diversion, amounts of groundwater recharge and surface water deliveries at United's facilities, and resultant forecasted groundwater elevations in the Oxnard Plain and Pleasant Valley basins, for pertinent diversion scenarios. All diversion scenarios except scenario 7 provided lower diversion amounts for recharge and surface-water deliveries in lieu of pumping, compared to scenario 2 (Water Rights Operations). Scenario 4 provides by far the lowest amount of average annual diversions (excluding scenario 1), approximately 20,000 AF per year less than scenario 2 and 22,000 AF per year less than scenario 7. Under the current assumptions, the differences in diversions between scenarios were predominantly reflected in differences in groundwater recharge to United's various recharge basins. Average annual recharge to El Rio and Saticoy basins was significantly lower under scenario 4 compared to all other scenarios (between approximately 8,000 and 15,000 AF per year). In turn, significantly higher amounts of water were directed towards the Noble, Rose and Ferro basins under scenario 7 compared to the other scenarios (between approximately 7,000 and 12,000 AF per year). Surface water deliveries and groundwater pumping are less sensitive to changes in diversions, except for lower surface water deliveries and corresponding groundwater pumping increases in the PTP and PV service areas under scenario 4 (approximately 2,000 AF per year). However, differences in surface water deliveries and groundwater pumping can be much greater during individual years.

Key conclusions of the evaluation of forecasted impacts to groundwater include:

- All of the modeled diversion scenarios are forecasted to have negative impacts on groundwater elevations in the UAS and LAS in the Oxnard Plain, Forebay, Pleasant Valley, and the Mound basins.
- Under each diversion scenario, groundwater elevations in the Oxnard Plain and Pleasant Valley basins are forecasted to rise and decline over time primarily in response to modeled groundwater recharge (largely from surface water obtained from the Freeman Diversion) and withdrawal (pumping) rates. Maintaining groundwater elevations above sea level is key to preventing further seawater intrusion and other groundwater quality problems from

occurring in the aquifers underlying the Oxnard coastal plain, and for achieving sustainable management of the Oxnard Plain, Forebay, and Pleasant Valley basins, as required by the State under the SGMA.

- There is a direct relationship between average annual diversions and the area where groundwater elevations are below sea level below the Oxnard coastal plain.
- In both the UAS and the LAS, groundwater elevations under diversion scenario 1 (surface-water diversions limited to those associated with releases from Santa Felicia Dam) are forecasted to be substantially lower than under the other diversion scenarios, remaining below sea level across most of the Oxnard coastal plain throughout the simulation period. This illustrates the importance of United's artificial recharge and surface-water deliveries in lieu of pumping for preventing or mitigating undesirable results (e.g. seawater intrusion) of groundwater-level declines in the aquifers underlying the Oxnard coastal plain.
- Under the assumptions applied to the groundwater model for this evaluation, forecasted groundwater elevations in the UAS remain above sea level across much of the Oxnard coastal plain during most average to wet years. However, forecasted groundwater elevations in areas of the southeastern part of the Oxnard Plain basin, southern Pleasant Valley basin, Mound basin, and northern Pleasant Valley basin remain below sea level under all scenarios (Figure 3.2-3). The southern Oxnard Plain and Pleasant Valley basin area has historically been the site of seawater intrusion, and is of particular concern for achieving sustainable groundwater management. The area of the UAS below sea level is smallest under diversion scenarios 2 and 7, are larger under scenarios 3, 6A, and 6B (1,400 to 4,900 acres greater than under scenario 2), and are substantially larger (19,000 acres, encompassing most of the remaining farmland in the eastern Oxnard coastal plain east of Oxnard and south of Camarillo) under scenario 4. Because of the long distance between the southeastern Oxnard Plain and the artificial-recharge basins of the Forebay basin, continuing direct delivery of surface water to farms in lieu of groundwater pumping would likely to be the most effective way to raise groundwater elevations and mitigate seawater intrusion in this area.
- In the LAS, groundwater elevations below most of the Oxnard coastal plain are forecasted to remain well below sea level throughout the simulation period under all diversion scenarios. Similar to the UAS, the forecasted areas below sea level for scenarios 2 and 7 are roughly equal, are somewhat larger under scenarios 3, 6A, and 6B (2,600 to 4,900 acres greater than under scenario 2), and are substantially larger (21,000 acres) under scenario 4. This will almost certainly increase the rate and areal extent of seawater intrusion into the LAS in the Oxnard Plain and Pleasant Valley basins, and could prevent the FCGMA from achieving sustainable management as required under the SGMA. However, GSPs being developed by the FCGMA may include pumping reductions in portions of the LAS most susceptible to seawater intrusion, as a potential approach to assist in achieving achieve sustainable yield. United will consider updating this analysis when sufficient information is released by FCGMA during its groundwater sustainability planning efforts to simulate locations and magnitudes of potential LAS (or UAS) pumping reductions.

Historically, the Freeman Diversion (and United's previous diversion structures near Saticoy) have been the single most effective project providing groundwater recharge to the Oxnard Forebay and the Oxnard Plain. Any reduction in United's ability to divert water from the Santa Clara River has a direct impact on the sustainable yield of these groundwater basins and the protection and continued viability of the dependent water uses and associated economies and communities. Considering the forecasted impacts on groundwater levels described above for each diversion scenario evaluated in this analysis, Scenario 2, which reflects operations consistent with United's surface-water right, would accomplish the purposes of the Freeman Diversion better than any alternative flow operations that do not rely on additional infrastructure or new water rights. The forecasted negative impacts to groundwater levels of scenarios 1 and 4 are substantially greater than all other scenarios, increasing the potential for seawater intrusion and other undesirable results. United developed Scenario 6 to address conservation objectives for steelhead migration. However, Scenario 6A would have a larger impact to groundwater levels compared to Scenario 2. This report does not evaluate the feasibility of those actions needed to take water at higher flows.

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FIGURES

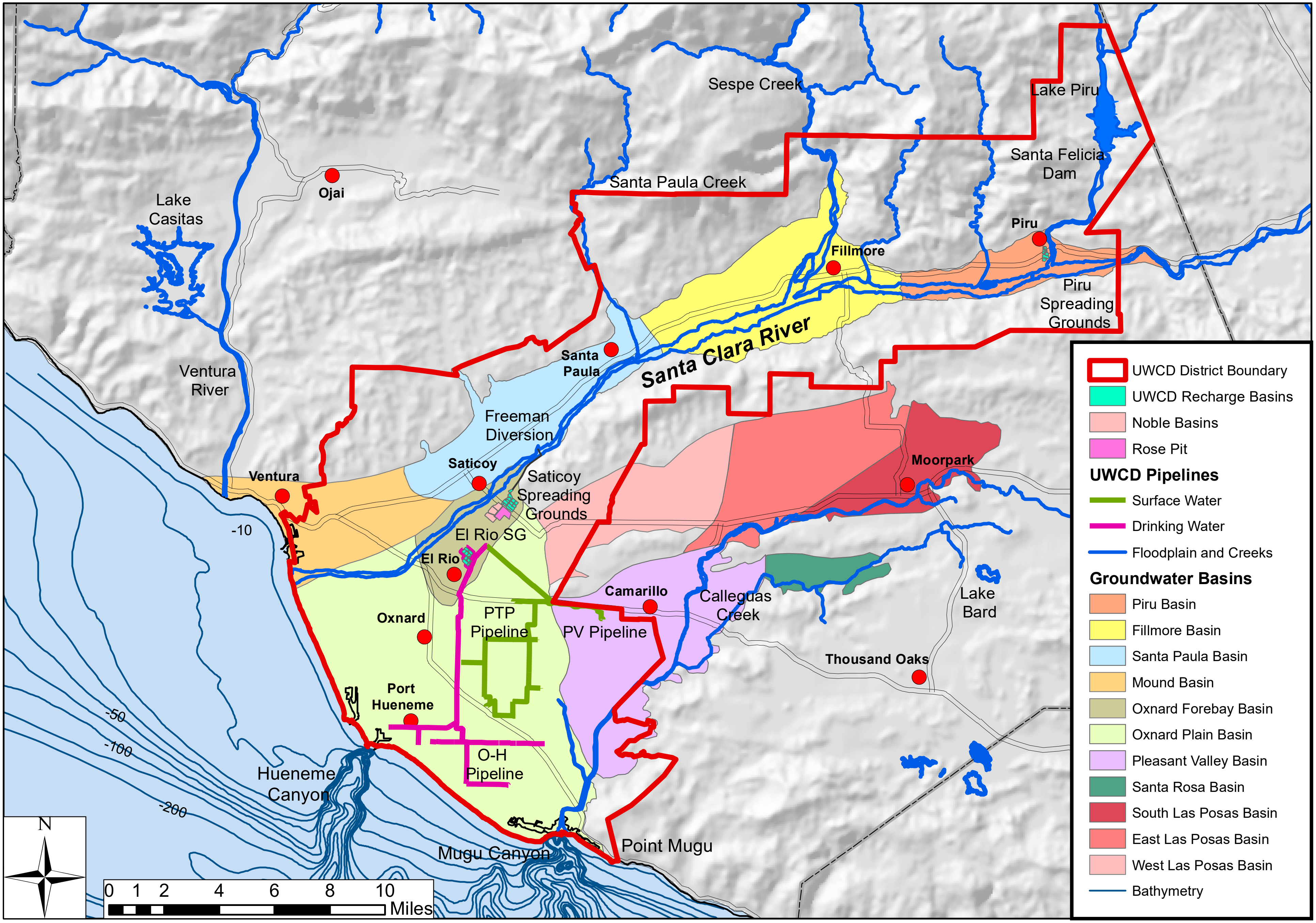


Figure 1.1-1. Groundwater basins, District boundary, and major recharge and conveyance facilities.

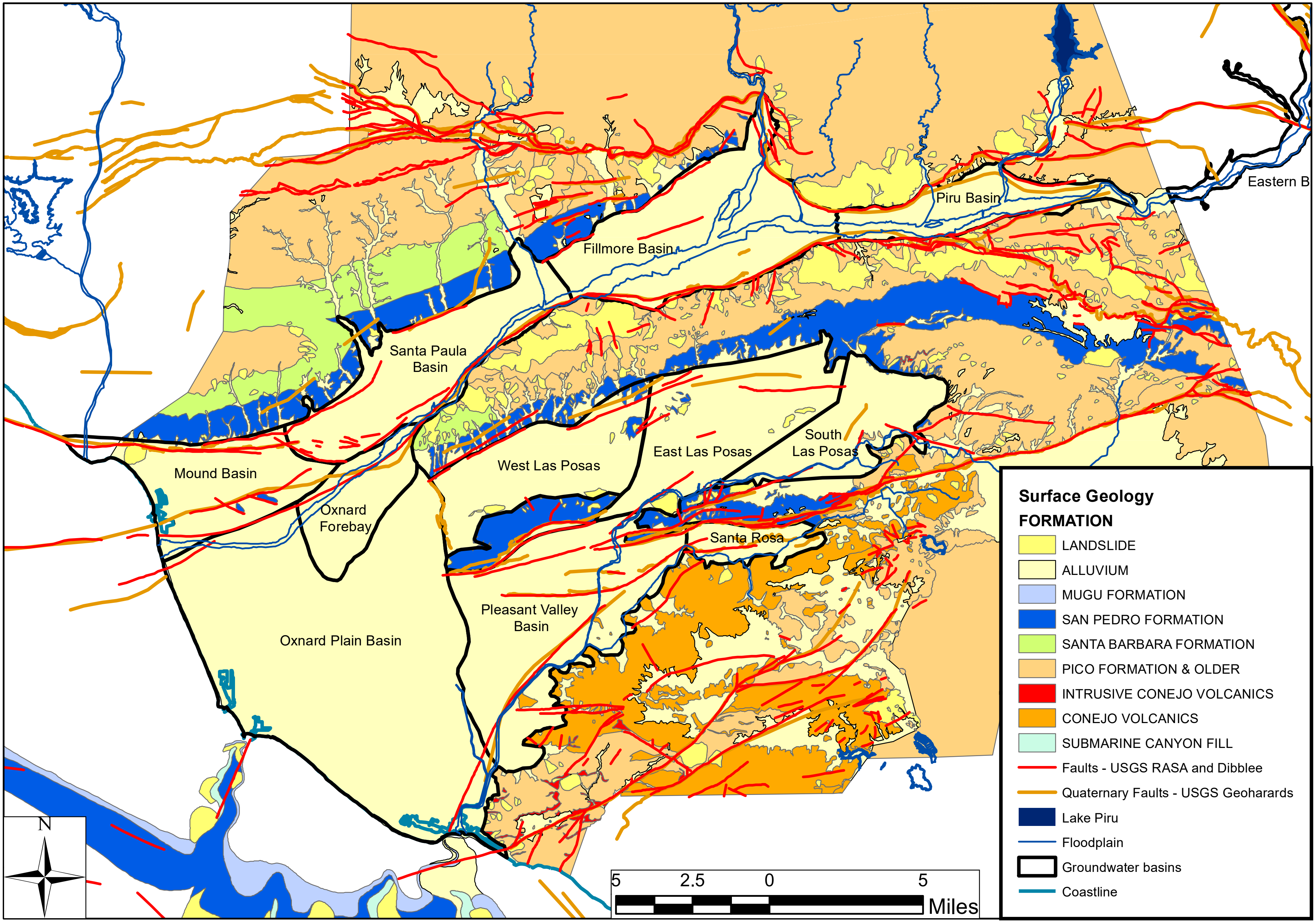


Figure 1.3-1. Surface geology and faults.

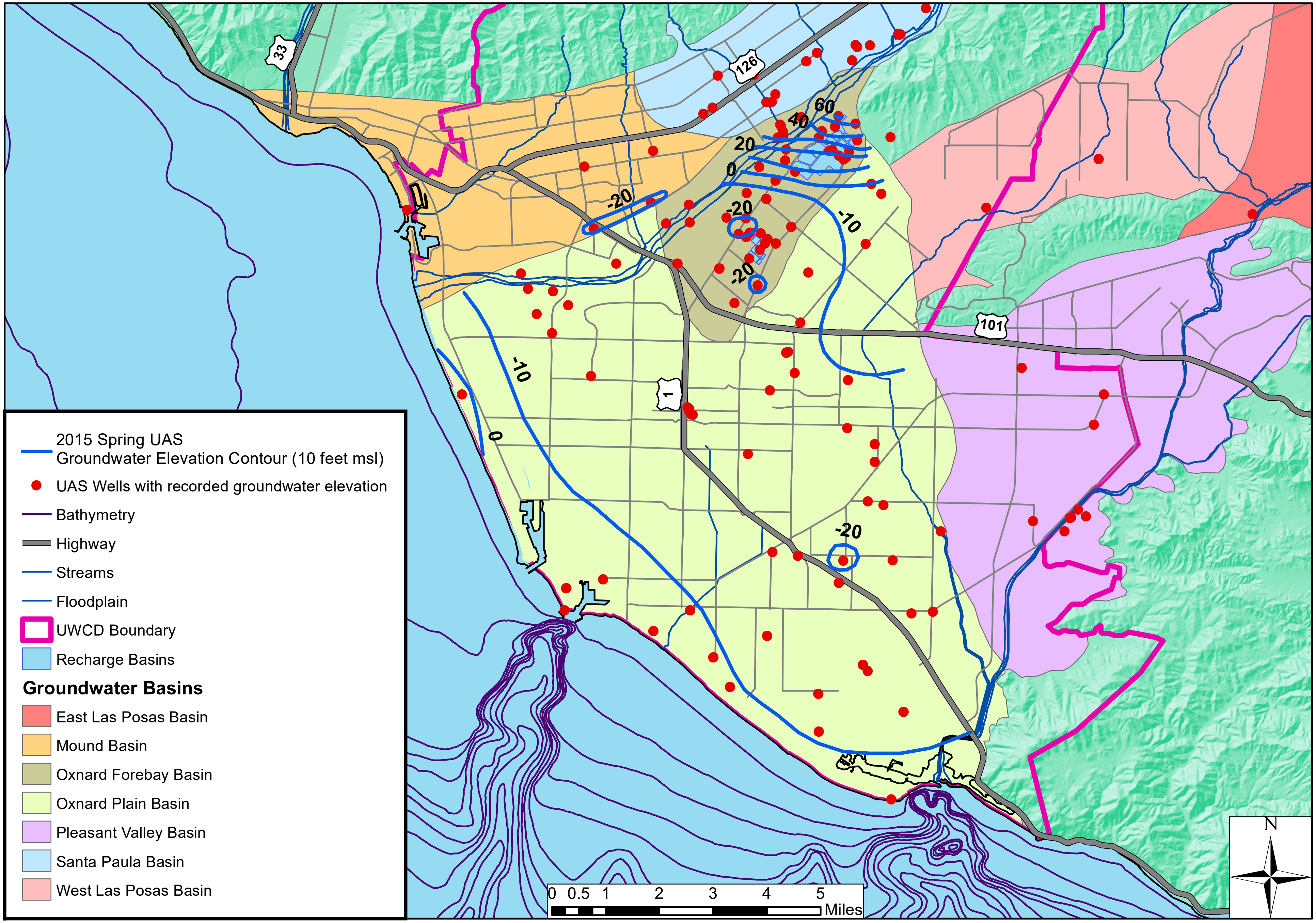


Figure 1.4-1. Spring 2015 groundwater elevations, Upper Aquifer System wells.

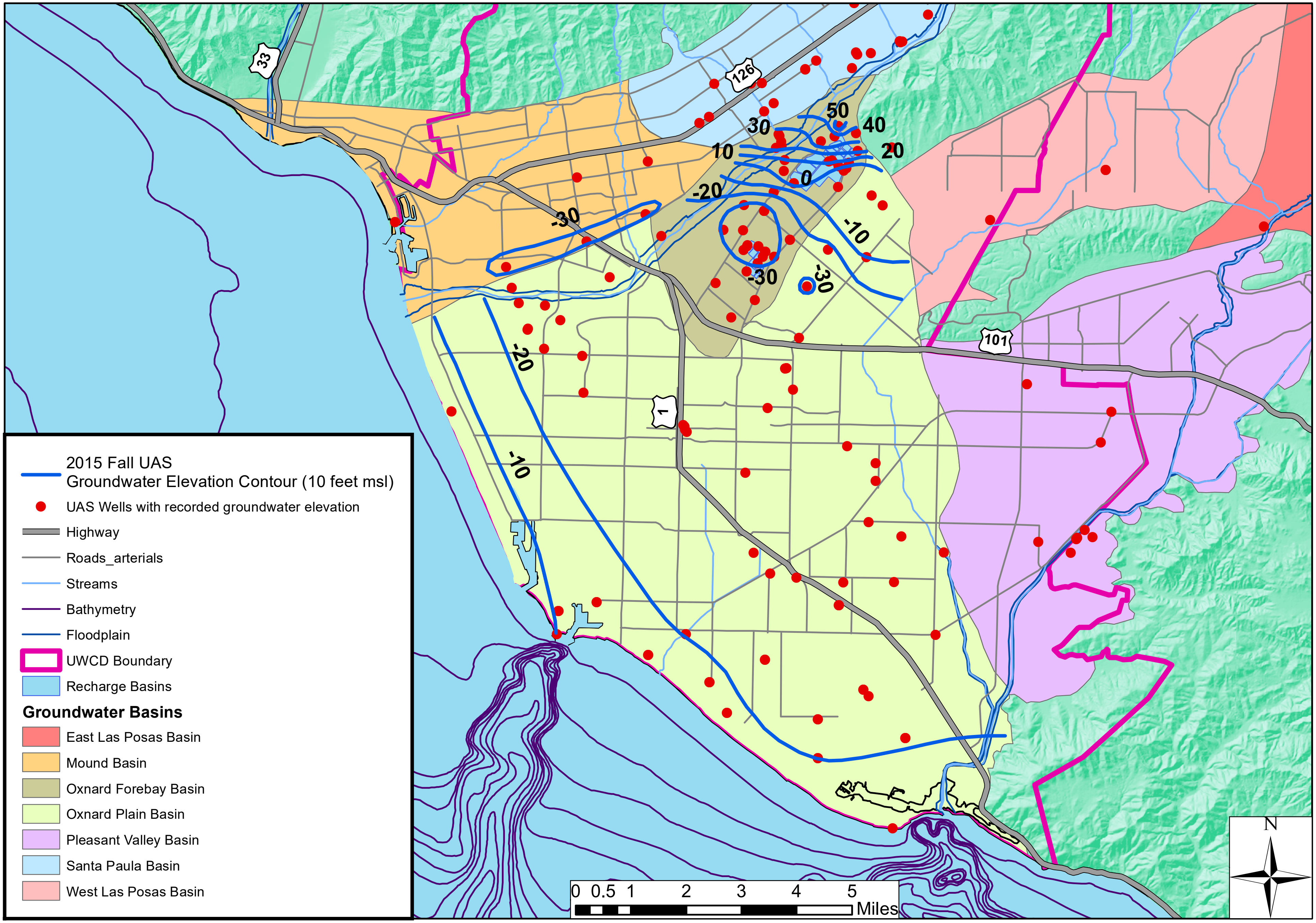


Figure 1.4-2. Fall 2015 groundwater elevations, Upper Aquifer System wells.

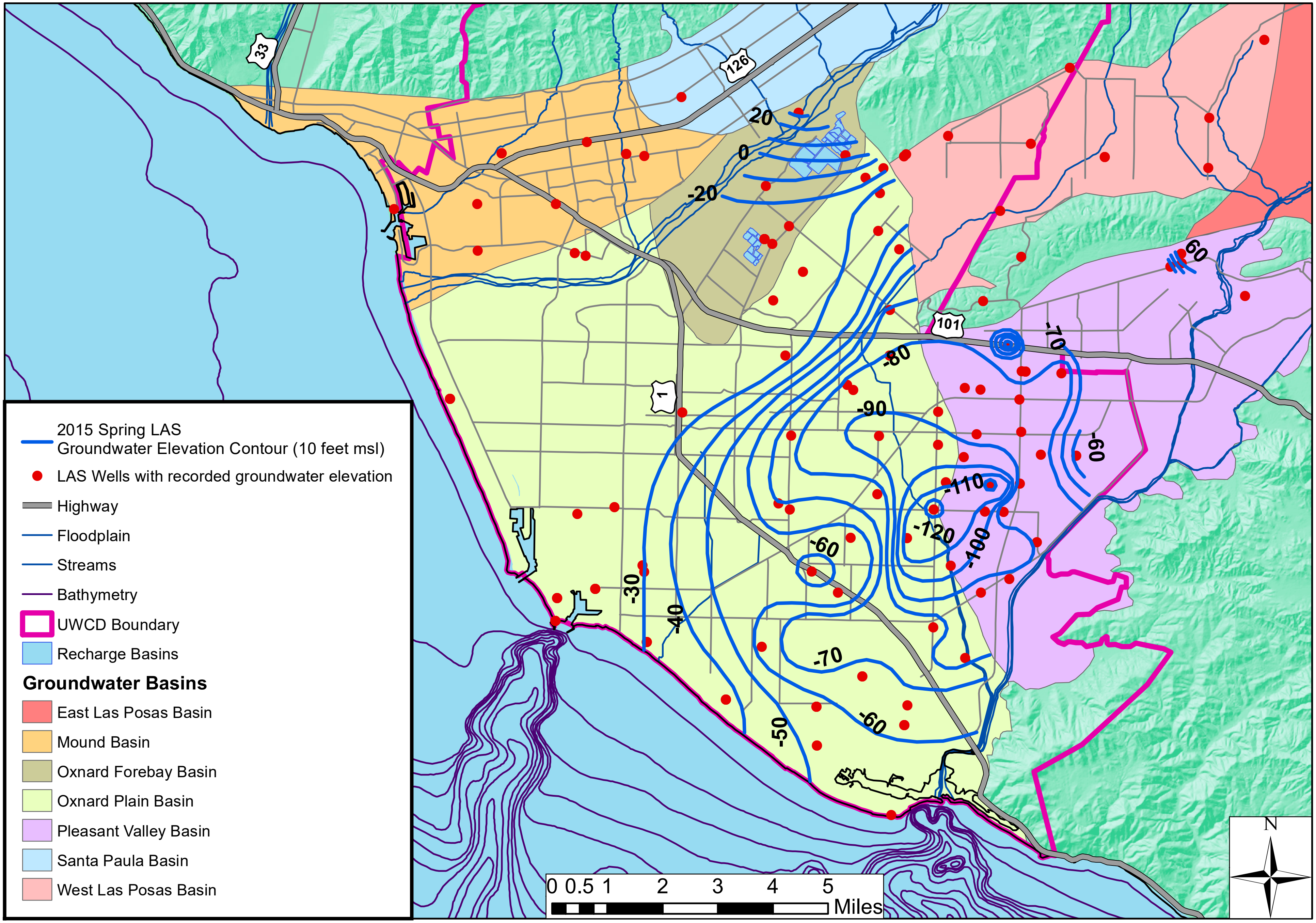


Figure 1.4-3. Spring 2015 groundwater elevations, Lower Aquifer System wells.

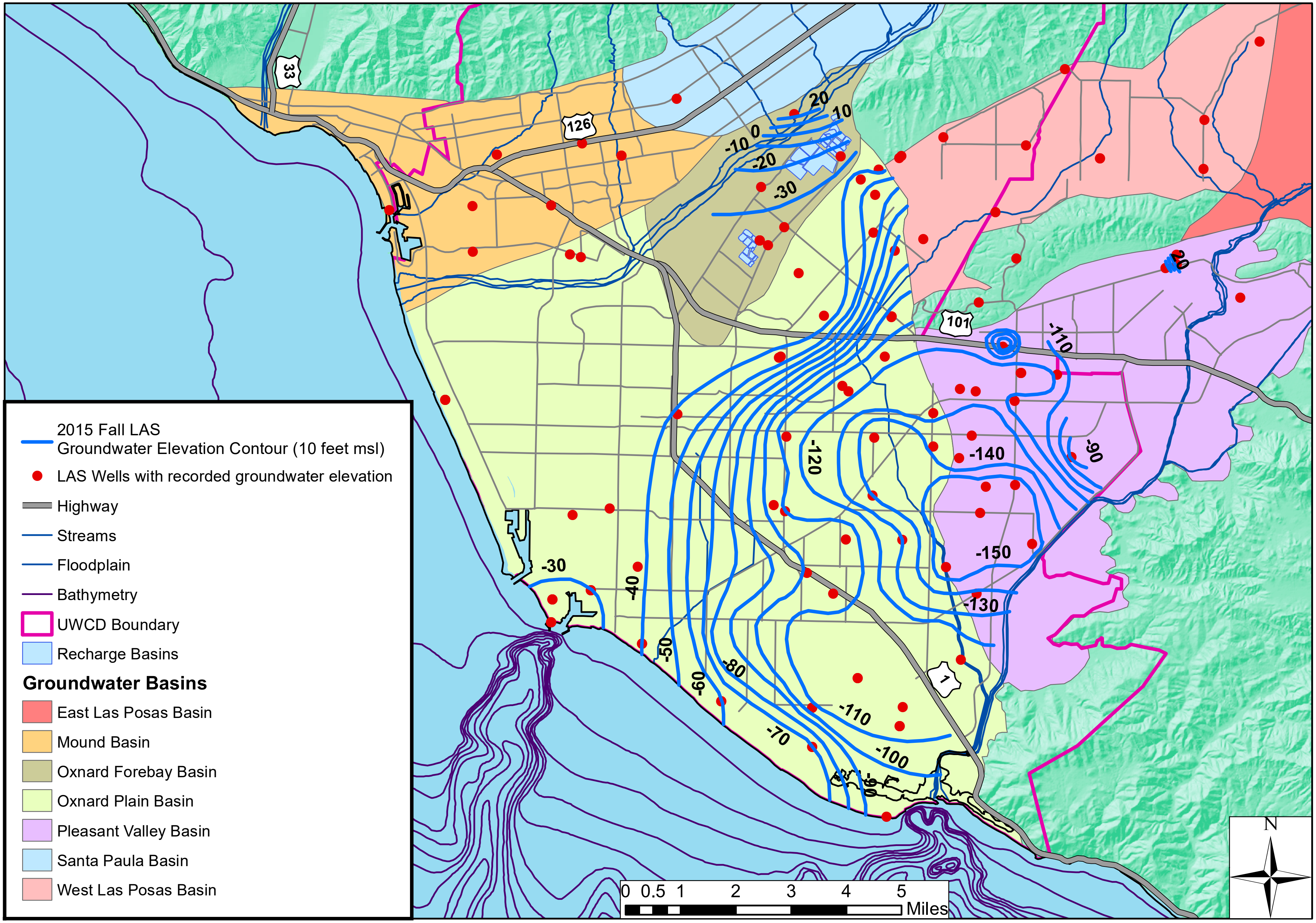


Figure 1.4-4. Fall 2015 groundwater elevations, Lower Aquifer System wells.

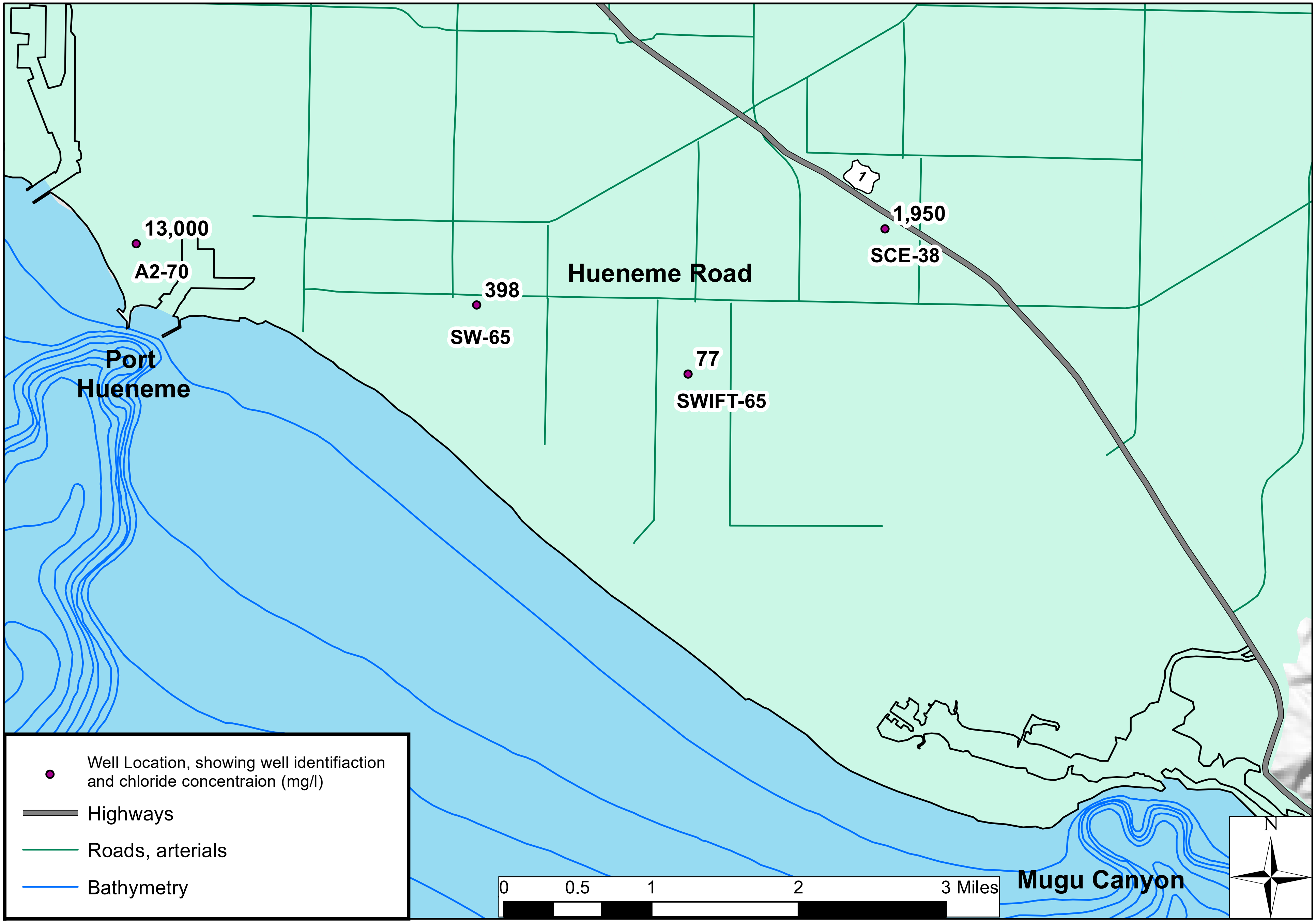


Figure 1.4-5. Semi-perched aquifer chloride concentrations, coastal monitoring wells, fall 2015. Interpreted source of elevated chloride levels key: Black label = Background level.

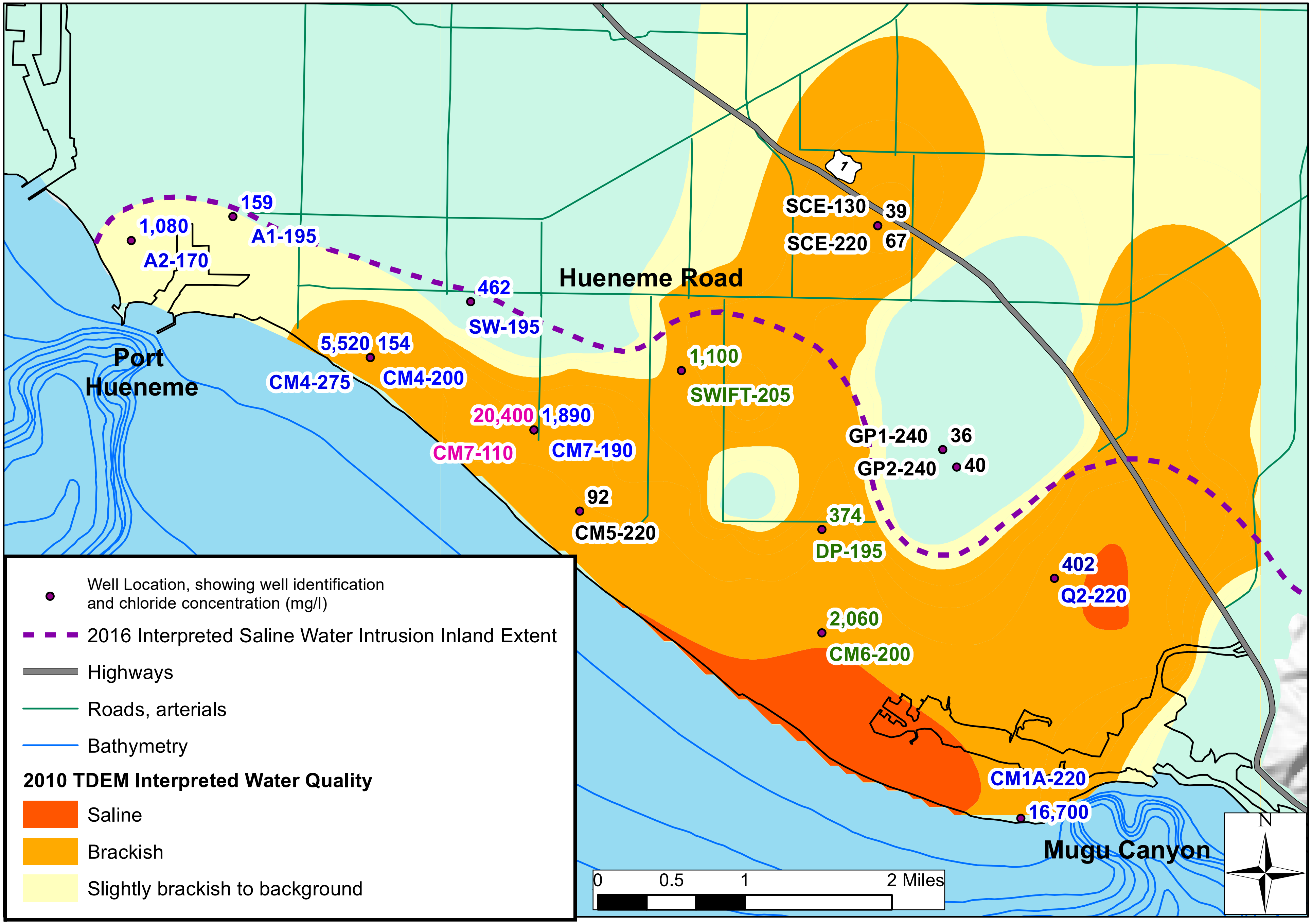


Figure 1.4-6. Oxnard aquifer chloride concentrations, coastal monitoring wells, fall 2015.
Interpreted source of elevated chloride levels key: Green label = Sediments; Blue label = Seawater; Pink label = Semi-perched water; Black label = Background level.

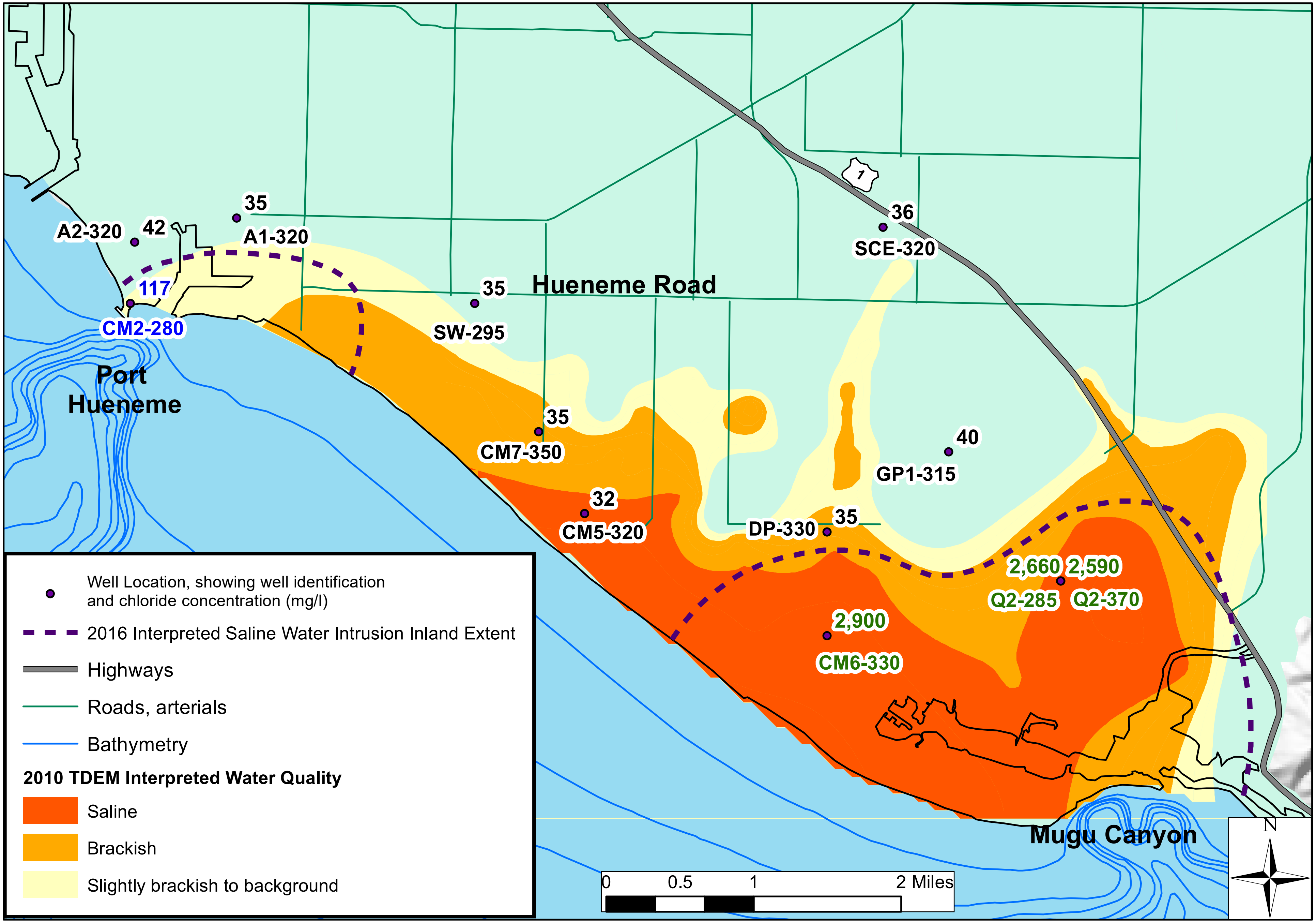


Figure 1.4-7. Mugu aquifer chloride concentrations, coastal monitoring wells, fall 2015.
Interpreted source of elevated chloride levels key: Green label = Sediments; Blue label = Seawater; Black label = Background level.

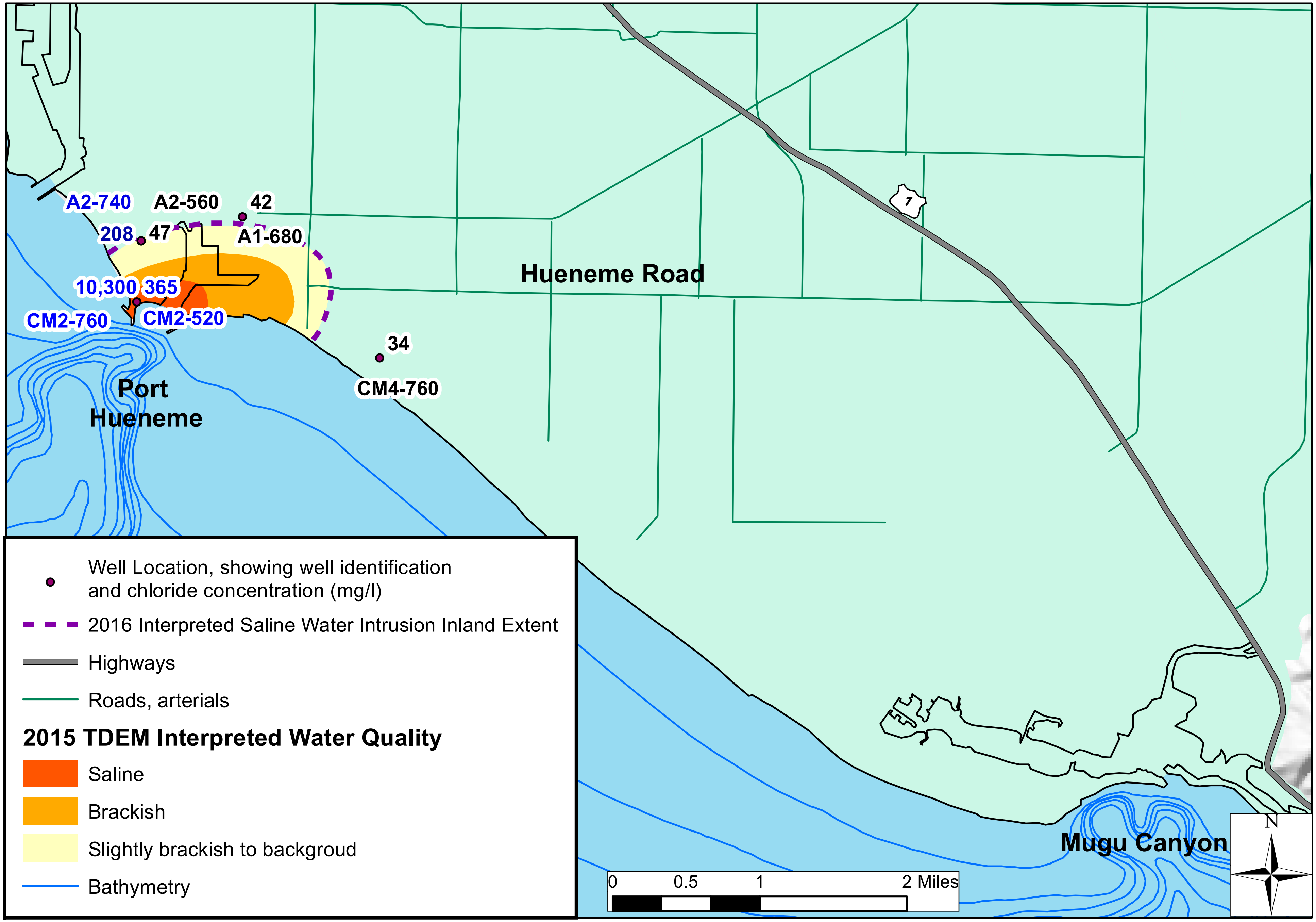


Figure 1.4-8. Hueneme aquifer chloride concentrations, coastal monitoring wells, fall 2015.
Interpreted source of elevated chloride levels key: Blue label = Seawater; Black label = Background level.

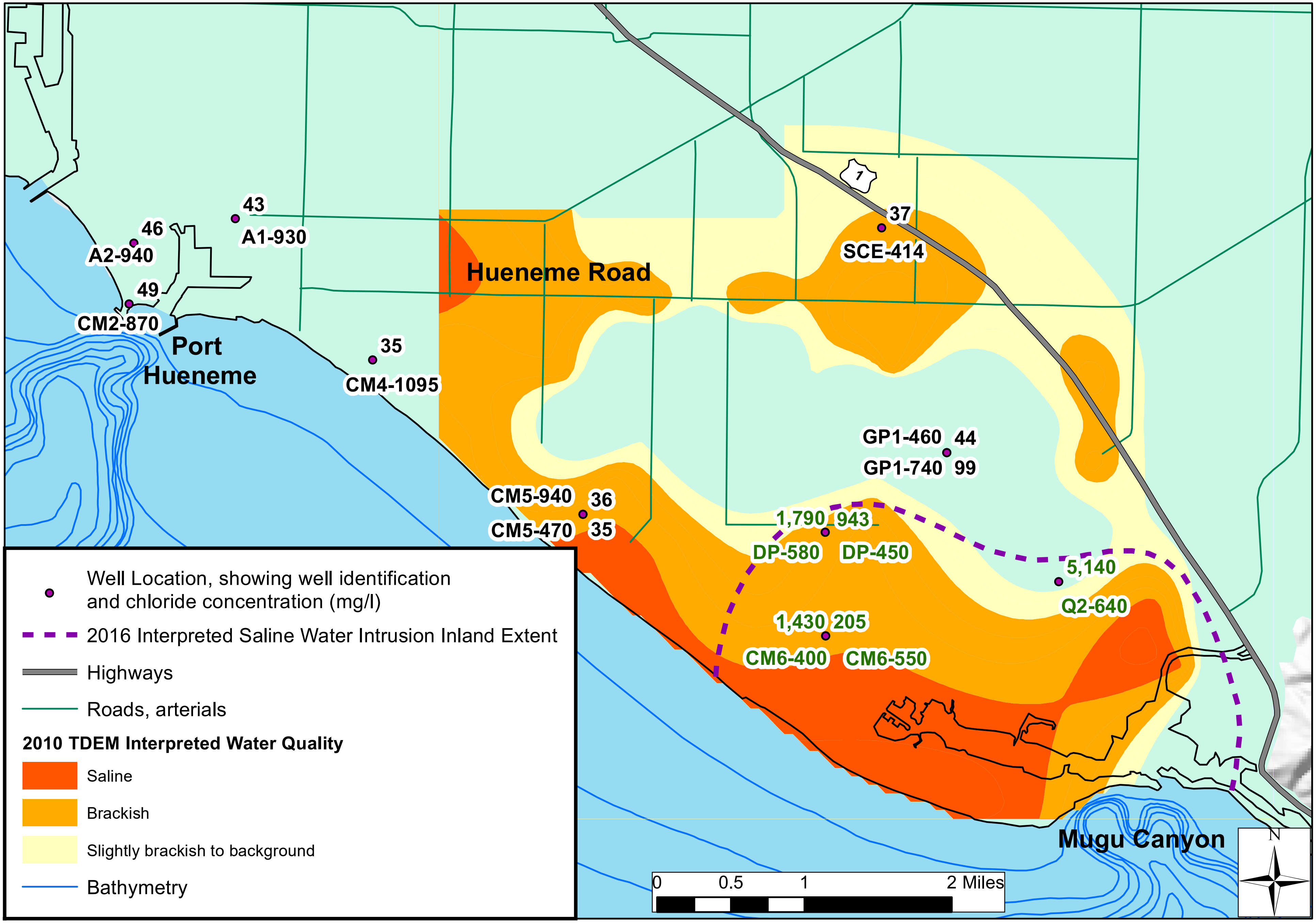


Figure 1.4-9. Fox Canyon aquifer chloride concentrations, coastal monitoring wells, fall 2015.
Interpreted source of elevated chloride levels key: Green label = Sediments; Black label = Background level.

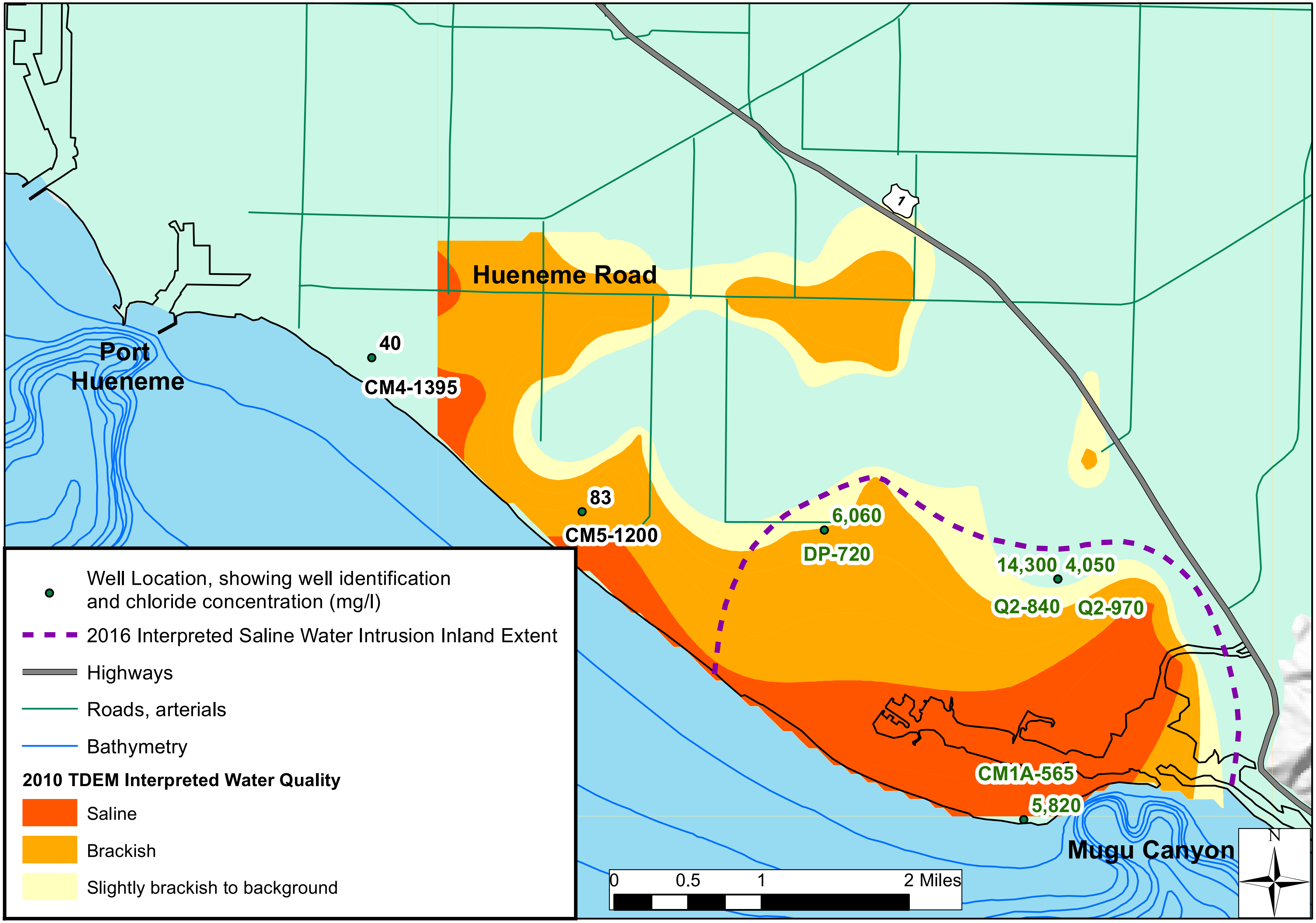
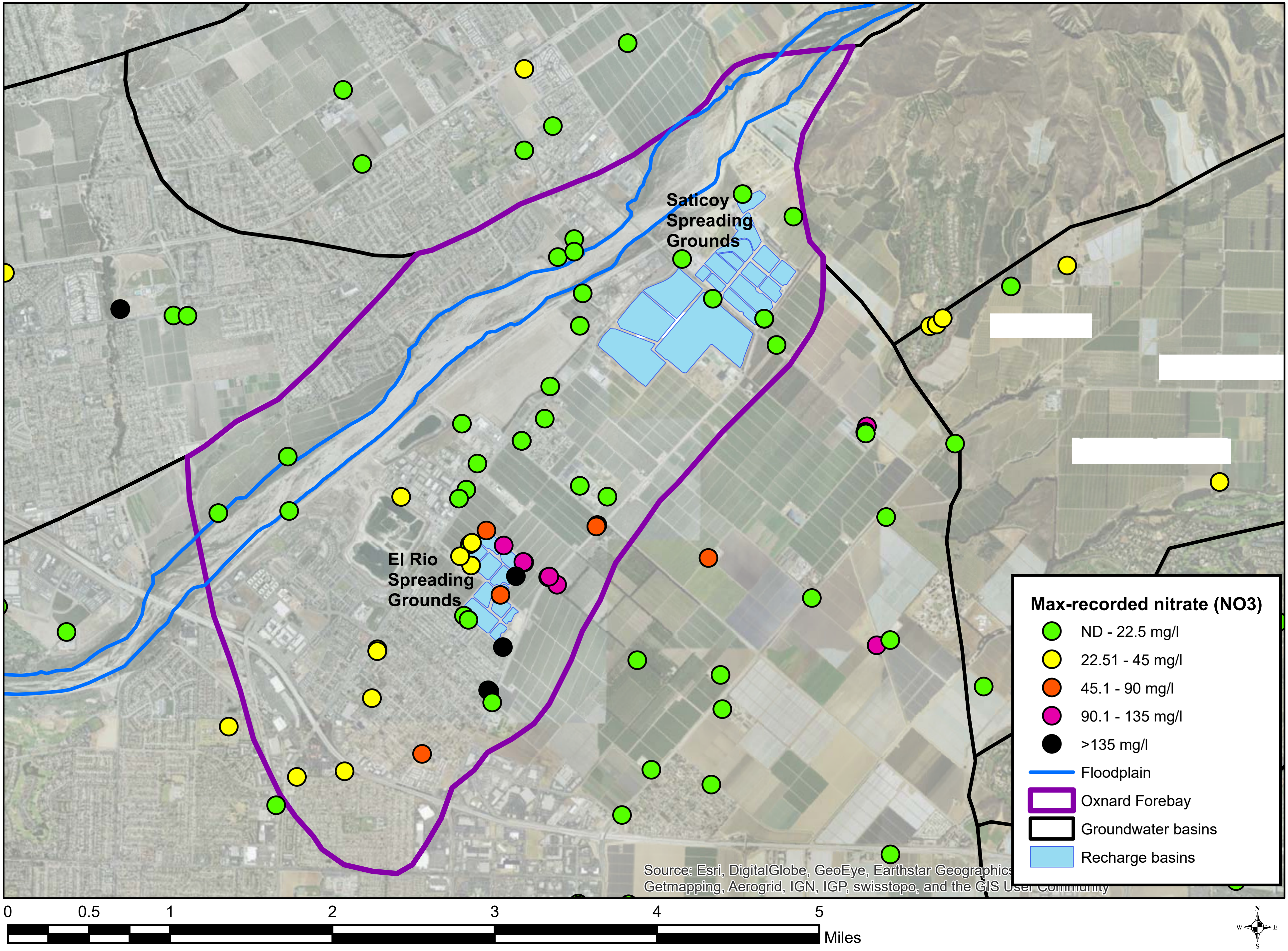


Figure 1.4-10. Grimes Canyon aquifer chloride concentrations, coastal monitoring wells, fall 2015. Interpreted source of elevated chloride levels key: Green label = Sediments; Black label = Background level.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics
Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 1.4-11. Maximum recorded nitrate in wells, 2015 calendar year.

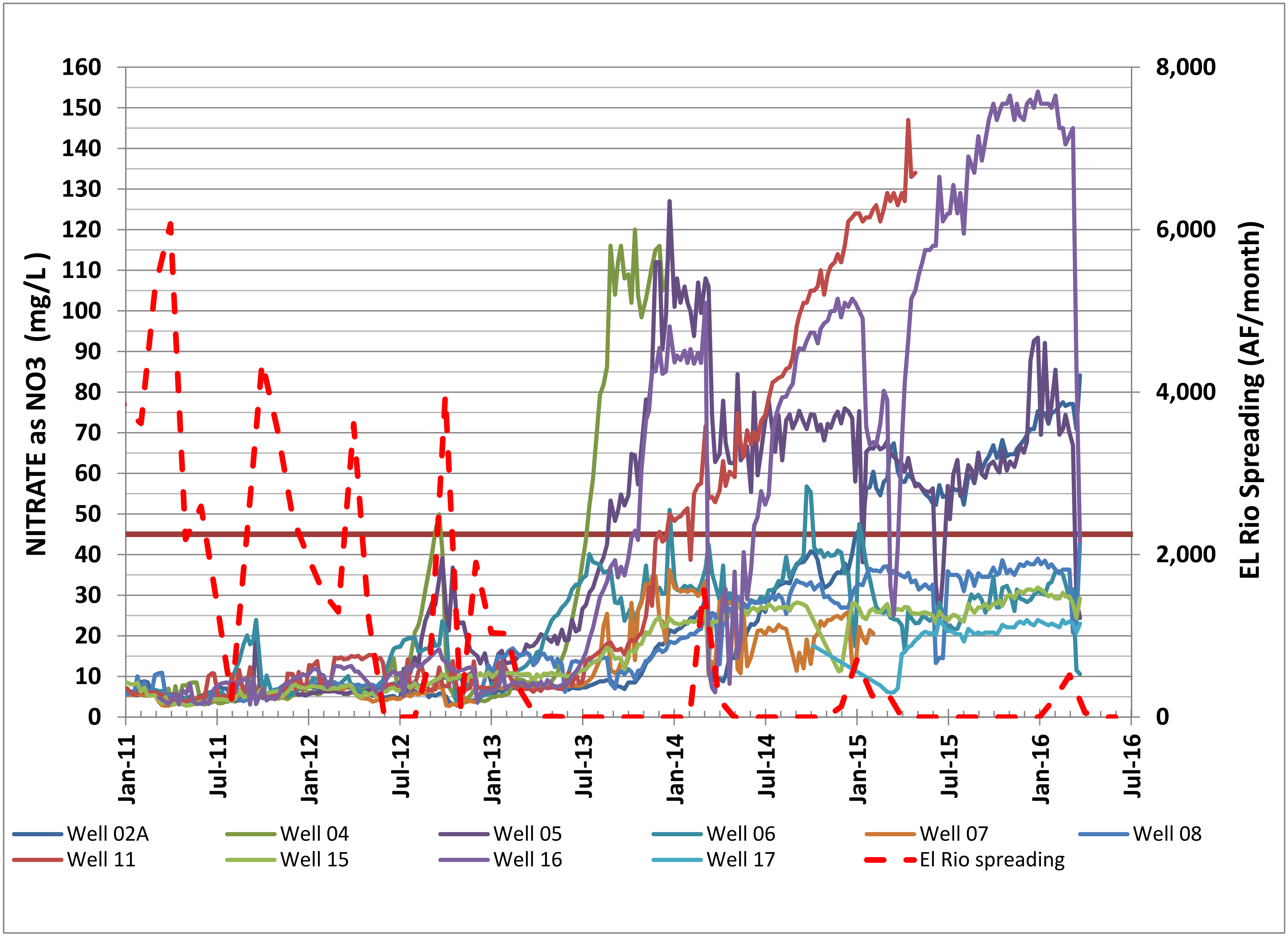


Figure 1.4-12. Recorded nitrate concentrations in El Rio UAS wells, with monthly recharge volumes.

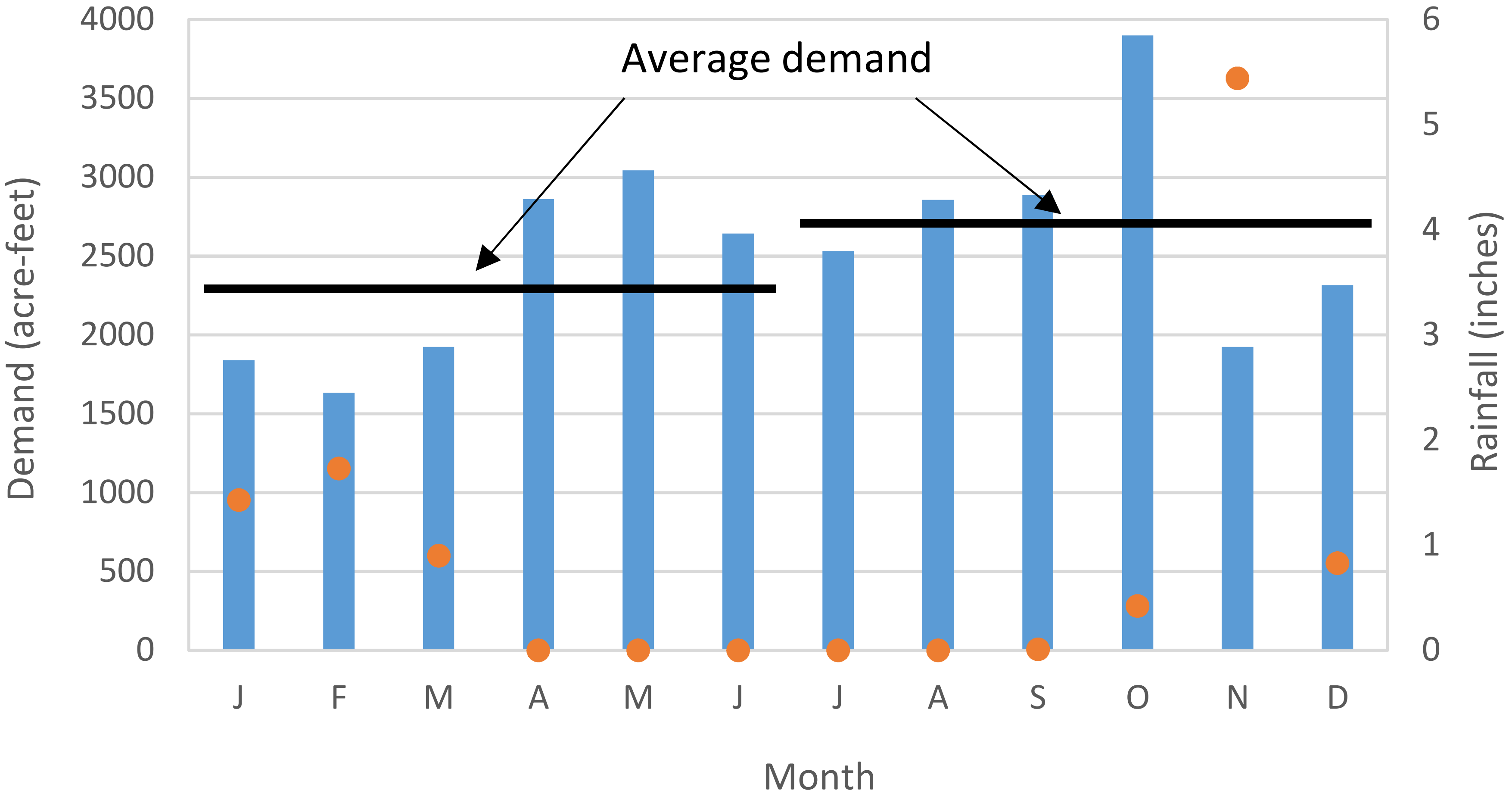
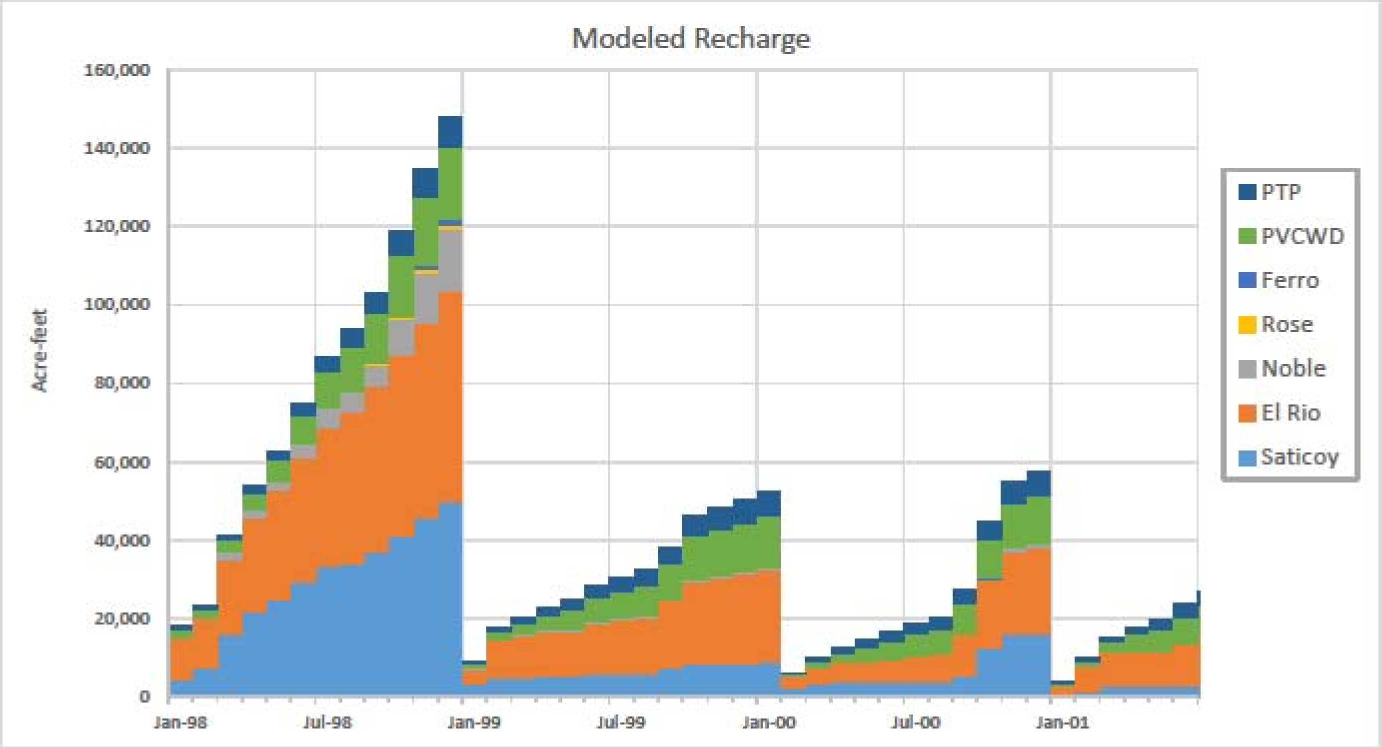


Figure 2.1-1. Irrigation demands for Pleasant Valley County Water District service area (1985). Black lines indicate average demands for each 6-month period, bars indicate adjusted monthly demands, and circles indicate monthly rainfall.



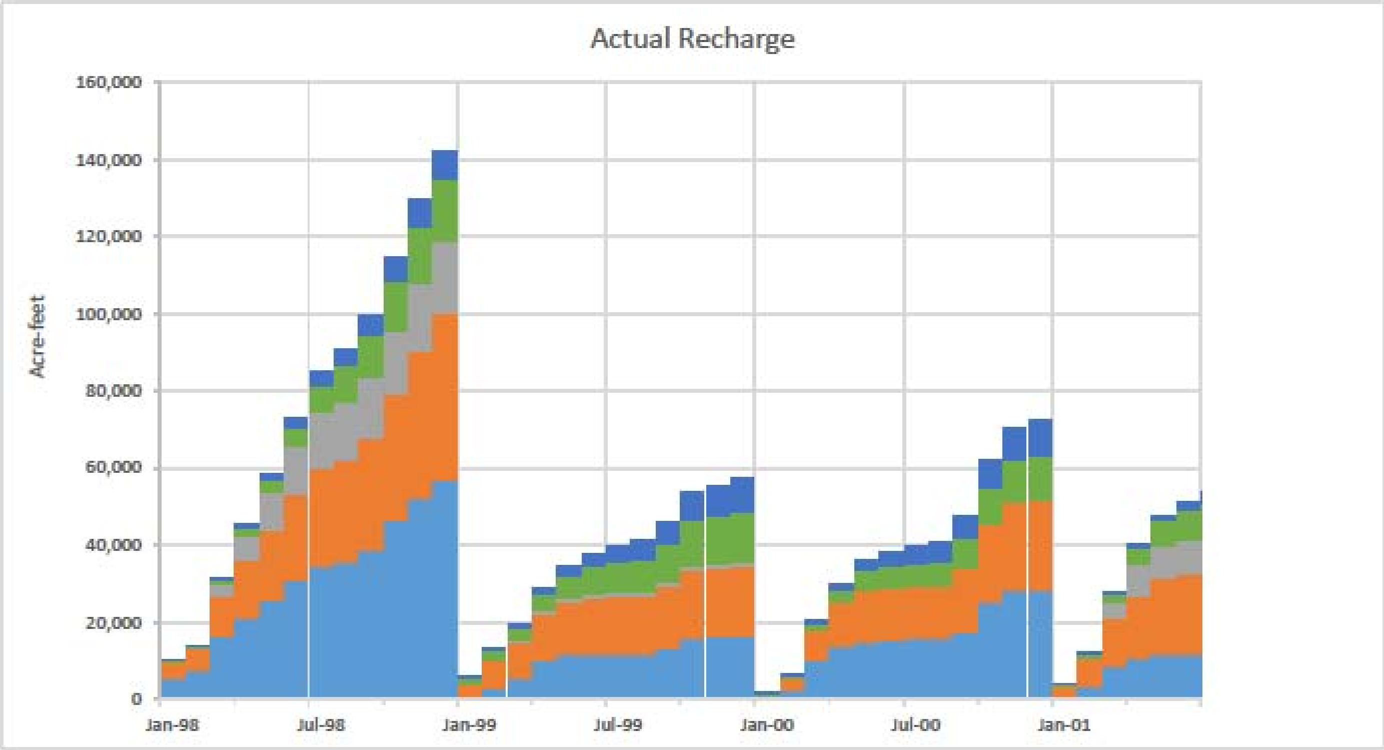


Figure 2.1-2. Cumulative volumes (annual) of modeled and actual recharge and surface water deliveries for 1998 to 2001.

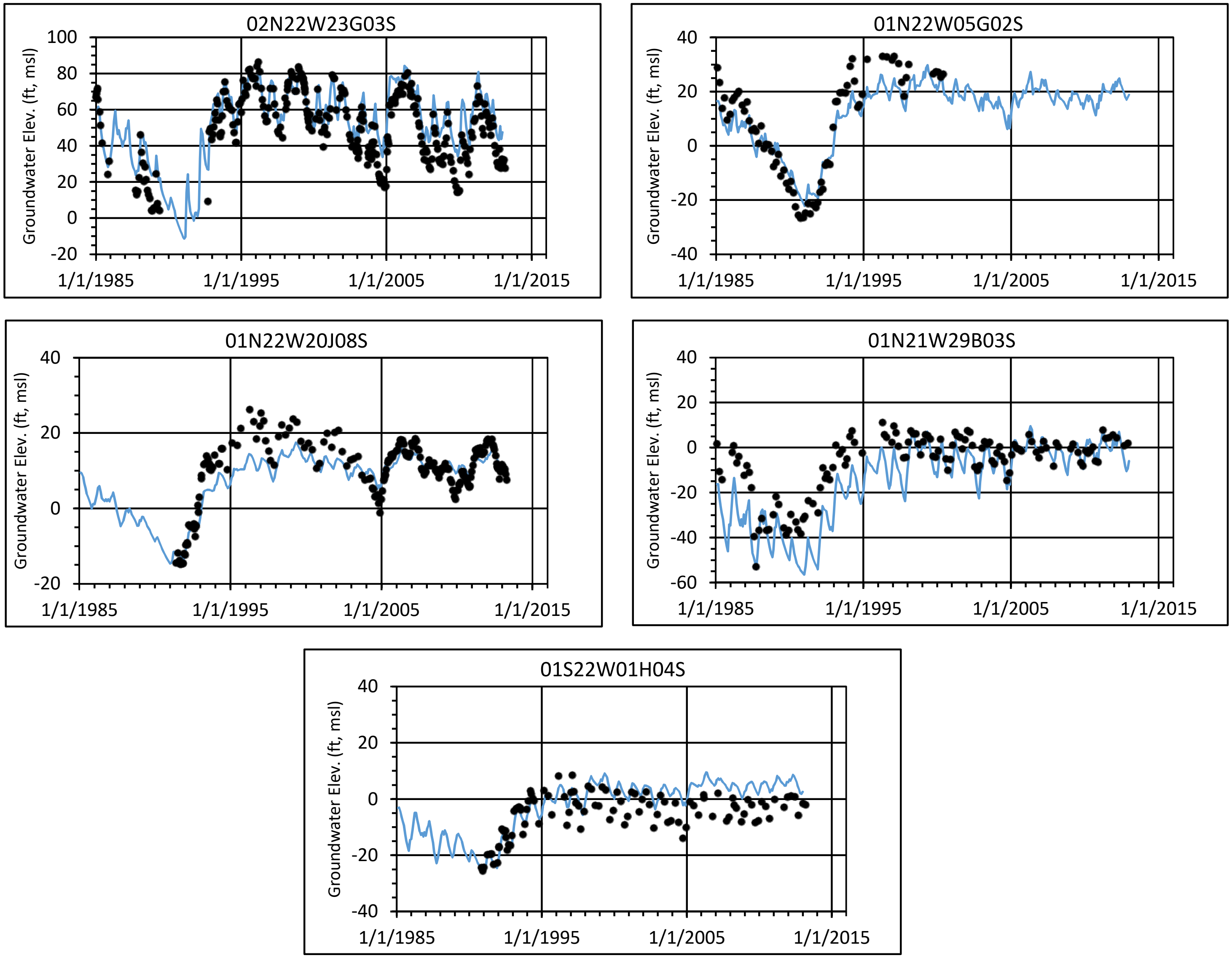


Figure 2.1-3. Model calibration hydrographs for selected UAS wells in Oxnard Plain, Oxnard Forebay, and Pleasant Valley basins.

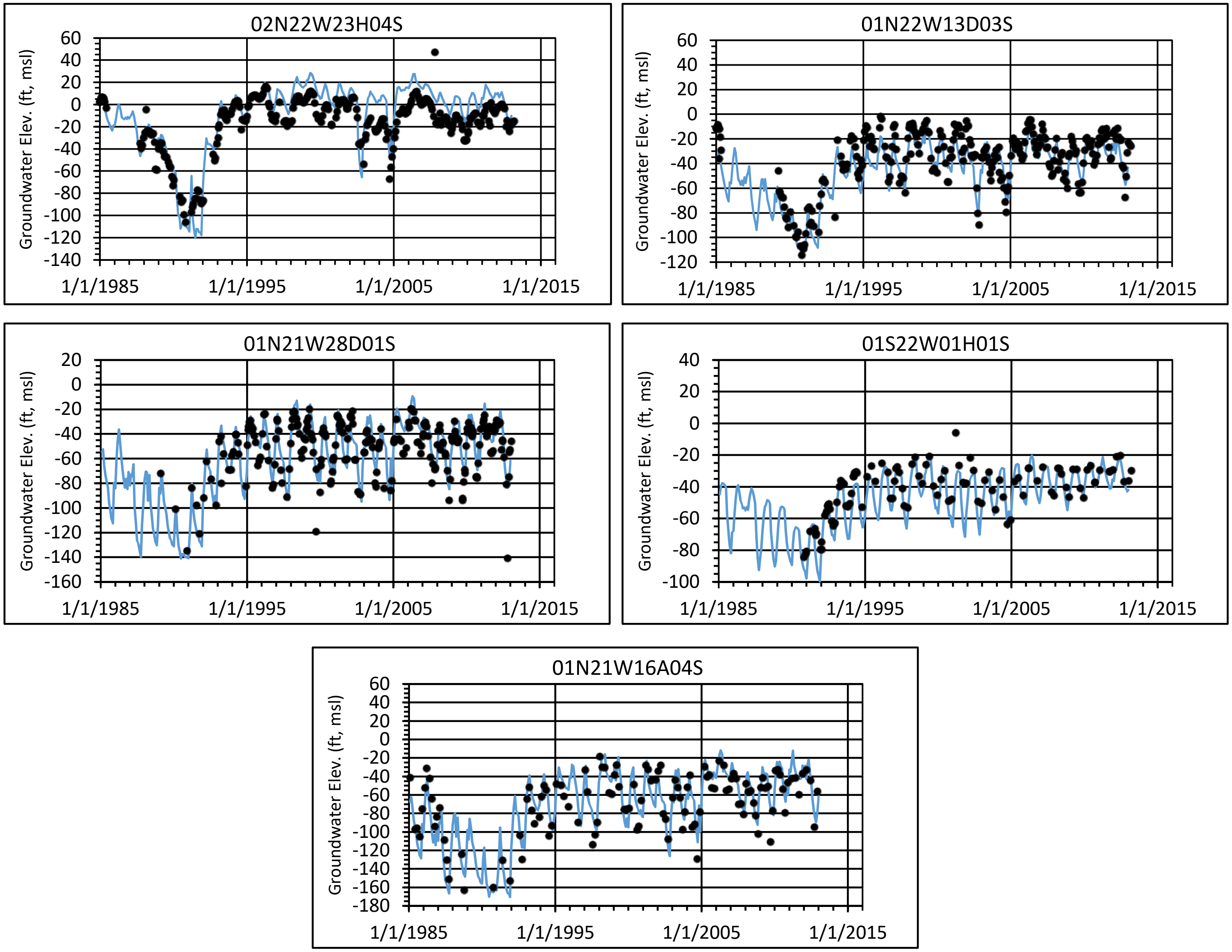


Figure 2.1-4. Model calibration hydrographs for selected LAS wells in Oxnard Plain, Oxnard Forebay, and Pleasant Valley basins.

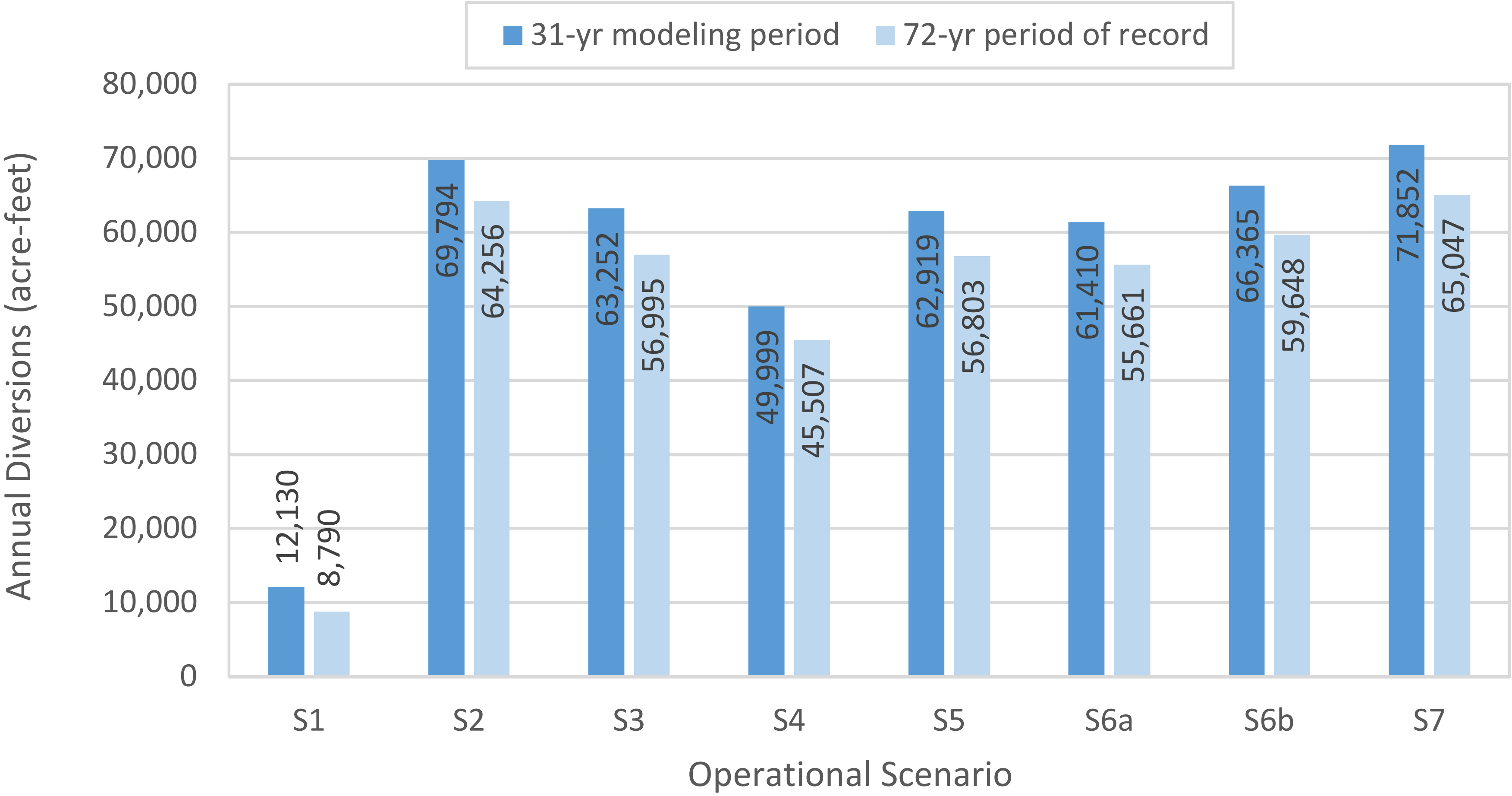


Figure 3.1-1. Average annual diversions for each operational scenario (1985-2015 and 1944-2015).

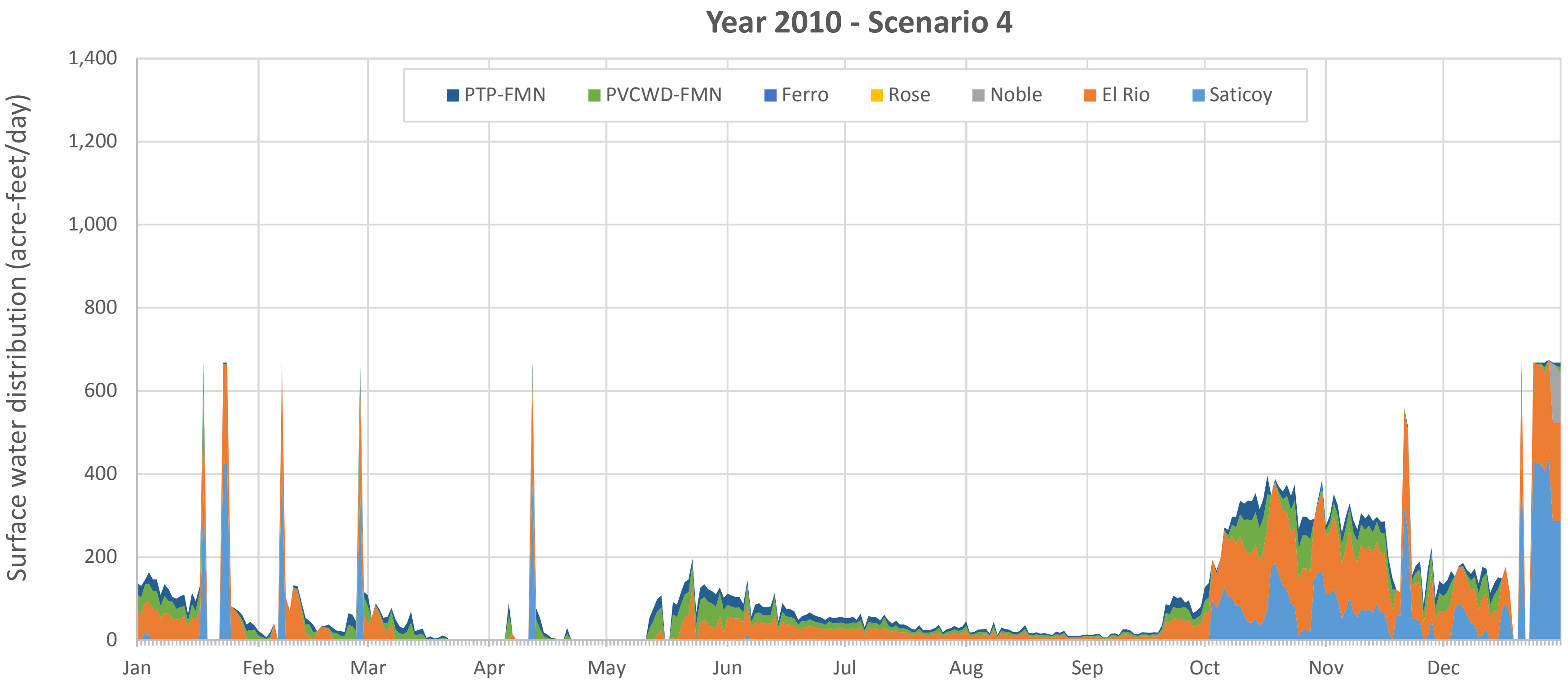


Figure 3.1-2a. Surface water distribution to recharge basins and surface water deliveries for scenario 4 (model year 2010).

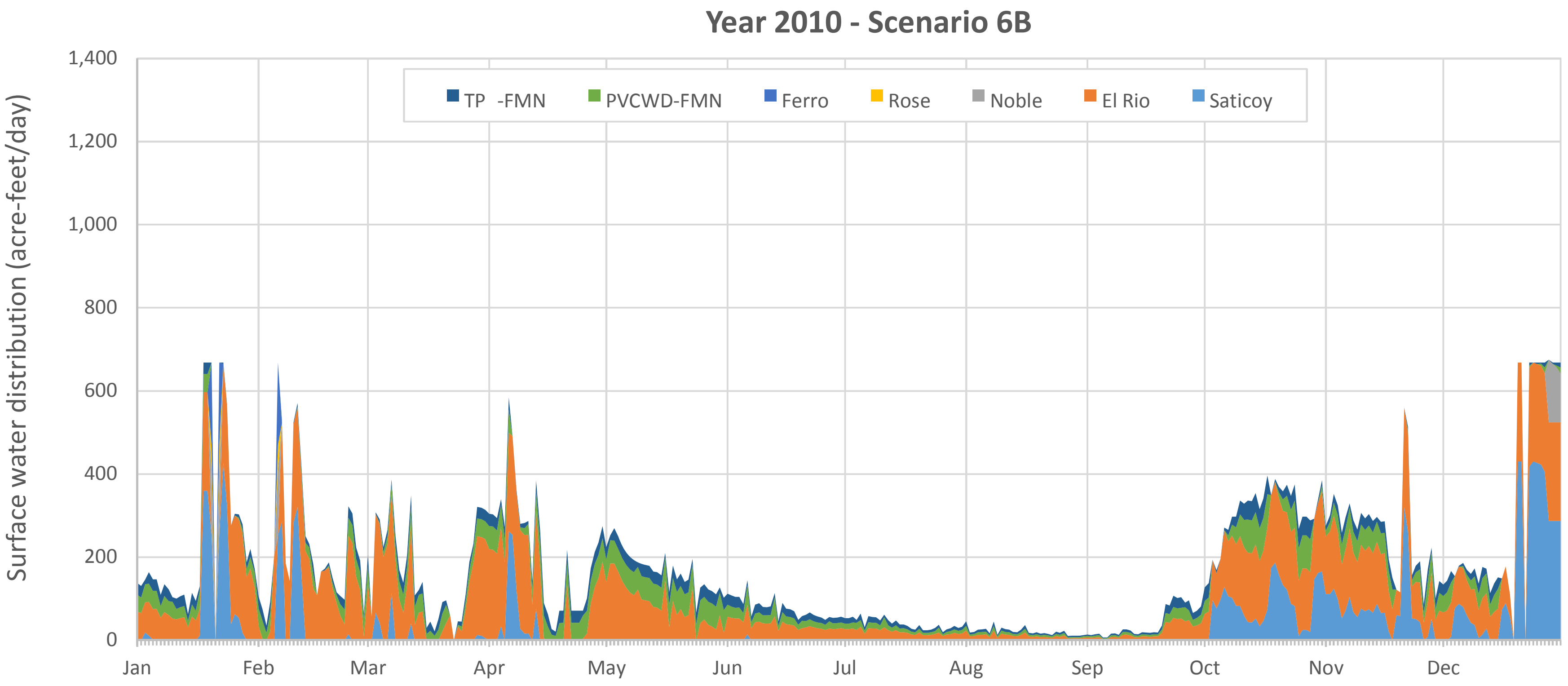


Figure 3.1-2b. Surface water distribution to recharge basins and surface water deliveries for scenario 6B (model year 2010).

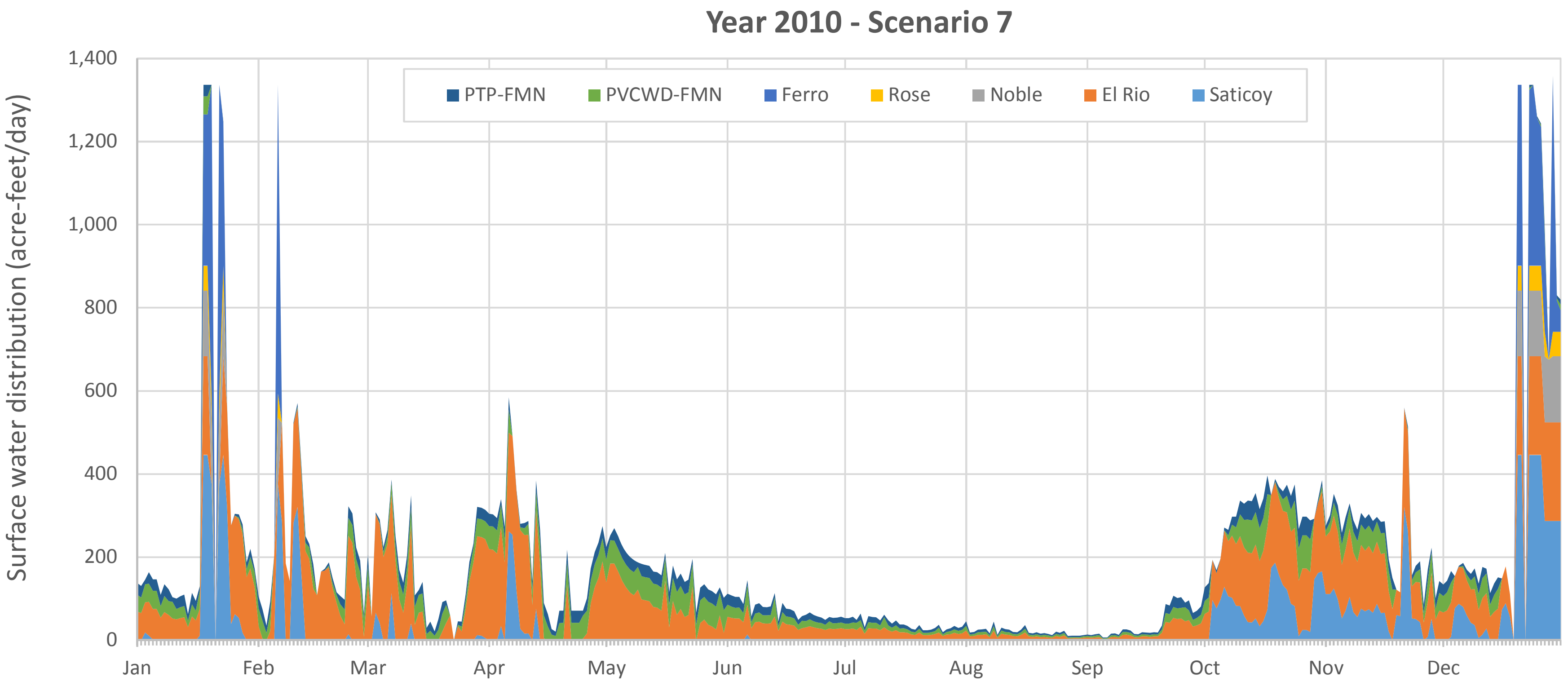


Figure 3.1-2c. Surface water distribution to recharge basins and surface water deliveries for scenario 7 (model year 2010).

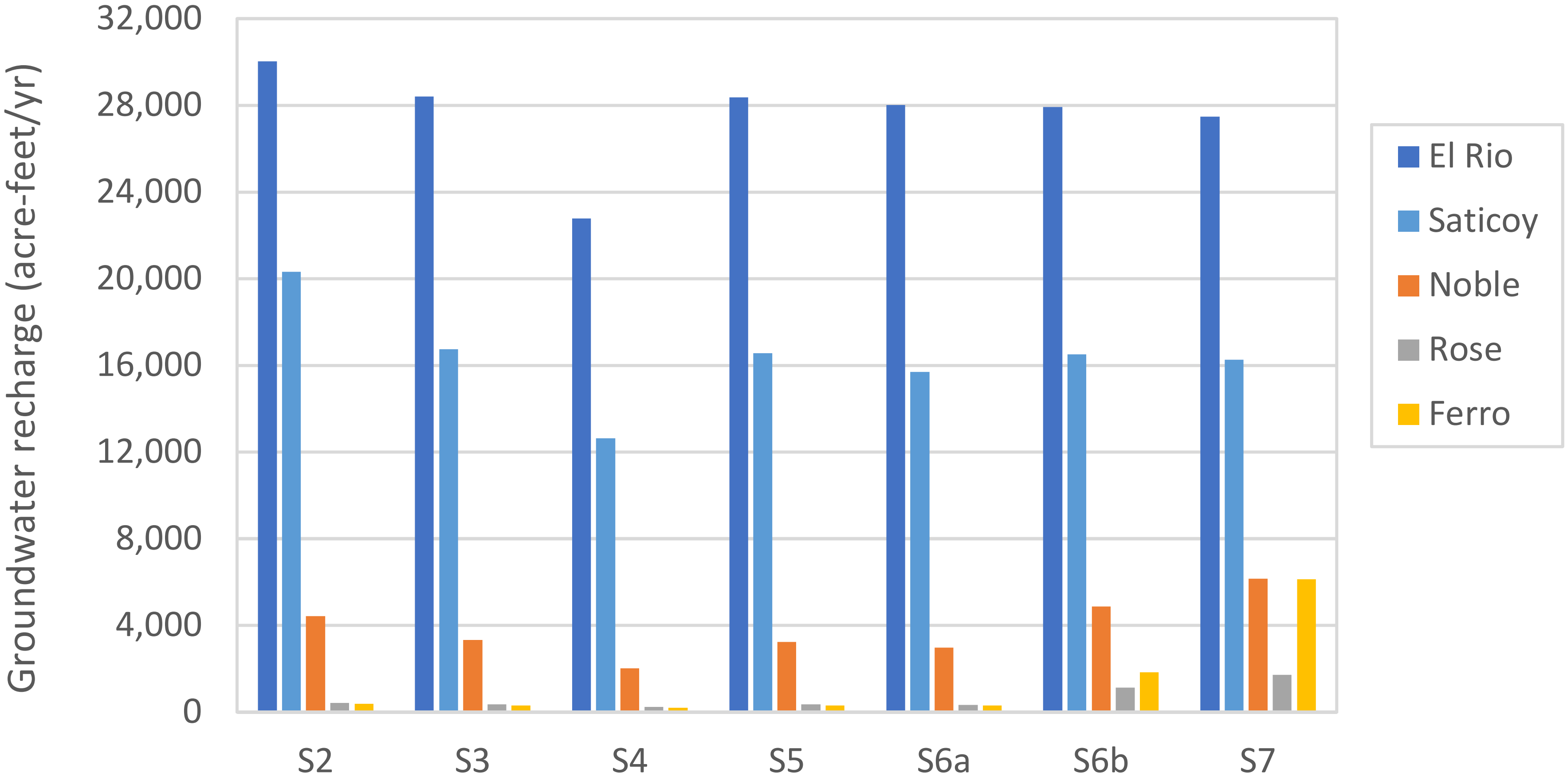


Figure 3.1-3. Comparison of average annual groundwater recharge between scenarios for the 1985-2015 modeling period.

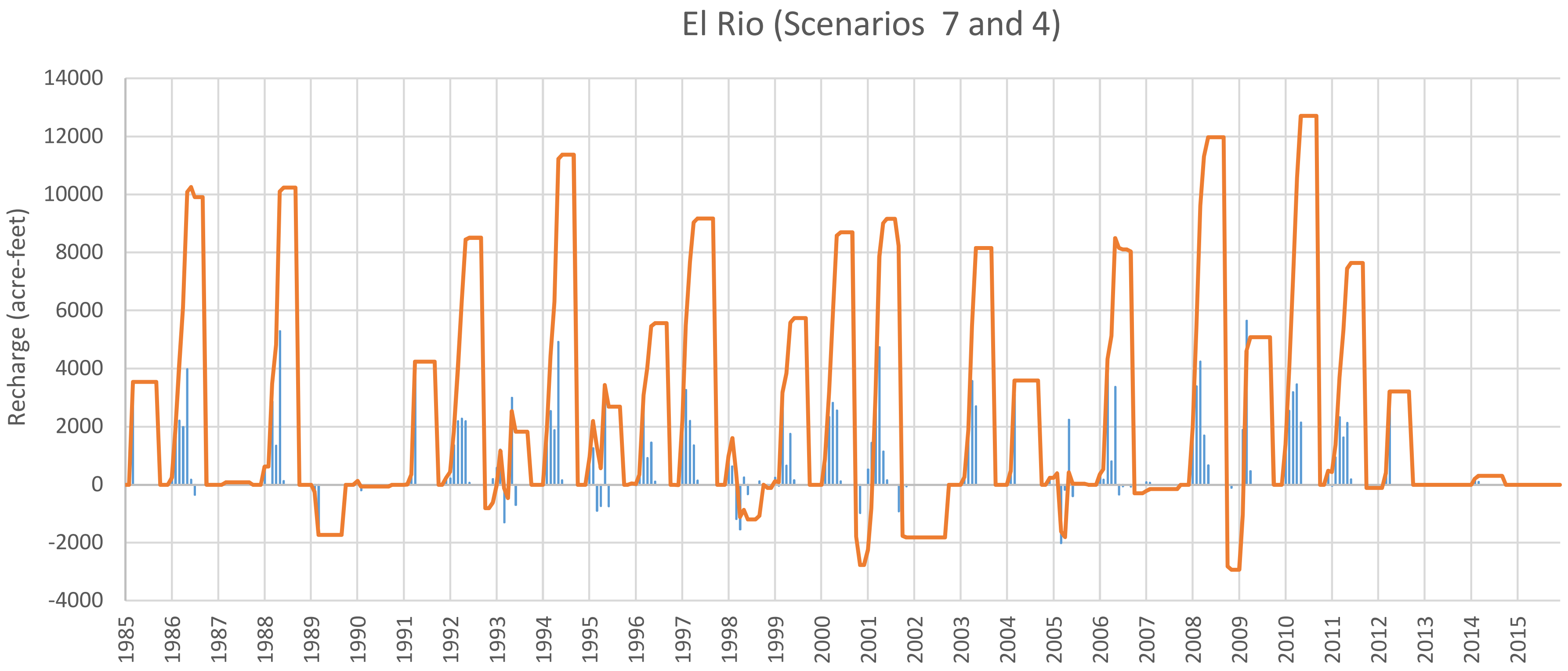


Figure 3.1-4a. Difference in recharge at El Rio between scenarios 7 and 4. A positive difference indicates higher deliveries under scenario 7. Bars indicate monthly amounts, line indicates cumulative amounts per water year.

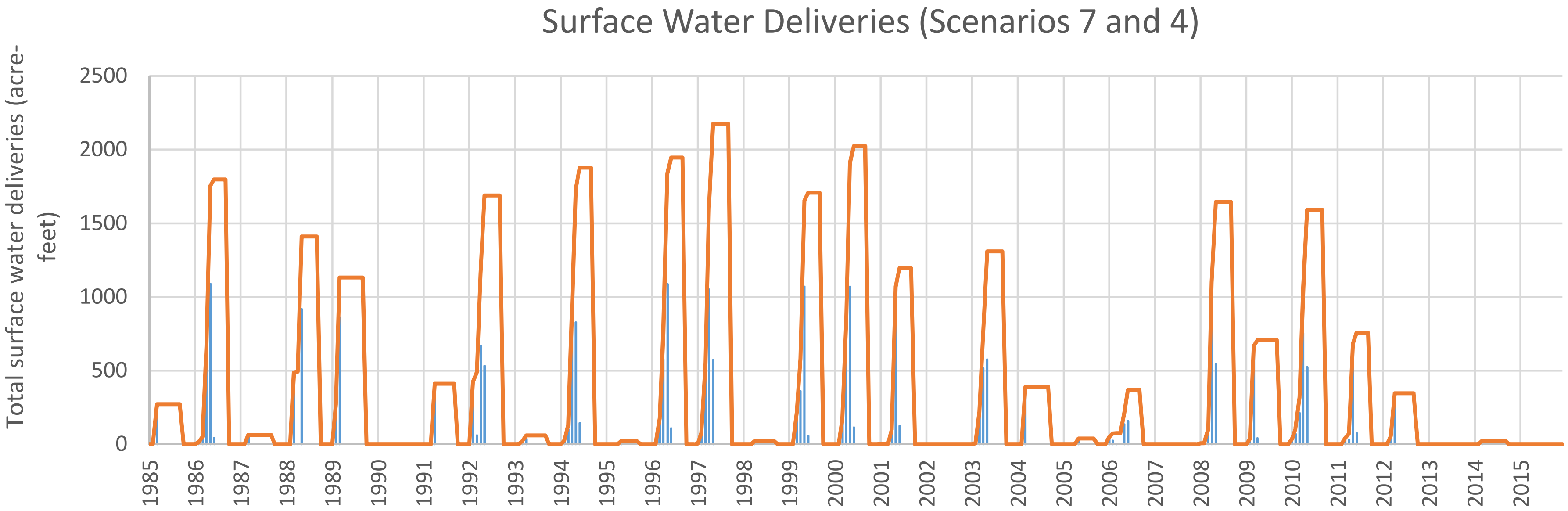
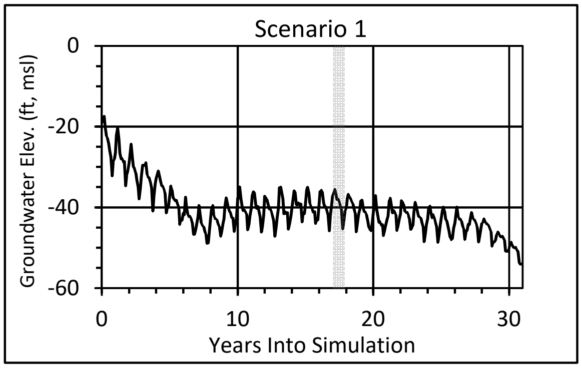
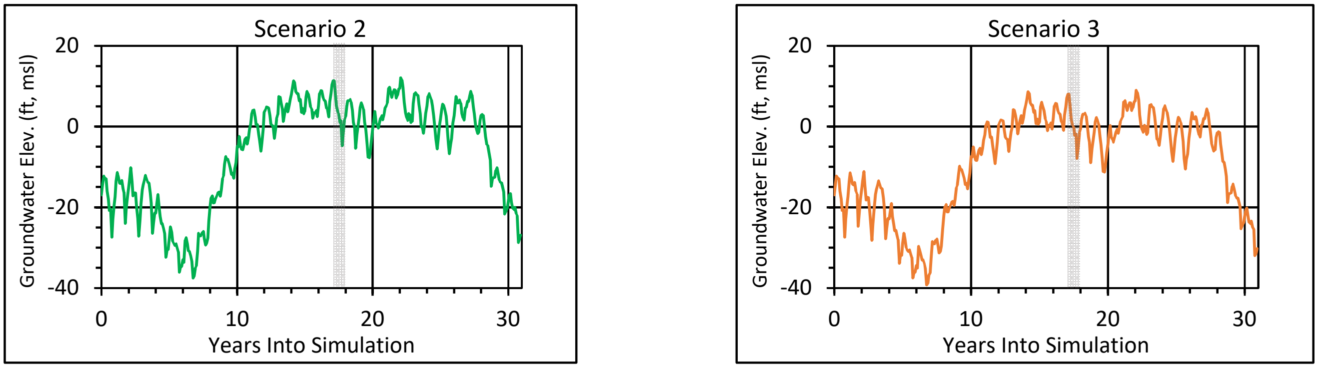


Figure 3.1-4b. Difference in deliveries to surface water delivery system between scenarios 7 and 4. A positive difference indicates higher deliveries under scenario 7. Bars indicate monthly amounts, line indicates cumulative amounts per water year.

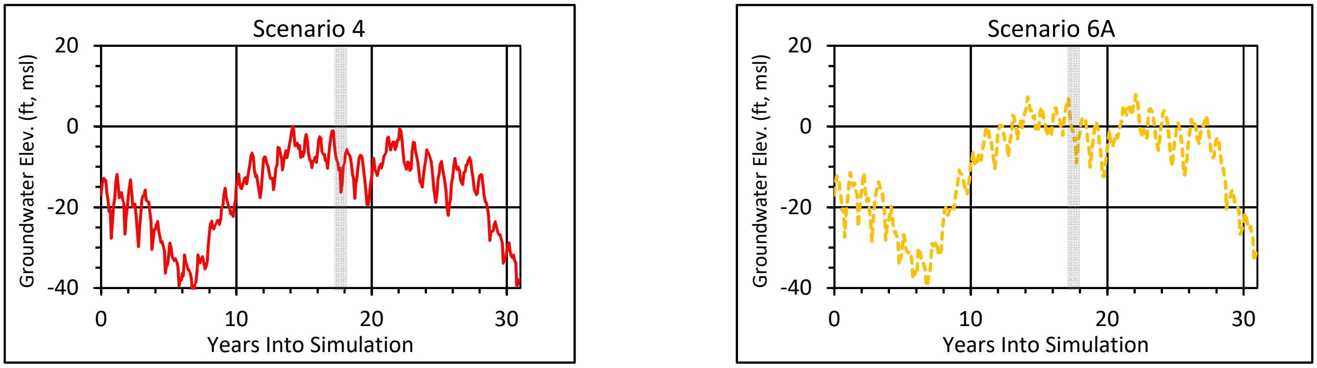


Percent of time groundwater levels are below sea level = 100%



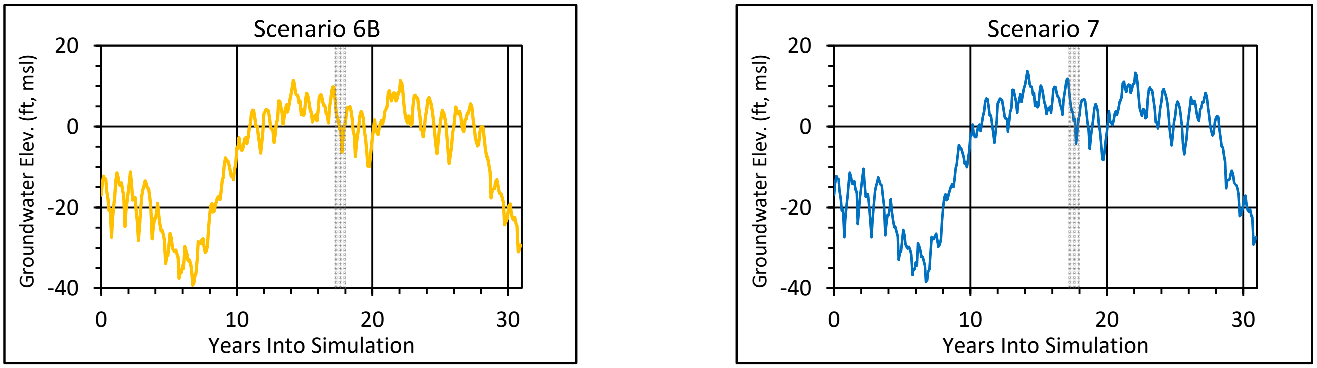
Percent of time groundwater levels are below sea level = 54%

Percent of time groundwater levels are below sea level = 67%



Percent of time groundwater levels are below sea level = 100%

Percent of time groundwater levels are below sea level = 76%



Percent of time groundwater levels are below sea level = 59%

Percent of time groundwater levels are below sea level = 51%

Figure 3.2-1. Forecasted hydrographs for UAS well 01N21W17D02S (in eastern part of Oxnard Plain basin; gray bar on graphs highlights year 17 of the simulation).

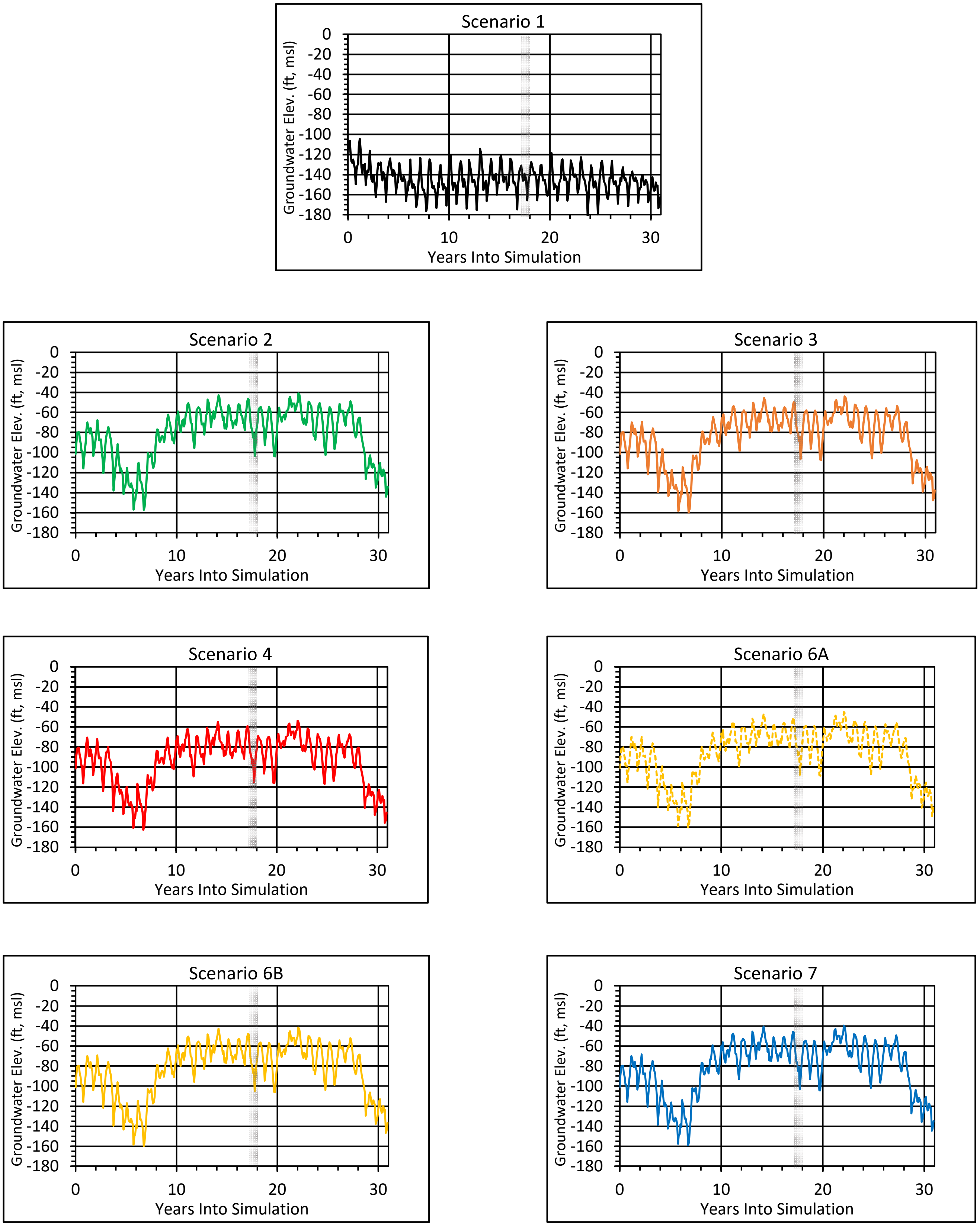


Figure 3.2-2. Forecasted hydrographs for LAS well 01N21W07J02S (in eastern part of Oxnard Plain basin; gray bar on graphs highlights year 17 of the simulation).

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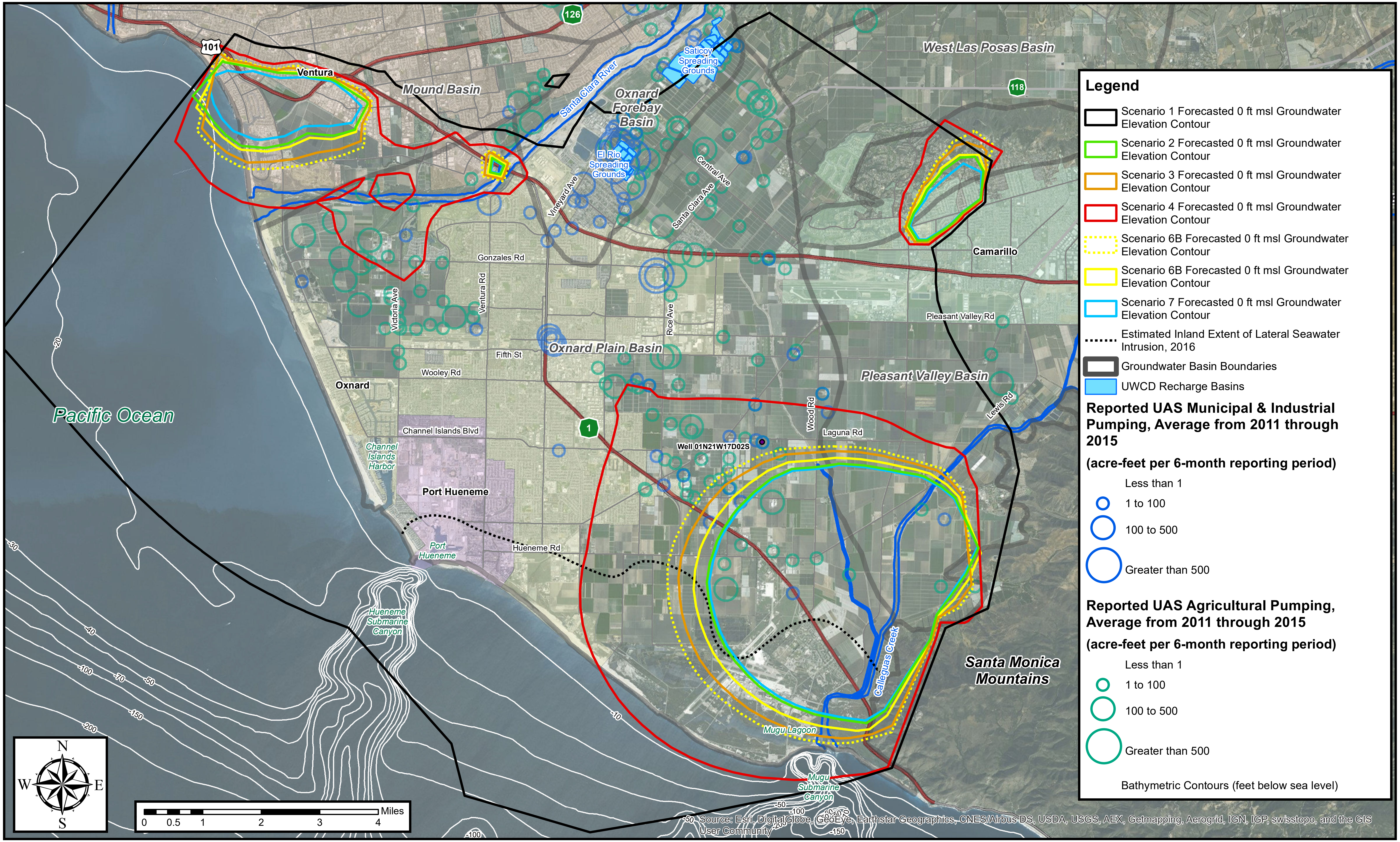


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3.2-3. Areas where groundwater elevations in the UAS (Oxnard Aquifer) are forecasted to be below sea level during a typical water year.

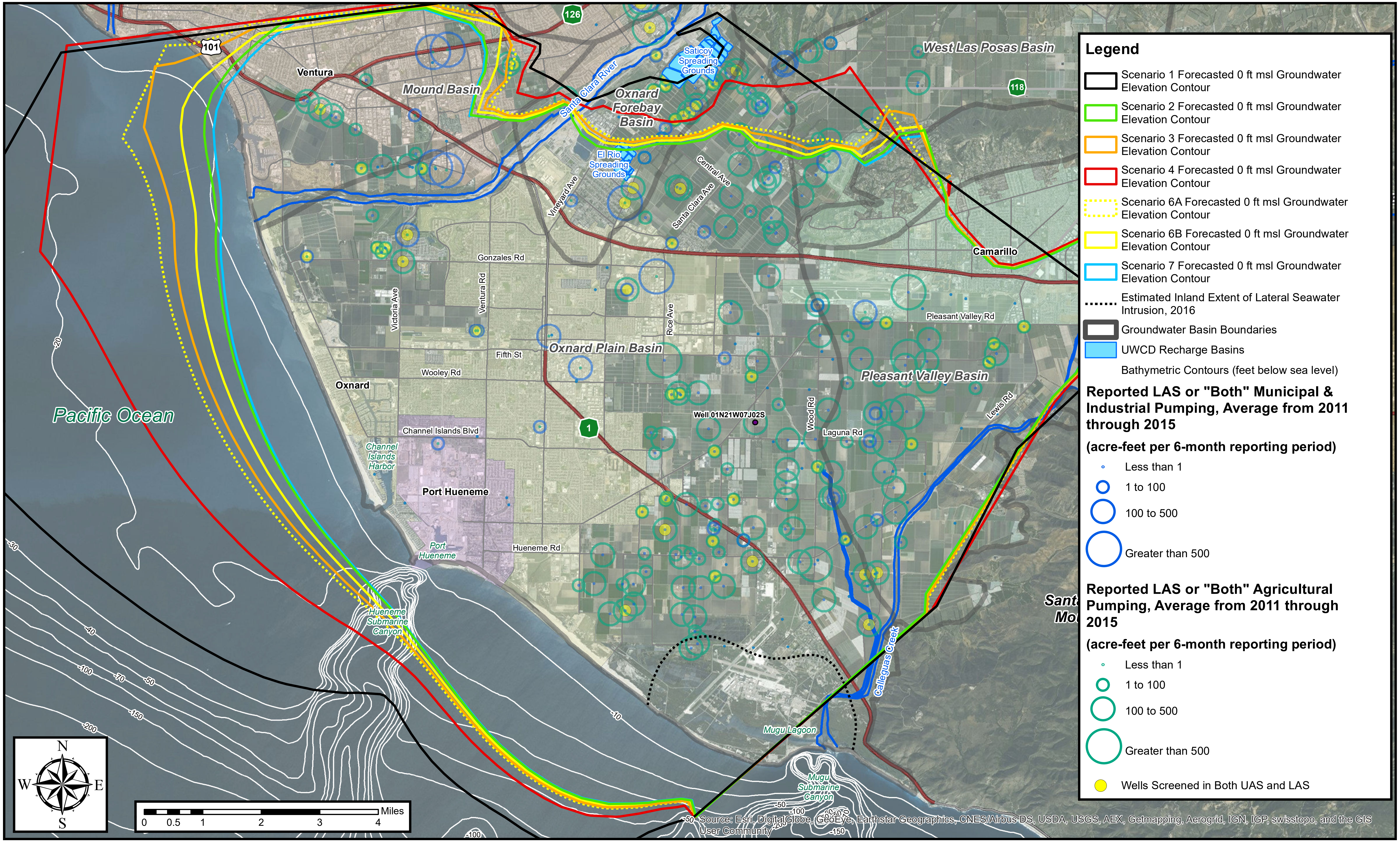
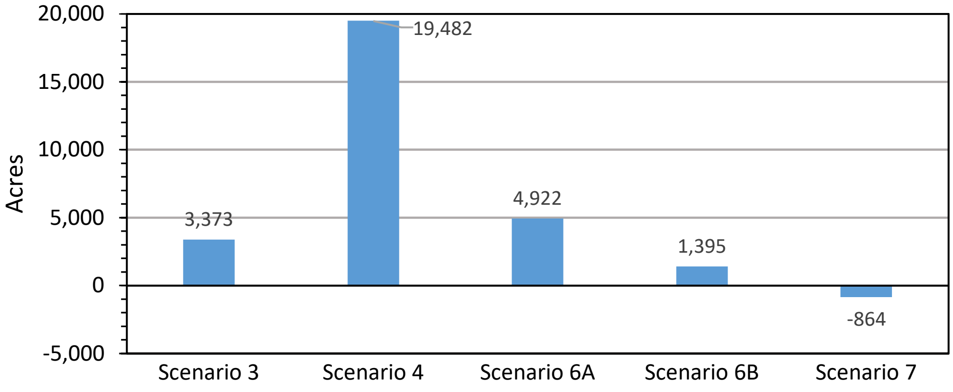
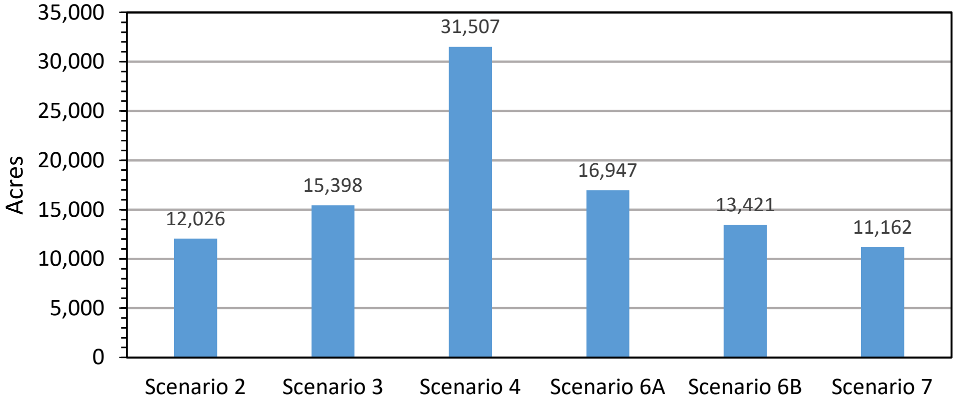


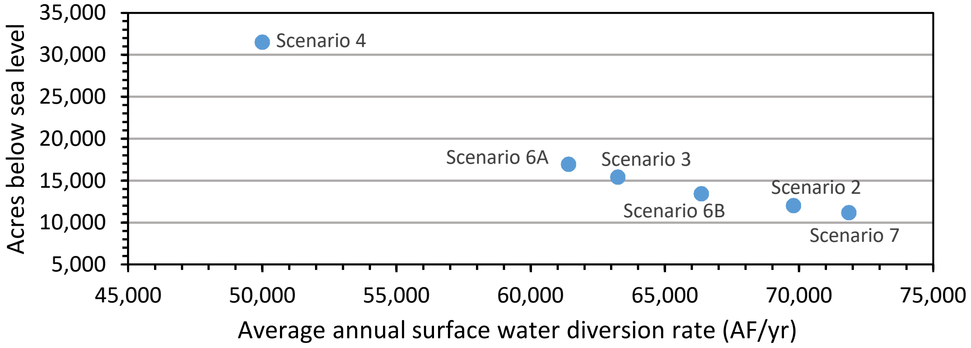
Figure 3.2-4. Areas where groundwater elevations in the LAS (Fox Canyon Main Aquifer) are forecasted to be below sea level during a typical water year.



a) Additional area (compared to Scenario 2) in Mound, Forebay, Oxnard Plain, and Pleasant Valley basins where groundwater levels in the Oxnard aquifer are forecasted to be below mean sea level during a typical (non-drought) water year

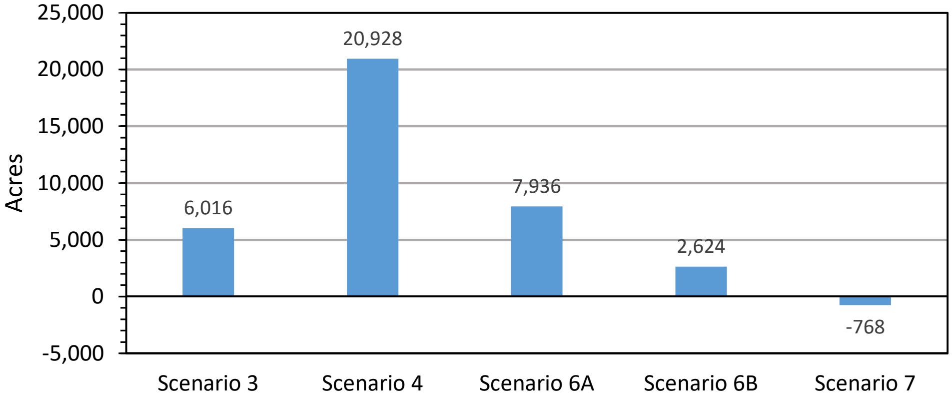


b) Total area in Mound, Forebay, Oxnard Plain, and Pleasant Valley basins where groundwater levels in the Oxnard aquifer are forecasted to be below mean sea level during a typical (non-drought) water year

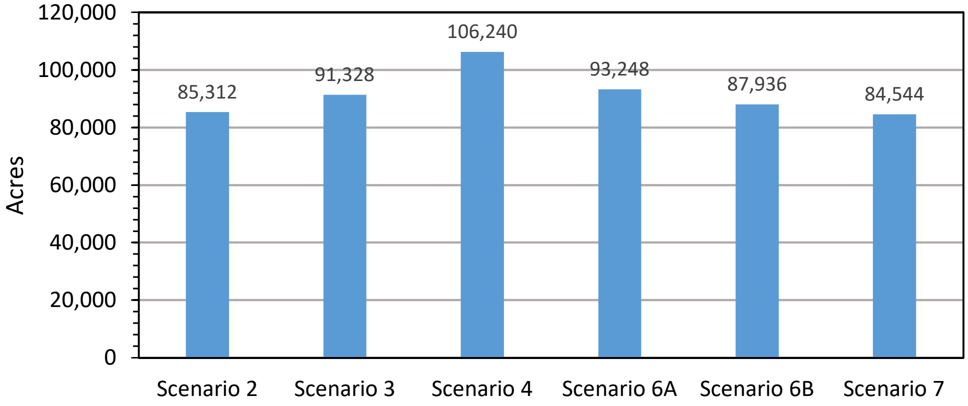


c) Average annual Freeman Diversion rate versus total area in Mound, Forebay, Oxnard Plain, and Pleasant Valley basins where groundwater levels in the Fox Cyn. aquifer are forecasted to be below mean sea level during a typical (non-drought) water year

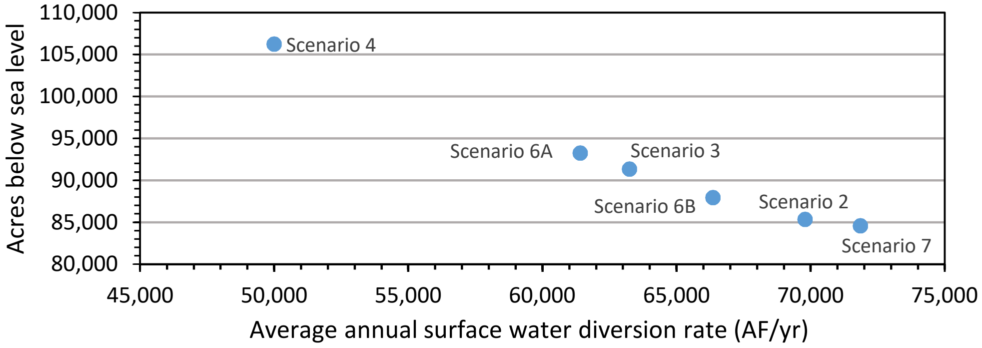
Figure 3.2-5. Graphical comparison of effects of diversion scenarios on groundwater elevations in the UAS.



a) Additional area (compared to Scenario 2) in Mound, Forebay, Oxnard Plain, and Pleasant Valley basins where groundwater levels in the Fox Cyn. aquifer are forecasted to be below mean sea level during a typical (non-drought) water year



b) Total area in Mound, Forebay, Oxnard Plain, and Pleasant Valley basins where groundwater levels in the Fox Cyn. aquifer are forecasted to be below mean sea level during a typical (non-drought) water year



c) Average annual Freeman Diversion rate versus total area in Mound, Forebay, Oxnard Plain, and Pleasant Valley basins where groundwater levels in the Fox Cyn. aquifer are forecasted to be below mean sea level during a typical (non-drought) water year

Figure 3.2-6. Graphical comparison of effects of diversion scenarios on groundwater elevations in the LAS.