PRELIMINARY EVALUATION OF IMPACTS OF POTENTIAL GROUNDWATER SUSTAINABILITY INDICATORS ON FUTURE GROUNDWATER EXTRACTION RATES – OXNARD PLAIN AND PLEASANT VALLEY GROUNDWATER BASINS

Open-File Report 2017-02
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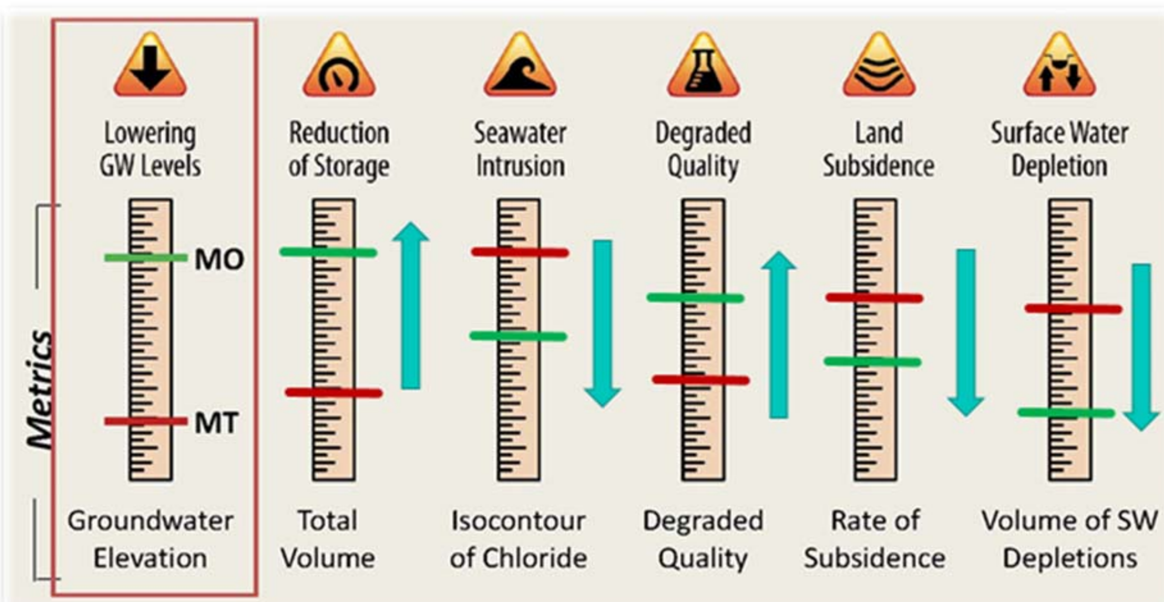

THIS REPORT IS PRELIMINARY AND IS SUBJECT TO MODIFICATION BASED UPON FUTURE ANALYSIS AND EVALUATION

PREPARED BY
GROUNDWATER
RESOURCES
DEPARTMENT

UNITED WATER
CONSERVATION
DISTRICT

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Cover Image: Graphic of the six sustainability indicators that must be considered under the Sustainable Groundwater Management Act.

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EXECUTIVE SUMMARY

This evaluation was performed to estimate the combined sustainable yield of the Oxnard Plain (including the Forebay) and Pleasant Valley groundwater basins (the study area). The purpose is to provide supporting information to United Water Conservation District's (United) management and Board of Directors in establishing groundwater management policies that are consistent with the mission of the agency. United recognizes that the compliance actions associated with the Sustainable Groundwater Management Act (SGMA), the formation of a Groundwater Sustainability Agency (GSA), and the creation and implementation of Groundwater Sustainability Plans (GSPs) have the potential to change how groundwater resources are managed in Ventura County. This report was prepared for the benefit of United's Board of Directors and senior management, and is ***not*** intended to serve as a GSP, define how the sustainable yield should be determined by the GSA, or specify what value or range of values should be used as the sustainable yield. The analyses and results are meant to be used as a starting point in evaluating potential impacts to United's operations as a result of sustainability planning already underway by the Fox Canyon Groundwater Management Agency (FCGMA) for the study area.

Groundwater overdraft and deteriorating groundwater quality, particularly increasing chloride concentrations resulting from saline intrusion in the Oxnard aquifer, have long been a concern in the study area. In 1985, the FCGMA adopted a groundwater management plan (GMP) that recommended reducing groundwater pumping by 25% over a 20-year period to maintain the groundwater balance, and new surface-water diversion, recharge, and delivery projects were initiated by United and Calleguas Municipal Water District. Combined, these efforts resulted in significant slowing or reversal of seawater intrusion in the upper aquifer system (UAS) within the study area; however, the area impacted by saline intrusion in the lower aquifer system (LAS), particularly in the area surrounding Mugu Lagoon, expanded. In a 2007 update of the GMP, groundwater modeling indicated that pumping would have to be further reduced throughout the FCGMA service area (including the Las Posas basins and part of the Santa Rosa basin), with focused reductions in the southern Oxnard Plain and Pleasant Valley basins. It was also noted by the FCGMA that such reductions were considered as "an initial target level, but should be revisited as that goal is approached to ensure that it is sufficiently protective in the future."

On January 1, 2015, state legislation (AB 1739, SB 1168 and SB 1319; collectively referred to as SGMA) was enacted requiring every groundwater basin in California to be managed sustainably by the year 2042. The legislation provides for the formation of local GSAs that will be responsible for writing and implementing GSPs. The FCGMA is currently developing GSPs for the basins in their service area (including the Oxnard Plain and Pleasant Valley basins), and anticipate completing them in late 2017. In the interim, United's Board of Directors directed its staff to use available data and United's new groundwater model to estimate the sustainable yield under current conditions, without assuming construction of new water-supply projects, in the Oxnard Plain basin (including the Forebay sub-basin) and Pleasant Valley basin, to allow United to plan for potential changes in how groundwater resources are managed within its service area.

The approach taken for this evaluation is limited in scope compared to the GSP process currently underway by the FCGMA, as it does not include other compliance actions (e.g., stakeholder engagement or planning of future water-supply projects) that are required in the GSP regulations, and it relies on some simplifying assumptions regarding possible future water-supply scenarios. The overall technical approach taken for this evaluation consisted of three main steps, as follows:

1. Assume minimum thresholds for applicable sustainability indicators defined in the GSP regulations. For this evaluation, the assumed minimum thresholds for each applicable sustainability indicator are expressed as groundwater elevations, as allowed under the GSP regulations.
2. Determine the groundwater elevation corresponding with the highest of the assumed minimum thresholds in each basin and management area. In this report, that elevation is referred to as the "target groundwater level."
3. Use groundwater flow modeling to evaluate the extent to which several hypothetical future groundwater-extraction (pumping) scenarios could achieve the target groundwater levels as described above. The goal was to estimate the range of potential minimum sustainable yield values that might result from the groundwater sustainability planning process currently underway by the FCGMA, assuming no new water-supply sources were developed in the region.

Sustainability indicators, as defined in the GSP regulations, consist of:

- Lowering groundwater levels;
- Reduction in groundwater storage;
- Seawater intrusion;
- Water quality degradation;
- Land subsidence; and
- Surface water depletion.

Groundwater elevation is the common metric used to establish each of the assumed minimum thresholds in this evaluation. Target groundwater levels are applied across the Oxnard Plain and Pleasant Valley basins, in effect becoming comprehensive minimum thresholds for all indicators and eliminating the need for a stand-alone "Lowering Groundwater Levels" indicator.

Quantitative assumed minimum thresholds developed for seawater intrusion, land subsidence, degraded water quality, and reduction of groundwater storage were used to develop the comprehensive target groundwater levels assumed for this evaluation; the target groundwater levels are summarized in Table ES-1. Minimum thresholds for the "surface water depletion" indicator were not established for this evaluation because local surface-water bodies are fed by a local perched aquifer that is minimally influenced by pumping from the regional aquifers used for water-supply. It is assumed for this evaluation that if groundwater elevations can be maintained at or above the target groundwater levels under most circumstances, then minimum thresholds will be met and management objectives likely achieved under most circumstances.

Table ES-1. Assumed Minimum Thresholds and Target Groundwater Levels

Area	Aquifer System	Assumed Minimum Threshold for Each Sustainability Indicator (feet NGVD29)						Target Groundwater Level[a] (feet NGVD29)
		Lowering Groundwater Levels	Reduction of Groundwater Storage	Seawater Intrusion	Degraded Water Quality	Land Subsidence	Surface Water Depletion	
Forebay	UAS	---	-100	---	+20	-100	---	**+20**
	LAS	---	-150	---	---	-150	---	**-150**
Oxnard Plain basin (excluding Forebay)	UAS	---	-100	---	---	-100	---	**-100**
	LAS	---	-150	---	---	-150	---	**-150**
Pleasant Valley basin	UAS	---	-100	---	---	-100	---	**-100**
	LAS	---	-200	---	---	-200	---	**-200**
Assumed Seawater Intrusion Management Area	UAS	---	-100	+6	---	-100	---	**+6**
	LAS	---	-150	+18.5	---	-150	---	**+18.5**

Notes: --- = Not applicable

[a] Target groundwater levels represent the highest of the minimum thresholds, and represent the lowest that groundwater elevations could be without causing undesirable results. Groundwater elevations can be higher than the target groundwater levels without causing undesirable results.

United has constructed a numerical groundwater flow model to simulate and forecast groundwater flow in the aquifers underlying the Oxnard coastal plain. The United model is still being updated, tested, and reviewed; however, based on calibration results to date and initial review by an expert panel, is considered a capable tool for this preliminary evaluation. The United model was used to forecast groundwater level responses to simulated changes in pumping rates and locations.

The overall approach for using the groundwater model to evaluate effects of hypothetical pumping scenarios on groundwater levels and potential sustainable yield consisted of simulating reduced pumping rates in the Oxnard Plain and Pleasant Valley basins, then determining the extent to which target groundwater levels were achieved under each scenario. Seawater intrusion has historically been (and continues to be) the most pressing groundwater sustainability challenge within the study area. Achieving management objectives for seawater intrusion by raising groundwater elevations (as a result of simulated pumping reductions) to target groundwater levels in the assumed seawater intrusion management area was anticipated to raise groundwater elevations above target groundwater levels elsewhere in the Oxnard Plain and Pleasant Valley basins, thereby achieving the management objectives for other sustainability indicators. Modeling results were reviewed to determine the degree to which assumed minimum thresholds for all sustainability indicators were met, not just those for seawater intrusion.

The modeled base period for the hypothetical pumping scenarios was January 1985 through December 2015 (31 years). Each pumping scenario consisted of simulating 1985 through 2015 boundary conditions, with extractions under each pumping scenario reduced proportionately relative to reported extractions from 1985 through 2015. Forecasting of future climatic conditions, land use, and changes in water sources in the study area was beyond the scope of this initial effort. Therefore, this approach is, in effect, an evaluation of the reduction in pumping that would have been required to achieve sustainable yield in the study area during the period from 1985 through 2015.

The scenarios that were simulated include:

- **Base Case Scenario**—This scenario used reported pumping rates to simulate, to the extent feasible, measured groundwater levels (and their changes) during the period from 1985 through 2015. These simulated groundwater levels were used as the basis for comparing potential impacts of the subsequent hypothetical pumping scenarios rather than measured groundwater levels, because the model provides discrete results for head (groundwater level) in each aquifer, during every month, across the entire study area.
- **Scenario A**—Simulated pumping rates in the Oxnard Plain (excluding the Forebay) and Pleasant Valley basins were reduced by 50 percent in both the UAS and the LAS compared to actual 1985 through 2015 rates. This scenario comprises the simplest approach to raising groundwater elevations to achieve target groundwater levels (minimum thresholds)—a uniform reduction in pumping. Simulated reductions in pumping were not applied to the Forebay, due to its distance (more than 3 miles) from areas where groundwater quality has been impaired by seawater intrusion. Continued operation of groundwater recharge and pumping operations by United in the Forebay is expected to be a key factor to eventually achieving sustainable yield in the Oxnard Plain and surrounding basins.
- **Scenario B**—Simulated pumping rates for wells screened solely in the LAS in the Oxnard Plain (excluding the Forebay) and Pleasant Valley basins were reduced by 75 percent compared to 1985 through 2015 rates, while pumping rates for wells screened in the UAS were unchanged from historical rates. Pumping rates for wells that are screened across both the UAS and the LAS were also left unchanged from historic rates (these wells make up a relatively small proportion of total pumping in the Oxnard Plain basin). Scenario B focused on reducing pumping solely in the LAS because measured groundwater levels in

most of the UAS are currently closer to the target groundwater levels than are groundwater levels in the LAS.

- **Scenario C**—Simulated pumping rates for all wells (UAS and LAS) within an assumed future seawater intrusion management area were reduced by 100 percent (no pumping), while pumping rates for all other wells in the Oxnard Plain (including the Forebay) and Pleasant Valley basins remained at historic rates. The goal of this scenario was to determine whether target groundwater levels could be achieved with a complete pumping moratorium in the area where seawater intrusion has been and continues to be the greatest concern, while pumping continued at historic rates elsewhere in the study area.

- **Scenario D**—Simulated pumping rates for all wells (UAS and LAS) within the seawater intrusion management area were reduced by 100 percent, pumping rates for LAS wells throughout the remainder of the Oxnard Plain (excluding the Forebay) and Pleasant Valley basins were reduced by 70 percent, and pumping rates for UAS wells throughout the remainder of the Oxnard Plain and Pleasant Valley basins continued at historic rates. The intent of this scenario was to determine whether a combination of eliminating pumping in the seawater intrusion management zone and significantly reducing pumping from the LAS could more effectively achieve target groundwater levels compared to Scenario B, which assumed some pumping would continue in the seawater intrusion management area.

- **Scenario E**—Simulated pumping rates for all wells (UAS and LAS) within the seawater intrusion management area were again reduced by 100 percent, pumping rates for LAS wells in the remainder of the Oxnard Plain (excluding the Forebay) and Pleasant Valley basins were reduced by 75 percent, and pumping rates for UAS wells outside of the seawater intrusion management area were ***increased*** by 50 percent above historic rates. The intent of this scenario was to take advantage of the fact that groundwater levels in the UAS in the northwestern part of the Oxnard Plain basin have historically been well above target levels much of the time, and likely would rise farther if LAS pumping were reduced in the Oxnard Plain and Pleasant Valley basins. Despite the presence of an aquitard between the UAS and LAS, vertical conductance between these aquifer systems was anticipated to allow a modest groundwater-level response in the UAS as a result of large-scale reductions in pumping from the LAS. Therefore, pumping could potentially be increased in the UAS (raising the sustainable yield) while still achieving target groundwater levels.

Table ES-2 summarizes the annual average groundwater extraction rates assumed under each modeled scenario, by individual basin and as the sum for all three modeled basins. Also shown, for reference purposes, is the sum of annual average groundwater and surface water use for the modeled basins combined, including:

- Reported pumping from wells (varies by pumping scenario);

- Average imports from the State Water Project (26,600 acre-feet per year [AF/yr]); and

- Average deliveries of diverted surface water from the Santa Clara River and Conejo Creek (17,700 AF/yr).

The quantity of surface water imported or diverted to the basins and used for municipal, agricultural, or industrial purposes is not input directly into the groundwater flow model. However, surface water imports indirectly influence actual and modeled groundwater pumping and agricultural return flows. The percent reductions in groundwater use and total water use (groundwater plus surface water imports and diversions) assumed in each scenario—compared to the base case—are shown in the right-hand column of Table ES-2.

An important assumption for the approach used in this evaluation is that it is based on climatic conditions in the study area during the period from 1985 through 2015. Development of independent forecasts of future climatic conditions was beyond the scope of the current effort. Other key assumptions applied to the modeling effort include:

- No new water-supply sources (e.g., desalination, expansion of imports) were assumed to be developed;
- Reported groundwater withdrawals (pumpage from wells) during the period from 1985 through 2015 are repeated, or reduced proportionally from historic withdrawal rates (i.e., no wells were assumed to be destroyed, and no new wells were assumed to be drilled); and
- The sole approach considered for achieving sustainable yield for this evaluation was to modify pumping rates and locations in the UAS and/or LAS.

Other pumping distributions are theoretically possible that could potentially increase sustainable yield to a modest degree (i.e., achieve minimum thresholds with smaller pumping reductions), or new water-supply enhancement or mitigation projects could be constructed to specifically address one or more groundwater sustainability indicators (e.g., injection or extraction barriers in areas vulnerable to seawater intrusion). Consideration of new projects and detailed evaluation of the numerous potential distributions of pumping distributions are beyond the scope of this effort, but are expected to be undertaken by the FCGMA as their groundwater sustainability planning efforts continue.

To simplify the analysis to a level commensurate with the ”in-progress” status of the FCGMA’s GSP, potential alternative climate scenarios, changes in land-use and water-supply conditions, and proposals for development of new projects that target specific groundwater sustainability concerns (e.g., United’s proposed brackish-water treatment project, the City of Oxnard’s recycled water initiatives, etc.) were not included in this analysis. However, the uncertainties associated with excluding these possible changes in future conditions does not limit the utility of the model for evaluating the overall changes in groundwater levels, or for comparing relative differences, of each pumping scenario that was simulated.

Table ES-2. Summary of Pumping Rates Assumed for Each Modeled Scenario

Scenario	Average Groundwater Extractions (AF/yr)				Average Combined Groundwater and Surface Water Use (AF/yr)	Percent Reduction Compared to Base Case (Groundwater / Total Water)
	Oxnard Plain	Forebay	Pleasant Valley	Sum		
Base Case (no changes in pumping from 1985-2015 rates)	54,200	24,000	20,800	**99,000**	**143,000**	**0% / 0%**
Scenario A (50% reduction in pumping from UAS and LAS in Oxnard Plain [excluding the Forebay] and Pleasant Valley basins)	27,300	24,000	10,400	**61,700**	**105,000**	**38% / 27%**
Scenario B (75% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basin, no reduction in UAS pumping)	30,500	24,000	6,100	**60,600**	**104,000**	**39% / 27%**
Scenario C (100% reduction in pumping in seawater intrusion management area, no reductions in remainder of basins)	44,700	24,000	20,600	**89,300**	**133,000**	**10% / 7%**
Scenario D (no pumping in seawater intrusion management area, 70% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basin, no reduction in UAS pumping)	28,900	24,000	7,000	**59,900**	**104,000**	**39% / 27%**
Scenario E (no pumping in seawater intrusion management area, 75% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basin, 150% increase in UAS pumping)	38,600	24,100	6,600	**69,300**	**113,000**	**30% / 21%**
AF/yr = acre-feet per year						

The key conclusions of this evaluation (incorporating the assumptions described below) are as follows:

1. In the southern Oxnard Plain and Pleasant Valley basins, where groundwater elevations are historically lowest, target groundwater levels likely would be highest, primarily as a result of the assumed minimum thresholds for seawater intrusion. Therefore, prevention of seawater intrusion is a primary driver for pumping reductions aimed at achieving sustainable yield. When groundwater elevations rise sufficiently to limit or reverse seawater intrusion along the

coast, they are typically higher than target groundwater levels and assumed minimum thresholds for the other sustainability indicators throughout the Oxnard Plain and Pleasant Valley basins under the reduced-pumping scenarios considered in this evaluation.

2. Overall, results of this evaluation indicated that to achieve target groundwater levels with minimal cuts in pumping (maximizing sustainable yield), pumping reductions should be focused in the LAS rather than the UAS, and in both aquifer systems near the coast where seawater intrusion is known to enter the aquifers via the Hueneme and Mugu submarine canyons. However, reducing, or even eliminating, pumping solely in the area along the coast that has been impacted by past saline water intrusion (the assumed seawater intrusion management area) cannot, by itself, raise groundwater elevations in the LAS above target levels (thereby stopping seawater intrusion). Some pumping reductions are required further inland in the Oxnard Plain and Pleasant Valley basins in order to achieve target groundwater levels in the seawater intrusion management area.
3. Assuming that sustainable yield would be achieved solely via reductions in pumping (no new sources of water supply), and that climatic conditions, land-use changes, or regulatory issues don't change the balance of water supply and demand substantially, this evaluation concludes that the combined sustainable yield for the Oxnard Plain (including the Forebay) and Pleasant Valley basins would be approximately 60,000 to 69,000 AF/yr. The low end of this range was arrived at under two pumping scenarios (B and D) that assumed reductions in pumping chiefly in the LAS, with elimination of both UAS and LAS pumping near the coast in Scenario E. The high end of this range was arrived at under only one pumping scenario (E), which assumed reductions in pumping in the LAS, elimination of both UAS and LAS pumping near the coast, and ***increased*** pumping from the UAS inland from the coast. Implementation of such a pumping scheme would increase sustainable yield, but likely would require construction of new UAS wells and conveyance infrastructure to take advantage of the increased water supply from the UAS.

During the GSP development process, the FCGMA could use different assumptions, or develop other pumping scenarios that would result in higher or lower sustainable yields. However, the range of sustainable yields resulting from this evaluation are in the same order of magnitude as "annual yield" estimated as part of the FCGMA's 2007 GMP update (100,000 AF/yr combined annual yield for the Oxnard Plain, Pleasant Valley, Santa Rosa, and West/East/South Las Posas basins, or approximately 65,000 AF/yr combined for the Oxnard Plain and Pleasant Valley basins). Therefore, unless development of new water-supply sources is assumed, it seems probable that the FCGMA's GSP, when completed, will include a sustainable yield estimate (or range of estimates) similar to the range estimated in this evaluation, unless new water-supply projects are proposed.

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1 BACKGROUND AND INTRODUCTION

United Water Conservation District (United) is a public agency authorized under the California Water Code section 74500 et al. 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, and to prevent interference with or diminution of stream/river flows and associated natural subterranean flows, and other activities. The area under United's jurisdiction includes much of the Ventura County portion of the Santa Clara River Valley and the Oxnard coastal plain. The District is governed by a seven-person board of directors elected by region, and receives revenue from property taxes, pump charges, recreation fees, and water delivery charges. United conducts various monitoring programs and reports on basin conditions as part of its mission of water resource management.

1.1 PURPOSE AND SCOPE OF THIS EVALUATION

The analyses and conclusions included in this report are intended to guide United's management and its Board of Directors in establishing groundwater management policies that are consistent with the mission of the agency. United recognizes that the compliance actions associated with the Sustainable Groundwater Management Act (SGMA), the formation of a Groundwater Sustainability Agency (GSA), and the creation and implementation of Groundwater Sustainability Plans (GSPs) have the potential to change how groundwater resources are managed in Ventura County. Specifically, this report was conceived and produced to provide technically defined answers to questions posed by United management and its Board of Directors with respect to the Oxnard Plain (including the Forebay area, unless noted otherwise in this report) and Pleasant Valley groundwater basins, such as:

1. Which of the Groundwater Sustainability Indicators defined in the SGMA are the most restrictive to groundwater extractions in the Oxnard Plain and Pleasant Valley basins?
2. Upon implementation of GSPs, will reductions in pumping rates be required to reach the sustainability goal(s)?
3. Should/could the aquifers or aquifer systems be managed in combination or are specific management targets needed for each aquifer (or aquifer system) in order to meet the sustainability goals?
4. Will new water-supply development projects (e.g., pipelines, wells, treatment facilities) be needed to supplement existing groundwater supplies and infrastructure in order to meet goals of the GSPs for each basin? This information is a crucial input factor to United's water resource master planning efforts.
5. What are the potential fiscal impacts of reduced groundwater extractions on United?

This report was prepared for the benefit of United's Board of Directors and senior management, and is ***not*** intended to serve as a GSP, define how the sustainable yield should be determined by the

GSA, or specify what value or range of values should be used as the sustainable yield. The analyses and results are meant to be used as a starting point in evaluating potential impacts to United's operations as a result of sustainability planning already underway by the Fox Canyon Groundwater Management Agency (FCGMA).

1.2 PREVIOUS GROUNDWATER MANAGEMENT PLANNING

The FCGMA began operating in 1983 for the purpose of "planning, managing, controlling, preserving, and regulating the extraction and use of groundwater within the territory of the agency," which includes the Oxnard Plain and Pleasant Valley basins, as well as the Las Posas and Santa Rosa basins to the east (FCGMA and others, 2007). The impetus for forming the FCGMA was concern about groundwater overdraft and deteriorating groundwater quality, particularly increasing chloride concentrations resulting from seawater intrusion in the Oxnard aquifer, caused by long-term overdraft and associated declines in groundwater elevation within the FCGMA's service area.

In 1985, a groundwater management plan (GMP) for the FCGMA, developed by the Ventura County Public Works Agency, was adopted (Ventura County Public Works Agency, 1985). Initial goals included balancing water supply and demand in the Upper Aquifer System (UAS) by 2000 and in the Lower Aquifer System (LAS) by 2010. The combined "annual yield" of the groundwater basins within the FCGMA (i.e., Oxnard Plain [including the Forebay], Pleasant Valley, Santa Rosa, and Las Posas [East, West, and South] basins) was estimated to be 120,000 acre-feet per year (AF/yr) in 1985. The GMP recommended reducing groundwater pumping by 25% over a 20-year period to maintain the groundwater balance, and new surface-water diversion, recharge, and delivery projects were initiated by United and Calleguas Municipal Water District. Combined, these efforts resulted in significant slowing or reversal of seawater intrusion in the UAS; however, the area impacted by saline intrusion in the LAS, particularly in the area surrounding Mugu Lagoon, expanded (United, 2016).

Improved data collection and analysis subsequent to formation of the FCGMA resulted in a better understanding of the causes and effects of basin overdraft, seawater intrusion, and other water quality concerns, leading to an update of the GMP in 2007 (FCGMA and others, 2007). The 2007 GMP Update established Basin Management Objectives (BMOs), which consisted of groundwater elevation objectives and water quality goals for selected wells. If groundwater levels were above the BMOs more than 50 percent of the time, they were anticipated to "protect the aquifers from further saline intrusion and other water quality problems" (FCGMA and others, 2007). To achieve the BMOs more than 50 percent of the time, particularly in the LAS and in the Mugu Lagoon area (where groundwater-level decline and seawater intrusion were greatest), groundwater modeling indicated that pumping would have to be further reduced to 100,000 AF/yr, focusing those reductions in the southern Oxnard Plain and Pleasant Valley basins, where pumping reductions of 85 percent were forecasted to be required (FCGMA and others, 2007). It was also noted by the FCGMA that such reductions were considered as "an initial target level, but should be revisited as that goal is approached to ensure that it is sufficiently protective in the future."

In addition to pumping reductions, the 2007 GMP Update recommended additional management strategies for future implementation that could aid in achieving the BMOs, including:

- Short-term efforts to continue pumping reductions and treat/use wastewater and other poor-quality water;
- Mid-term (5- to 10-year) efforts to protect existing groundwater quality, enhance conservation of water, enhance/protect surface-water-supply sources, and develop additional infrastructure to provide surface water in lieu of pumping in the southern Oxnard Plain basin; and,
- Long-term (15-year or longer) efforts to construct hydraulic barriers to seawater intrusion, recharge additional flows from the Santa Clara River, shift pumping away from the southern Oxnard Plain and Pleasant Valley basins, and further reduce pumping if BMO targets were still not met.

1.3 SUSTAINABLE GROUNDWATER MANAGEMENT ACT (SGMA)

On January 1, 2015, state legislation (AB 1739, SB 1168 and SB 1319) was enacted requiring every groundwater basin in California to be managed sustainably by the year 2042. These three original sustainability bills are collectively known as the SGMA. The legislation provides for the formation of local GSAs that will be responsible for writing and implementing GSPs. GSPs are to be submitted to the California Department of Water Resources (CA DWR) for review and approval. Groundwater basins that have had their water rights adjudicated (such as the Santa Paula basin) are exempt from a number of the SGMA requirements but do have new requirements to report basin conditions to the CA DWR. All other basins, including those formerly governed under AB 3030, will be managed under the new legislation. A number of pumper associations and various public agencies, including United, are now involved in the formation of GSAs in southern Ventura County to comply with SGMA requirements.

1.4 GROUNDWATER SUSTAINABILITY AGENCY

The FCGMA has existed since 1983, and the SGMA legislation allows that existing management agencies have the option of becoming the sole GSA for the basins within their existing jurisdictions. In January 2015, the FCGMA elected to be the GSA for the Oxnard Plain (including the Forebay), Pleasant Valley, and portions of the Las Posas (West, South, and East) and Santa Rosa groundwater basins. The FCGMA has a consulting team under contract to develop GSPs for the four basins they manage.

1.5 TECHNICAL APPROACH

The approach taken for this evaluation is limited in scope compared to the GSP process currently underway (by the FCGMA and their consultants), as it does not include the other compliance actions (e.g., stakeholder engagement or planning of future water-supply projects) that are required in the GSP regulations, and it relies on some simplifying assumptions regarding possible future water-supply scenarios. The overall technical approach taken for this evaluation consisted of three main steps, as follows:

1. Develop assumed minimum thresholds for each of the six sustainability indicators defined in the GSP regulations. These assumed minimum thresholds are based on simplifying assumptions about current and future hydrogeologic conditions and undesirable results that may (or may not) be similar to the approaches ultimately taken by the FCGMA to determine minimum thresholds for their GSPs. For this evaluation, the assumed minimum thresholds for each sustainability indicator are expressed as groundwater elevations, as allowed under the GSP regulations.
2. Determine the groundwater elevation corresponding with the highest of the assumed minimum thresholds in each basin and management area. In this report, that elevation is referred to as the "target groundwater level." It is assumed that if groundwater elevations are maintained above the target groundwater levels most of the time, significant and unreasonable undesirable results can be avoided, leading to sustainable groundwater management.
3. Use a groundwater flow model developed by United to evaluate the extent to which several hypothetical future groundwater-extraction (pumping) scenarios could achieve the target groundwater levels as described above. Simulated pumping rates that were forecasted to raise groundwater elevations from current record lows to target groundwater levels or higher most of the time were considered to potentially be representative of sustainable yield for the Oxnard Plain and Pleasant Valley basins. The goal of this step was to estimate the range of potential minimum sustainable yield values that might result from the groundwater sustainability planning process currently underway by the FCGMA and their consultant, assuming no new water-supply sources were developed in the region.

The physical characteristics and hydrogeologic conditions in the Oxnard Plain and Pleasant Valley basins that establish the hydraulic parameters for this evaluation are summarized in Section 2. Key GSP definitions and guidelines are presented in Section 3. Details regarding selection of assumed minimum thresholds for each sustainability indicator are provided in Section 4. Finally, Section 5 describes the technical approach to developing target groundwater levels, modeling the different pumping scenarios considered in this evaluation, and assessing the sustainability of groundwater conditions forecasted under each pumping scenario.

2 BASIN DESCRIPTIONS AND HYDROGEOLOGIC SETTING

The Oxnard Plain and Pleasant Valley basins are the two major groundwater basins underlying the Oxnard coastal plain, as shown on Figure 2-1.1. These basins occupy the downstream portions of the watershed of the Santa Clara River and Calleguas Creek, respectively. Both basins are heavily developed for both urban and agricultural use, supported in part by extensive groundwater production from a large number of both public and private wells. This report generally includes the Oxnard Forebay sub-basin (the Forebay) as part of the Oxnard Plain basin, unless explicitly noted otherwise.

2.1 OXNARD PLAIN BASIN

The Oxnard Plain basin occupies approximately 75 square miles of the Oxnard coastal plain (Figure 2.1-1). The Forebay occupies 10 square miles in the northern portion of Oxnard Plain basin and is where most of the groundwater recharge to the Oxnard Plain basin occurs. Recharge in the Forebay also benefits other coastal basins (Mound, West Las Posas, Pleasant Valley), but a majority of the groundwater recharged to the Forebay flows downgradient to the confined aquifers of the Oxnard Plain basin. The shallow sediments of the Forebay 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. Recharge to the Forebay comes from percolation of Santa Clara River flows, artificial recharge from United's recharge basins, irrigation return flows, septic tanks, percolation of rainfall, underflow from the Santa Paula basin, and mountain-front recharge from South Mountain. In the area of the Forebay between United's Saticoy and El Rio recharge facilities, the LAS has been uplifted and truncated along its contact with the UAS (John F. Mann Jr. and Associates, 1959). In this area recharge from surface sources may enter both the UAS and the underlying LAS, but much of the water is believed to remain in the shallower aquifers of the UAS. In the southern portions of the Forebay the LAS becomes more hydraulically isolated from the UAS.

The aquifers of the Forebay are continuous with those of the Oxnard Plain basin, which is overlain by an extensive confining clay layer ("clay cap" or Semi-perched aquitard). Thus, the primary source of recharge for the Oxnard Plain basin is lateral groundwater flow from the Forebay rather than deep percolation of near-surface water across the basin. Natural and artificial recharge to the Forebay serves to raise groundwater elevations in this upgradient area of the groundwater flow system for the Oxnard Plain. Changes in groundwater elevation in the 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. Higher groundwater levels in the Forebay are beneficial, as they maintain seaward hydraulic gradients from the Forebay to coastal areas. While the physical movement of groundwater out of the Forebay is fairly slow, the pressure response in the confined aquifers of the Oxnard Plain basin is rapid. When groundwater elevations are below sea level along the coastline, there can be significant recharge of the Oxnard Plain basin by seawater flowing into the aquifers (United, 2016). In areas near Port Hueneme and Point Mugu where submarine canyons extend nearly to the coastline, the fresh-water aquifers may be in direct contact with seawater a short distance offshore.

Vertical gradients also commonly exist between aquifer units on the Oxnard Plain basin, resulting in some degree of vertical groundwater movement through low-permeability units that occur between most of the major aquifers. When LAS groundwater levels are substantially lower than UAS groundwater levels (creating a downward gradient), there is substantial leakage of UAS groundwater into the LAS through the various aquitards that separate the aquifer units, and through wells that are screened across both aquifer systems. Likewise, a downward pressure gradient can exist between the Semi-perched aquifer and the Oxnard aquifer when hydraulic heads in the Oxnard aquifer are lowered (either regionally by drought conditions or locally by pumping wells). The movement of poor quality groundwater 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 and others, 1992; Stamos and others, 1992; Predmore, 1993). Conversely, during rare periods of artesian conditions, upward vertical gradients may exist between deeper confined aquifers and the Semi-perched aquifer.

The highly-permeable deposits of the UAS are relatively flat lying across approximately the upper 400 feet (ft) of the Oxnard Plain. In the northern Oxnard Plain basin, hydraulic heads are often similar in the Oxnard and Mugu aquifers, but hydraulic heads in the Mugu aquifer are considerably lower than those in the Oxnard aquifer in the vicinity of Mugu Lagoon. This may be indicative of increased connectivity between the Mugu and Fox Canyon aquifers in this area, and the downward movement of groundwater from the Mugu aquifer to the Fox Canyon aquifer.

Deposits comprising the aquifers of the LAS are generally finer-grained than those of the UAS, resulting in lower hydraulic conductivity, and have been deformed by folding and faulting in many areas. An uneven distribution of pumping, along with structural and stratigraphic changes within the LAS, results in varied hydraulic heads among the deep wells across the Oxnard Plain. Faulting and uplift associated with the Sycamore fault and changes in LAS stratigraphy may limit direct contact of the LAS with seawater in the area offshore from Mugu Lagoon (Izbicki, 1996b; Hanson and others, 2003).

2.2 PLEASANT VALLEY BASIN

The Pleasant Valley basin, with an area of 33 square miles, is bounded to the south and east by the Santa Monica Mountains, to the north by the Camarillo Hills, and to the west by the Oxnard Plain (Figure 2-1.1). The Bailey fault is a major structural feature that trends NE near the base of the Santa Monica Mountains, and the Springville fault bounds the basin 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 ft thick. In Pleasant Valley basin, much of the UAS is fine grained and not extensively pumped for water supply

(Turner, 1975; Hanson and others, 2003). UAS deposits in the Pleasant Valley basin are comprised of sediments from the Calleguas Creek watershed, a smaller and less mountainous drainage than that of the Santa Clara River which deposited the coarser UAS deposits of the Oxnard Plain basin. Some coarse-grained UAS deposits do exist in the Pleasant Valley basin, but these deposits tend to be thin or discontinuous.

The LAS in the Pleasant Valley basin is composed of the Hueneme, Fox Canyon, and Grimes Canyon aquifers to depths greater than 1,500 ft. The Hueneme aquifer is relatively thin in the Pleasant Valley basin and 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 Pleasant Valley basin.

In Pleasant Valley the LAS is surrounded and underlain by partly consolidated marine deposits and volcanic rocks, which typically do not yield a sufficient quantity or quality of groundwater to wells for most uses. Marine deposits are present in the Camarillo Hills (Las Posas Sand) and along the western edge of the Santa Monica Mountains near the coast (Lower Topanga Formation shale). Volcanic rocks consisting of basalts, submarine volcanic flows, and debris flows are present in the Santa Monica Mountains along the southeastern edge of Pleasant Valley basin (Weber and others., 1976).

Under pre-development conditions in the Pleasant Valley basin, groundwater movement in the UAS and LAS was likely from recharge areas in the northeast toward the Oxnard Plain basin to the southwest. The LAS in Pleasant Valley basin appears to be isolated from most sources of recharge, and the age of groundwater ranges from about 3,000 to more than 6,000 years before present (Izbicki, 1996a).

Over the past two decades groundwater levels recorded in at least two wells in northern Pleasant Valley have recovered more than 250 ft (UWCD, 2014). The re-establishment of surface flow in Arroyo Las Posas south of the community of Somis that subsequently percolates near the northern margin of the basin is now recognized as a source of recharge to the basin. The degree to which this large recharge mound serves to recharge the LAS in the central portion of the basin is not well established, as the distribution of wells available for groundwater-level monitoring in the northern Pleasant Valley basin is poor. The City of Camarillo has plans to construct a large-scale desalter to treat and utilize this groundwater which tends to be more mineralized than the older and deeper groundwater native to the basin. The groundwater mound in the northern Pleasant Valley basin has subsided by about 100 ft since 2012 as flow in Arroyo Las Posas has diminished.

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3 GROUNDWATER SUSTAINABILITY PLAN (GSP) REGULATIONS

The CA DWR issued the final GSP Regulations in 2016that provide guidance to GSAs in the creation of GSPs (CA DWR, 2016). These regulations, while illustrative of the concepts guiding the premise of sustainability, do not provide detailed instructions on how to develop a GSP.

Selected major overview sections from the GSP regulations are provided below, and throughout this section:

> *§ 350. Authority and Purpose*
> *These regulations specify the components of groundwater sustainability plans, alternatives to groundwater sustainability plans, and coordination agreements prepared pursuant to the Sustainable Groundwater Management Act (Part 2.74 of Division 6 of the Water Code, beginning with Section 10720), and the methods and criteria used by the Department to evaluate those plans, alternatives, and coordination agreements, and information required by the Department to facilitate that evaluation.*
>
> *Note: Authority cited: Section 10733.2, Water Code.*
>
> *§ 350.2. Applicability*
>
> *(a) The process and standards for an Agency to develop and submit a Plan for evaluation by the Department, and for Department evaluation of that Plan and its implementation, as described in these regulations, are also applicable to multiple Agencies developing multiple Plans, as described in Article 8, and to entities submitting Alternatives, as described in Article 9.*
>
> *(b) Unless as otherwise noted, section references in these regulations refer to this Subchapter.*
>
> *Note: Authority cited: Section 10733.2, Water Code.*
>
> *Reference: Sections 10727.6, 10733.2, 10733.4, and 10733.6, Water Code.*

3.1 GROUNDWATER SUSTAINABLE MANAGEMENT CRITERIA

The GSP regulations contain language that describes the concepts of sustainable management criteria. These criteria are designed, when implemented, to help guide a basin into a sustainable condition.

Major sections in the GSP referencing sustainable management criteria include the following:

§ 350.4. General Principles
Consistent with the State's interest in groundwater sustainability through local management, the following general principles shall guide the Department in the implementation of these regulations.

(a) Groundwater conditions must be adequately defined and monitored to demonstrate that a Plan is achieving the sustainability goal for the basin, and the Department will evaluate the level of detail provided considering the basin setting.

(b) To comply with the Department's statutory mandate to evaluate Plans, Plan implementation, and the effect on Plan implementation on adjacent basins, Plan content information must be sufficiently detailed and readily comparable.

(c) The Department shall evaluate the adequacy of all Plans, including subsequent modifications to Plans, and reports and periodic evaluations based on a substantial compliance standard as described in Article 6, provided that the objectives of the Act are satisfied.

(d) Sustainable management criteria and projects and management actions shall be commensurate with the level of understanding of the basin setting, based on the level of uncertainty and data gaps, as reflected in the Plan.

(e) An Agency shall have the responsibility for adopting a Plan that defines the basin setting and establishes criteria that will maintain or achieve sustainable groundwater management, and the Department shall have the ongoing responsibility to evaluate the adequacy of that Plan and the success of its implementation.

(f) A Plan will be evaluated, and its implementation assessed, consistent with the objective that a basin be sustainably managed within 20 years of Plan implementation without adversely affecting the ability of an adjacent basin to implement its Plan or achieve and maintain its sustainability goal over the planning and implementation horizon.

(g) The Department shall consider the state policy regarding the human right to water when implementing these regulations.

Note: Authority cited: Section 10733.2, Water Code.

Reference: Sections 106.3, 113, 10720.1, 10720.9, 10727.6, 10733, and 10733.2, Water Code.

Sustainability indicators, as defined in the GSP regulations, include:

- Lowering groundwater levels;
- Reduction in groundwater storage;
- Seawater intrusion;
- Water quality degradation;
- Land subsidence; and

- Surface water depletion.

3.2 MINIMUM THRESHOLDS

Minimum thresholds are defined by SGMA as numeric values "for each sustainability indicator used to define undesirable results." If the minimum threshold values are not achieved for a particular sustainability indicator, then undesirable results would be anticipated to occur, indicating that groundwater management in the basin may not be sustainable. The GSP regulations contain the following guidance regarding the need to establish minimum thresholds for all sustainability indicators:

§ 354.28. Minimum Thresholds

> *(d) An Agency may establish a representative minimum threshold for groundwater elevation to serve as the value for multiple sustainability indicators, where the Agency can demonstrate that the representative value is a reasonable proxy for multiple individual minimum thresholds as supported by adequate evidence.*
>
> *(e) An Agency that has demonstrated that undesirable results related to one or more sustainability indicators are not present and are not likely to occur in a basin, as described in Section 354.26, shall not be required to establish minimum thresholds related to those sustainability indicators.*

The GSP regulations also contain the following specific language regarding minimum thresholds for each sustainability indicator:

> ***Chronic Lowering of Groundwater Levels.*** *The minimum threshold for chronic lowering of groundwater levels shall be the groundwater elevation indicating a depletion of supply at a given location that may lead to undesirable results. Minimum thresholds for chronic lowering of groundwater levels shall be supported by the following:*
>
> *(A) The rate of groundwater elevation decline based on historical trends, water year type, and projected water use in the basin.*
>
> *(B) Potential effects on other sustainability indicators.*

> ***Reduction of Groundwater Storage.*** *The minimum threshold for reduction of groundwater storage shall be a total volume of groundwater that can be withdrawn from the basin without causing conditions that may lead to undesirable results. Minimum thresholds for reduction of groundwater storage shall be supported by the sustainable yield of the basin, calculated based on historical trends, water year type, and projected water use in the basin.*

> ***Seawater Intrusion.*** *The minimum threshold for seawater intrusion shall be defined by a chloride concentration isocontour for each principal aquifer where seawater*

intrusion may lead to undesirable results. Minimum thresholds for seawater intrusion shall be supported by the following:

(A) Maps and cross-sections of the chloride concentration isocontour that defines the minimum threshold and measurable objective for each principal aquifer.

(B) A description of how the seawater intrusion minimum threshold considers the effects of current and projected sea levels.

Degraded Water Quality. *The minimum threshold for degraded water quality shall be the degradation of water quality, including the migration of contaminant plumes that impair water supplies or other indicator of water quality as determined by the Agency that may lead to undesirable results. The minimum threshold shall be based on the number of supply wells, a volume of water, or a location of an isocontour that exceeds concentrations of constituents determined by the Agency to be of concern for the basin. In setting minimum thresholds for degraded water quality, the Agency shall consider local, state, and federal water quality standards applicable to the basin.*

Land Subsidence. *The minimum threshold for land subsidence shall be the rate and extent of subsidence that substantially interferes with surface land uses and may lead to undesirable results. Minimum thresholds for land subsidence shall be supported by the following:*

(A) Identification of land uses and property interests that have been affected or are likely to be affected by land subsidence in the basin, including an explanation of how the Agency has determined and considered those uses and interests, and the Agency's rationale for establishing minimum thresholds in light of those effects.

(B) Maps and graphs showing the extent and rate of land subsidence in the basin that defines the minimum threshold and measurable objectives.

Depletions of Interconnected Surface Water. *The minimum threshold for depletions of interconnected surface water shall be the rate or volume of surface water depletions caused by groundwater use that has adverse impacts on beneficial uses of the surface water and may lead to undesirable results. The minimum threshold established for depletions of interconnected surface water shall be supported by the following:*

(A) The location, quantity, and timing of depletions of interconnected surface water.

(B) A description of the groundwater and surface water model used to quantify surface water depletion. If a numerical groundwater and surface water model is not used to quantify surface water depletion, the Plan shall identify and describe an equally effective method, tool, or analytical model to accomplish the requirements of this Paragraph.

3.3 MEASURABLE OBJECTIVES

The GSP regulations contain the following specific language regarding measurable objectives (MOs) for each sustainability indicator:

§ 354.30. Measurable Objectives

(a) Each Agency shall establish measurable objectives, including interim milestones in increments of five years, to achieve the sustainability goal for the basin within 20 years of Plan implementation and to continue to sustainably manage the groundwater basin over the planning and implementation horizon.

(b) Measurable objectives shall be established for each sustainability indicator, based on quantitative values using the same metrics and monitoring sites as are used to define the minimum thresholds.

(c) Measurable objectives shall provide a reasonable margin of operational flexibility under adverse conditions which shall take into consideration components such as historical water budgets, seasonal and long-term trends, and periods of drought, and be commensurate with levels of uncertainty.

(d) An Agency may establish a representative measurable objective for groundwater elevation to serve as the value for multiple sustainability indicators where the Agency can demonstrate that the representative value is a reasonable proxy for multiple individual measurable objectives as supported by adequate evidence.

(e) Each Plan shall describe a reasonable path to achieve the sustainability goal for the basin within 20 years of Plan implementation, including a description of interim milestones for each relevant sustainability indicator, using the same metric as the measurable objective, in increments of five years. The description shall explain how the Plan is likely to maintain sustainable groundwater management over the planning and implementation horizon.

(f) Each Plan may include measurable objectives and interim milestones for additional Plan elements described in Water Code Section 10727.4 where the Agency determines such measures are appropriate for sustainable groundwater management in the basin.

(g) An Agency may establish measurable objectives that exceed the reasonable margin of operational flexibility for the purpose of improving overall conditions in the basin, but failure to achieve those objectives shall not be grounds for a finding of inadequacy of the Plan.

Note: Authority cited: Section 10733.2, Water Code.

Reference: Sections 10727.2, 10727.4, and 10733.2, Water Code.

This evaluation relies on assumed minimum thresholds to select target groundwater levels, which are the primary drivers for estimating potential sustainable pumping rates for the Oxnard Plain and Pleasant Valley basins. Establishing measurable objectives and interim milestones is required as part of the groundwater sustainability planning process being conducted by the FCGMA and their consultant, but is not part of this evaluation. The goal of including measurable objectives and interim milestones in a GSP is to help evaluate the progress made from the time of adoption of a GSP to achievement of the sustainability goals of the subject basin(s). However, the objective of the evaluation described in this report is simply to estimate the range of potential sustainable yields under certain water-supply conditions. For such an evaluation, measurable objectives and interim milestones are not relevant.

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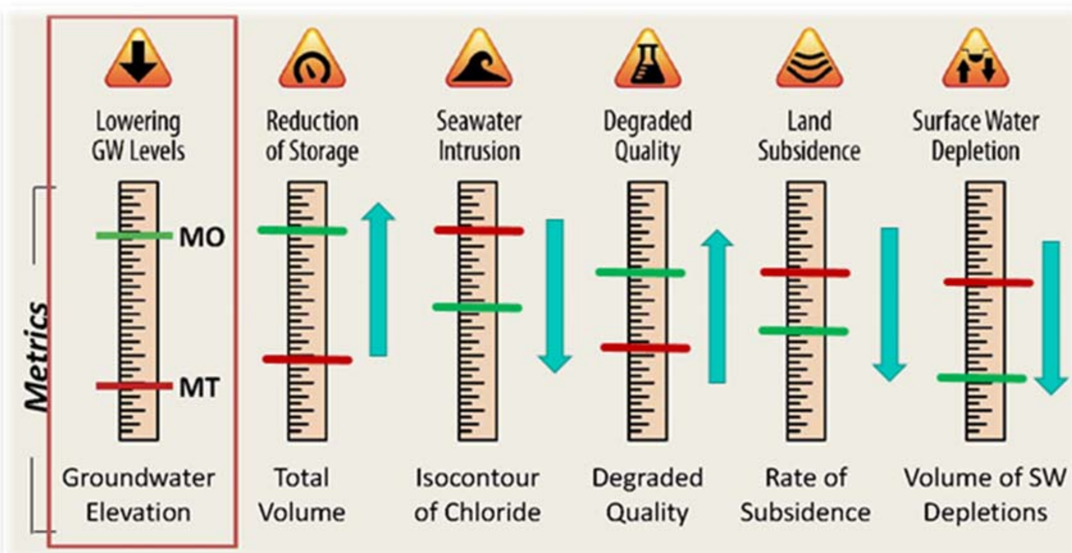
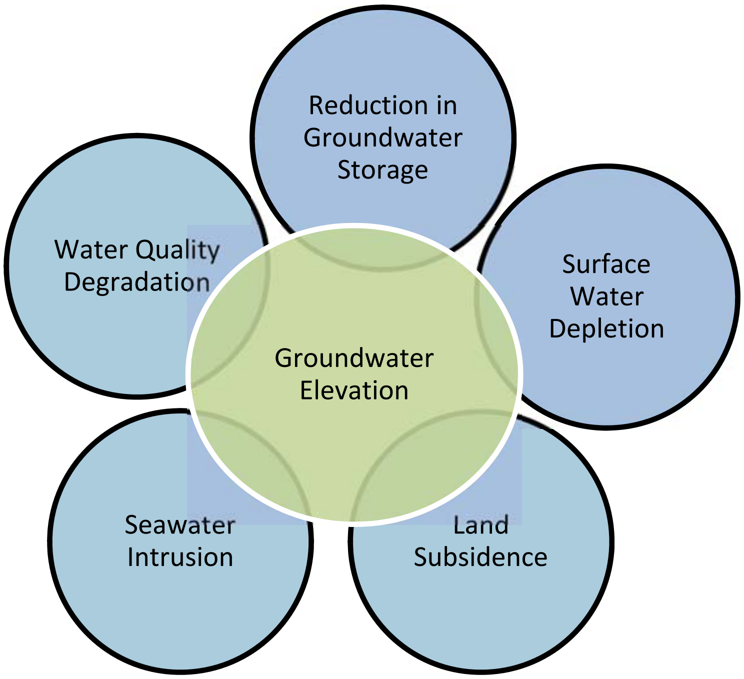
4 SUSTAINABILITY INDICATORS

The GSP regulations offer metrics that can be used to help establish the minimum thresholds and measureable objectives that will gauge progress towards sustainability. The metrics suggested in the regulations contain a mixed set of specific, quantifiable parameters, including rates of change (i.e., groundwater and land-surface elevations, streamflows), absolute values (i.e., groundwater elevations and chloride concentrations), volumes (i.e., groundwater in storage), and the more general indicator “degraded water quality.”



Development of practical, usable minimum thresholds from the “blended” metrics suggested by CA DWR is challenging. For example, how can rates of subsidence be compared to a change in the volume of groundwater in storage or to the changing position of a chloride isoconcentration contour? These metrics are difficult to integrate while retaining the importance of each individual sustainability indicator. However, the GSP regulations (*§ 354.28. Minimum Thresholds*) afford flexibility in how a GSA addresses the integration of the sustainability indicators and their minimum thresholds.

For the Oxnard Plain and Pleasant Valley groundwater basins, the approach to integrating the sustainability indicators used in this preliminary evaluation is to establish a common metric that can be used as a surrogate for all of the indicators. Groundwater elevation has been selected as the common metric for all of the sustainability indicators in this evaluation, as allowed under the GSP regulations [§354.28, paragraph (d)].



In addition, the GSP regulations (*§ 354.28. Minimum Thresholds*) state that sustainability indicators that are not present or not likely to occur need not have minimum thresholds established.

Groundwater elevation is a key variable and suitable surrogate for the determination of whether undesirable results are likely to occur as a result of current or future groundwater management options. The following sections describe how groundwater elevation were applied as the metric for each of the six SGMA sustainability indicators.

4.1 LOWERING GROUNDWATER LEVELS

Groundwater elevation is the common metric used to establish each of the assumed minimum thresholds. Consistent with *§ 354.28.*, assumed minimum thresholds will not be developed specifically for this sustainability indicator, but rather for each of the other five sustainability indicators. For the other indicator-specific assumed minimum thresholds, target groundwater levels are applied across the Oxnard Plain and Pleasant Valley basins (see Section 5 for details), in effect becoming comprehensive minimum thresholds for all indicators and eliminating the need for a stand-alone "Lowering Groundwater Levels" indicator.

4.1.1 Management Objective

Not applicable.

4.1.2 Metrics

Not applicable.

4.1.3 Data Sources

Not applicable.

4.1.4 Minimum Threshold

Not applicable.

4.1.5 Discussion

Not applicable.

4.1.6 Conclusions and Recommendations

Not applicable.

4.2 REDUCTION OF GROUNDWATER STORAGE

As a sustainability indicator in SGMA, “reduction of groundwater storage” is defined as the maximum amount (rate and/or volume) of groundwater withdrawal that does not yield undesirable results. The act of pumping groundwater reduces the volume of groundwater in storage because of the lowering of the water table (in an unconfined aquifer) or the lowering of the piezometric surface (the pressure head) in a confined aquifer. As the water table or piezometric surface are lowered during pumping, groundwater flow patterns and the amount of available drawdown in a supply well begin to change. Additionally, it is common in aquifer systems for pumping to exceed recharge during drought periods. Accordingly, groundwater basin management must look long-term at the amount of groundwater pumping that can occur through fluctuating hydrologic cycles, such that the recharge volume that the aquifer can infiltrate during non-drought periods offsets the recharge deficit during droughts; this balance governs the amount of groundwater withdrawal that can be sustained on a long-term basis.

4.2.1 Management objective

For the purpose of this evaluation, the primary management objective for the “reduction of groundwater storage” sustainability indicator is to maintain groundwater elevations in the UAS and LAS above historical low elevations. After the occurrence of historically low levels such as those observed during the 1960s, the early 1990s, and 2015, the aquifer demonstrated its ability to receive significant recharge during several “wet” periods (years of above-average rainfall), which in turn resulted in groundwater level recovery to pre-drought conditions. This historical recovery is assumed to be indicative of the aquifer’s recovery capability in the future. A secondary objective could be to maintain sufficient storage capacity within the UAS (i.e., don’t allow groundwater levels to rise to near ground surface) in the Forebay during dry periods such that a thick unsaturated zone capable of accommodating as much as 30,000 acre-feet per year of recharge from spreading basins is maintained, allowing artificial recharge to occur most efficiently when normal/wet conditions resume. This secondary objective is not explicitly incorporated into this evaluation, but could be considered during GSP development as an approach to maximize water supplies in the region.

4.2.2 Metrics

As discussed at the beginning of Section 4.1, "lowering groundwater levels" has been selected as the common metric for all six SGMA sustainability indicators. For evaluating groundwater conditions with respect to reduction of groundwater storage, groundwater elevations provide a more direct means of measuring storage conditions than attempting to estimate storage volumes, which are difficult to quantify and contain inherent uncertainties regarding aquifer hydraulic properties and dimensions.

4.2.3 Data sources

Time-series hydrographs of historical groundwater elevation data are the primary data source for establishing assumed minimum thresholds. Figures 4.2-1 and 4.2-2 show the average and minimum groundwater elevations each year in the UAS and LAS, respectively. These hydrographs present the groundwater elevation data for each Public Land Survey System (PLSS) section within the area, with separate plots for the Forebay, Oxnard Plain, and Pleasant Valley basins. This method of analyzing the historical data provides a more thorough analysis than can be obtained from examining a few select wells and developing interpretations that could vary over time as a well's use changes or the monitoring well network in a given area is modified. As shown in Figures 4.2-1 and 4.2-2, the minimum groundwater levels are markedly lower during the drought periods of the mid to late 1960s, 1991, and 2013 through 2015 than at other times.

4.2.4 Minimum Threshold

Figures 4.2-1 and 4.2-2 show that groundwater levels in the UAS and LAS: (1) have been lowest during pronounced drought periods and (2) recover after the drought to similar levels as seen before the drought. Prolonged (e.g., multi-year or decadal) periods of low groundwater levels induced by drought conditions have not been sustained historically in the UAS and LAS following the end of a drought. Accordingly, the assumed minimum thresholds for the reduction of groundwater storage sustainability indicator are assumed to be the historic low groundwater elevations that have been commonly observed during past drought periods:

- 100 ft below mean sea level (-100 ft msl) in the UAS in both the Oxnard Plain (including Forebay) and Pleasant Valley basins;
- -150 ft msl in the LAS in the Oxnard Plain (including Forebay) basin;
- -200 ft msl in the LAS in Pleasant Valley basin.
- Historic lows in a few Public Land Survey System (PLSS) sections have occasionally been slightly lower than these assumed minimum thresholds; however, such data outliers were not incorporated into development of the assumed minimum thresholds.

4.2.5 Discussion

The establishment of assumed minimum thresholds related to the reduction of groundwater storage sustainability indicator focuses on the unconfined portions of the UAS and the LAS. In the Oxnard Plain, the UAS and the LAS are confined and historically have had their groundwater levels remain above the base of the Semi-perched aquitard, which overlies the UAS (localized areas of the UAS in the Oxnard Plain basin adjacent to the Forebay have periodically had groundwater levels below the base of the Semi-perched aquitard, but only during exceptional drought periods). Accordingly, the *confined* portions of the UAS and LAS are not drained during pumping, but instead release groundwater from storage due to compression of the aquifer matrix and expansion of the groundwater when the aquifer is subjected to pumping stresses. In contrast, for the *unconfined* portions of these two aquifers (the Forebay in the case of the UAS, and the northeastern portion of the Pleasant Valley basin in the case of the LAS), the act of pumping groundwater releases groundwater from pores via gravity as the water table is lowered in response to the pumping activity. Assumed minimum thresholds are not established for the surficial Semi-perched aquifer because it is not pumped and hence is not used as a source of groundwater supply.

4.2.6 Conclusions and Recommendations

The assumed minimum thresholds for the reduction of groundwater storage sustainability indicator are based on historically low groundwater elevations, given that these elevations occurred during past drought periods and were not sustained once drought conditions ended. The historically observed groundwater level recoveries after drought periods are indicators that the low groundwater elevations by themselves are not indicative of sustained reductions in storage; in other words, as the natural hydrology of the region returns to normal or wet conditions following a drought, the groundwater system on both the Oxnard Plain basin and the Pleasant Valley basin responds with notable rises (recovery) in groundwater levels to above historical lows, due largely to increased natural and artificial recharge in the Forebay. Accordingly, the establishment of -100 and -200 ft msl groundwater elevations as assumed minimum thresholds for the reduction in storage groundwater sustainability indicator is intended to prevent groundwater levels from dropping below the levels that were historically observed, given that groundwater pumping during these historical droughts did not prevent a return to the typically higher groundwater levels commonly seen during non-drought periods.

4.3 SEAWATER INTRUSION

The GSP regulations define seawater intrusion as “the advancement of seawater into a groundwater supply that results in degradation of water quality in the basin, and includes seawater from any source.” The primary cause for seawater intrusion in coastal aquifers is development of a landward hydraulic gradient in areas where groundwater pumping has caused groundwater elevations to decline below sea level. The confined aquifers of the southern Oxnard Plain and Pleasant Valley basins are particularly vulnerable to seawater intrusion due to the existence of two deep submarine canyons just offshore from Port Hueneme and Mugu Lagoon, where the aquifers crop out on the seafloor, allowing interchange of groundwater with seawater. The Pacific Ocean is effectively a constant-head, infinite source of potential recharge to the basins by seawater, if groundwater elevations inland of the coast fall below sea level. Groundwater quality may also be degraded by chloride in isolated areas not directly affected by lateral seawater intrusion, due to upwelling of connate saline water from deeper formations or the compaction of marine clays within aquifers, usually as a result of declining groundwater levels.

Seawater intrusion in the confined aquifers underlying the Oxnard coastal plain has been recognized for approximately 80 years. High chloride levels were first detected in groundwater inland from the Hueneme and Mugu submarine canyons in the early 1930s (CA DWR, 1971) and became a wider concern in the 1950s. Historically, groundwater quality problems resulting from saline intrusion under the Oxnard coastal plain were limited to the aquifers of the UAS, from which most groundwater production occurred. Over time, production increased from the aquifers of the LAS as drilling technology improved and groundwater users recognized the value of the lower total dissolved solids (TDS) concentrations in some of the deeper aquifers, and as degradation continued in the UAS. Seawater intrusion is not a problem in the Semi-perched aquifer, as essentially no groundwater pumping occurs in this aquifer and groundwater levels are normally above sea level.

In fall 1975, potentiometric heads in the UAS and LAS across much of the southeastern Oxnard Plain and southern Pleasant Valley basin were below sea level. These conditions led the State Water Resources Control Board (SWRCB) to consider adjudication of water rights in the basins (SWRCB, 1979). To improve groundwater conditions without resorting to adjudication, the FCGMA was formed in 1983, and its initial goals were to bring the aquifers of the UAS into balance by the year 2000, and of the LAS by the year 2010 (FCGMA and others, 2007). Since 1983, major investments have been made in infrastructure to enhance recharge and convey surface water to areas with the greatest pumping depressions, importation of water from the State Water Project was increased, and programs to reduce groundwater pumping were implemented by the FCGMA, United, and Calleguas MWD. These actions achieved some degree of success at limiting and even reversing the extent of seawater intrusion in the UAS. However, groundwater levels in much of the LAS in the southern Oxnard Plain and Pleasant Valley basins has remained below sea level during the intervening years. As a result of drought conditions since 2012, groundwater elevations in large areas of both the UAS and LAS in the coastal basins declined to record or near- record low levels (below sea level) in 2016, exacerbating the potential for seawater intrusion.

4.3.1 Management Objective

The management objective for seawater intrusion is assumed for this evaluation to be prevention of further inland (northward) migration of high-chloride, seawater-impacted groundwater in each of the six aquifers comprising the UAS and LAS. Conceptually, this objective could be achieved if a neutral or seaward hydraulic gradient were present along the boundary or interface between seawater-impacted and non-impacted groundwater within each aquifer, so that the high-saline groundwater “front” would stabilize or migrate southward, retreating toward the coastline. Multiple lines of evidence, including surface geophysical analysis, groundwater level data, and groundwater quality data from monitoring wells, have been used in combination to approximate the area of each aquifer that likely is impacted by saline water intrusion to a significant degree (United, 2016). Based on available data, significant seawater-intrusion impacts to the aquifers of the UAS and LAS appear to have occurred within a few miles of the coastline from Port Hueneme eastward to Calleguas Creek, near the eastern boundary of the basin. Figures 4.3-1 and 4.3-2 show the interpreted inland extent of lateral seawater intrusion into each aquifer of the UAS and LAS as of 2015.

In order to achieve the management objective for seawater intrusion with a reasonable degree of confidence, given the difficulty in precisely determining the saline water front in the aquifers, this evaluation assumes that a seawater intrusion management area will be established that is large enough to contain the interpreted area of significant seawater impacts to the aquifers (Figures 4.3-1 and 4.3-2). Within the seawater intrusion management area, groundwater levels would be maintained at sufficient elevations above sea level to induce neutral to seaward hydraulic gradients (accounting for the higher density of seawater relative to freshwater), thereby preventing further landward migration of seawater. Inland of the seawater intrusion management area, groundwater elevations would not necessarily need to be maintained above sea level, so long as groundwater levels within the seawater intrusion management area remained sufficiently high to prevent development of a landward gradient from the coast to these inland areas. Other approaches to prevent further seawater intrusion potentially include construction of injection wells (inland of the seawater front) or extraction wells (seaward of the front), or a mixture of the two types of wells, to create a hydraulic barrier that would prevent further landward migration of seawater. However, these approaches would require improved delineation of the seawater front, an extensive design process, and detailed input regarding potential fresh water sources (if injection were selected) and project feasibility, which are beyond the scope of this preliminary evaluation.

It is further assumed that raising UAS and LAS groundwater elevations above historic lows in the southern Oxnard Plain and Pleasant Valley basins (an expected result of raising groundwater elevations above sea level in the seawater intrusion management area) would mitigate existing and potential future groundwater quality impairment related to other saline intrusion processes (i.e., brine intrusion from clay lenses or adjacent formations).

4.3.2 Metrics

The assumed metrics for determination of whether minimum thresholds are being achieved for seawater intrusion are groundwater levels measured or estimated in each aquifer within the seawater intrusion management area. As discussed above, maintaining groundwater levels within the seawater intrusion management area sufficiently high to counter the higher density of seawater will create a neutral to seaward hydraulic gradient, which in turn will prevent further landward intrusion of seawater. Groundwater elevations are directly measurable and can also be directly simulated using a groundwater flow model. In contrast, groundwater quality within an aquifer can be affected by a variety of processes that may or may not be related to seawater intrusion, and is more challenging to accurately model, making water quality parameters a more difficult metric to apply to forecasting or monitoring potential seawater intrusion.

Due to the greater density of seawater (1.025 grams per cubic centimeter) compared to freshwater (1.00 gram per cubic centimeter), the standing elevation of groundwater inland from the saline-water front must be 1.025 times higher than the standing elevation of seawater on the opposite (seaward) side of the interface in order to achieve hydrostatic balance, which will, in turn, yield a neutral hydraulic gradient. In reality, the processes involved in seawater intrusion into freshwater aquifers are more complex than density-dependent hydrostatic balance, but this simplified approach is suitable for this preliminary, basin-scale evaluation of sustainable yield, and is consistent with the approach used by the FCGMA in their 2007 GMP update.

As an example of the approach used in this evaluation, freshwater potentiometric heads in the Oxnard aquifer, which has a submarine outcrop depth of approximately -200 ft msl, would have to be 205 ft above that depth, or +5 ft msl, in the seawater intrusion management area, to counteract the pressure head exerted by seawater and achieve a neutral horizontal hydraulic gradient that would prevent further landward seawater intrusion (2.5 ft of freshwater head required per 100 ft of outcrop depth). Submarine outcrop depth varies for each of the UAS and LAS aquifers, resulting in different freshwater elevations required to achieve hydrostatic balance, as summarized in Table 4.3-1. It should be noted that due to faulting and folding, the depths to the aquifers beneath land surface in the centers of the Oxnard Plain and Pleasant Valley basins can be substantially greater than the depths of their submarine outcrops below sea level (along the southwest margin of the groundwater basins). However, the relevant depth for this evaluation is the depth of the submarine outcrop below sea level.

The GSP regulations also require consideration of the effects of projected future sea levels, based on forecasts of sea-level rise associated with climate change during the planning period. As of November 2016, when data and information were collected to conduct this evaluation, CA DWR had posted on their Web site (http://www.water.ca.gov/climatechange/articles.cfm) a paper titled "State of California Sea-Level Rise Interim Guidance Document" (Sea-Level Rise Task Force, 2010). In this guidance document, forecasts of sea level rise along the California coast range from 5 to 8 inches by year 2030 to 10 to 17 inches by 2050. For the present evaluation, it was assumed that sea levels could rise as much as 1 ft, which is approximately the midpoint between the highest projections for sea-level rise for 2030 and 2050 tabulated in the guidance document. Under such conditions, mean sea level would be 1 ft greater than the current level, which would require a negligible increase (0.025 ft, or 0.3 inches) in freshwater-equivalent groundwater elevation above mean sea level to achieve hydrostatic balance between fresh water in the aquifer and seawater in the Pacific Ocean. However, assuming that mean sea level at the end of the planning horizon could be 1 ft higher than the 2016 mean sea level, which is approximately equal to the vertical datum used throughout this report and in United's database of groundwater elevations and reference points (NGVD29), groundwater elevations would have to be an additional 1 ft higher by that time to maintain parity with sea level rise and achieve hydrostatic balance with seawater. Adjusted freshwater elevations required to achieve hydrostatic balance, accounting for sea-level rise, are included in Table 4.3-1. The estimates of groundwater elevation required to achieve hydrostatic balance with seawater, assuming 1 ft of sea-level rise, as presented in the far-right column of Table 4.3-1, are used to develop the assumed minimum thresholds discussed in Section 4.3.4 of this report.

Table 4.3-1. Aquifer-Specific Freshwater Elevations Required to Achieve Hydrostatic Balance with Seawater

Aquifer System	Aquifer	Approximate Average Depth to Base of Submarine Outcrop (feet above NGVD29)	Groundwater Elevation Required to Achieve Hydrostatic Balance—Without Sea-Level Rise (feet above NGVD29)	Groundwater Elevation Required to Achieve Hydrostatic Balance—Assuming 1 Foot of Sea-Level Rise (feet above NGVD29)
UAS	Oxnard	-200	+5	+6
	Mugu	-300	+7.5	+8.5
LAS	Hueneme	-400	+10	+11
	Fox Canyon (main)	-700	+17.5	+18.5
	Fox Canyon (basal)	-900	+22.5	+23.5
	Grimes Canyon	-1,100	+27.5	+28.5

Note: The term "feet above NGVD29" is used in this table to clarify that the referenced elevations are based on the vertical datum typically used by United, which is approximately equivalent to present-day mean sea level. Because mean sea level may change between now and the end of the planning period, reference to elevations in terms of "ft msl" is not sufficiently precise for the purpose of this table.

4.3.3 Data Sources

The source of groundwater elevation data discussed and presented in this section is United's groundwater level database, which is populated with data collected primarily by United staff throughout United's 90-year history, and by other agencies and individuals. Information regarding past saline intrusion beneath the Oxnard Plain comes primarily from United's (2016) Saline Intrusion Update report, which relies largely on groundwater quality data for samples obtained by United and other agencies.

4.3.4 Minimum Threshold

To achieve the management objective for seawater intrusion in the Oxnard Plain and Pleasant Valley basins (i.e., prevent further inland migration of seawater-impacted groundwater in each of the six aquifers comprising the UAS and LAS), it is assumed that average groundwater elevations at the inland (northern) boundary of the seawater-intrusion management area would be maintained at or above the values provided in Table 4.3-1, assuming 1 ft of sea level rise by 2040. Groundwater elevations in the aquifers of the Oxnard Plain and Pleasant Valley basins vary by several feet to tens of feet on seasonal, annual, and multi-year cycles as a result of factors such as monthly variations in groundwater pumping needed to meet crop demands, seasonal rainfall patterns, and multi-year shifts in global climate patterns (e.g., the El Nino-Southern Oscillation) that affect rainfall and recharge amounts occurring in the basin. Groundwater elevations could be allowed to decline below the values in Table 4.3-1 seasonally, annually, or longer, so long as these declines are balanced by deviations above these levels of equivalent or greater magnitude and duration. Therefore, the minimum threshold for seawater intrusion in this evaluation is assumed to be 10-year running average (measured or simulated at regular intervals [e.g., quarterly or monthly]) groundwater elevations along the inland boundary of the seawater management area equal to or greater than the values given in the far right column of Table 4.3-1 (i.e., adjusted for sea level rise).

4.3.5 Discussion

It is possible that during an extended drought, minimum thresholds would not be achievable even after the GSP is implemented (e.g., 10-year average groundwater elevations could decline below the values in the far-right column of Table 4.3-1). Relatively short-term (monthly to annual) declines in groundwater elevation below the values shown in Table 4.3-1 would cause a minimal to zero net inland migration of seawater-impacted groundwater, as long as the duration and magnitudes of such downward fluctuations were equaled or exceeded in duration and magnitude by fluctuations above those values during the rainy season or particularly “wet” years. However, long-term groundwater declines below sea level (e.g., those occurring during the droughts in the late 1980s and mid-2010s, lasting 5 to 10 years) could potentially allow inland migration of seawater-impacted groundwater to an extent that might take years to reverse. Such long-term declines may require additional local or regional mitigation efforts that could be outlined in a GSP for the Oxnard Plain and Pleasant Valley basins, but are beyond the scope of this evaluation.

4.3.6 Conclusions and Recommendations

Basing assumed minimum thresholds for the seawater intrusion sustainability criterion on density-adjusted hydraulic heads is a simple quantitative approach to establishing the groundwater elevations that would prevent further landward migration of saline groundwater. This was the approach used by the FCGMA to select BMOs for seawater intrusion in their 2007 GMP update (FCGMA and others, 2007). Using the Oxnard aquifer to represent the UAS and the Fox Canyon aquifer to represent the LAS results in minimum threshold values of +5 ft NGVD29 and +17.5 ft NGVD29, respectively, ignoring the potential for future sea-level rise related to climate change. This evaluation further assumes sea-level rise of 1 ft by 2040, requiring upward adjustment of the assumed minimum thresholds to +6 ft NGVD29 and +18.5 ft NGVD29 for the Oxnard and Fox Canyon aquifers, respectively.

This approach to developing assumed minimum thresholds for seawater intrusion does not directly incorporate the rate of landward migration of chloride isoconcentration contours. It is possible that the rate of landward migration of chloride under present conditions could be slow enough to be considered not to cause undesirable results during the forecasting period required under SGMA. However, at this point in model development and testing, United is not prepared to use the model to simulate transport velocities of saline groundwater. Therefore, such an approach was not considered for this evaluation. If such an approach were to be considered, United's 2016 saline intrusion update concluded that "It would be desirable to have additional wells to better define the occurrence and movement of saline water within the various aquifers of the Oxnard Plain" (United, 2016). Construction of additional depth-specific monitoring wells at new locations within the seawater intrusion management area could be considered during GSP development, for the purposes of:

- further delineation of seawater-impacted groundwater,
- verification of transport-related modeling parameters,
- design of water-supply infrastructure (e.g., pipelines and replacement wells) required for mitigation of seawater intrusion, and
- long-term monitoring of groundwater levels and chloride concentrations to confirm whether the measurable objectives and minimum thresholds are met during GSP implementation.

4.4 DEGRADED WATER QUALITY

Degraded water quality can limit the beneficial use of groundwater produced from a basin. Potable drinking water systems are regulated so that delivered water is safe to drink. Southern Ventura County has relatively few large groundwater contamination sites (metals, organic compounds, radionuclides, etc.) that pose significant risk to public supply wells. Nitrate is the primary health standard most likely to be a problem in wells, particularly in shallow wells more vulnerable to water quality impacts from nearby land uses. Wells on the Oxnard coastal plain commonly produce groundwater that does not meet secondary (taste, odor, aesthetic) standards for certain naturally-occurring inorganic constituents such as TDS, sulfate, iron and manganese. Growers also prefer low TDS in water used for crop irrigation. Irrigation water demands are typically greater when water quality is poor, as additional soil leaching is required to maintain plant health. In addition, elevated concentrations of certain natural elements such as sodium can require the use of soil amendments to maintain desirable soil properties.

Water quality is somewhat variable among wells screened in mapped aquifer units on the Oxnard coastal plain. Monitoring wells exist in some locations, and are commonly constructed so that a water quality sample can be collected from a fairly constrained depth zone within a specific aquifer. Short-screen monitoring wells are poorly distributed on the Oxnard coastal plain. Many of the existing monitoring wells are located either in the Forebay or in the southern Oxnard Plain basin south of Hueneme Road.

In contrast to monitoring wells that commonly have a short screened interval, production wells are designed and constructed to maximize well yield. Well screens may span hundreds of feet, allowing groundwater to be produced from multiple aquifers. Water quality samples collected from these wells represent a blend of groundwater produced from the various productive aquifer zones screened by the well. It is possible to determine the amount of groundwater produced from each aquifer zone, and the water quality in each aquifer zone, by employing advanced well sampling techniques. These sampling techniques are relatively expensive and rarely used in the study area. If high concentrations of a certain analyte such as nitrate or chloride are measured in the bulk discharge of a well, rarely is it known from which aquifer zone the highest concentrations originate.

In 2007 the U.S. Geological Survey (USGS), in partnership with California's State Water Resources Control Board (SWRCB), sampled 53 wells in the basins of the Santa Clara River, Calleguas Creek and Ventura River watersheds. The selection of area wells for sampling was designed to provide an unbiased assessment of water quality representative of the primary production aquifers used for drinking water supply (Burton and others, 2011). More than half of the wells sampled were public water supply wells. Water quality analyses included an expansive suite of inorganic and organic analytes, many of which have established health standards or health advisory levels. A broad suite of compounds was measured to very low concentrations in order to document both the character of natural waters and the nature of anthropogenic contamination where it exists. While the identities of the wells sampled in the study remain confidential, results from this sampling effort allowed characterization of groundwater quality in the study area. Contamination related to human activities was found to be relatively uncommon, and associated with shallow wells screens and younger waters when present. Older and deeper groundwater in some areas has somewhat elevated mineral content, and elevated iron and manganese concentrations related to reducing groundwater conditions is not uncommon. The geologic setting and nature of the area's aquifers are largely responsible for the high mineral content in the groundwater, resulting in some aesthetic issues but not health concerns.

Well operators and water users would prefer that groundwater pumped from all aquifers of the Oxnard coastal plain meets all regulatory health standards. A number of existing wells produce groundwater that do not meet certain health standards, but with the exception of nitrate, these exceedances generally have not been demonstrated to be associated with either groundwater overdraft or anthropogenic contamination. However, a number of United's production wells at the El Rio Recharge Facility, shown in Figure 4.4-1, experience elevated nitrate concentrations when groundwater elevations in the basin decline. These wells supply the Oxnard-Hueneme (O-H) municipal-supply delivery system, and blending is commonly used to maintain nitrate concentrations below the state and federal maximum contaminant level (MCL), which is 45 milligrams per liter (mg/L) as nitrate. High nitrate concentrations are rarely a problem when surface water from the Santa Clara River is available and water is being distributed to recharge ponds near the active O-H wells. Under these conditions, recently-recharged surface water (with low nitrate concentration) provides some portion of the groundwater produced by the wells. When little or no surface water is available for recharge at the facility, the wells draw only groundwater from the regional flow system of the basin into their screens. Nitrate from land uses in the Forebay can be present in groundwater arriving at the wells. It is difficult to estimate where near-surface nitrate-rich water entered the groundwater flow system, and what complex and possibly lengthy groundwater flow path nitrate may have taken before being drawn into long-screen production wells.

The wells on the upgradient (northeast) margin of the O-H well field typically have the highest nitrate concentrations. Time-series graphs of recorded nitrate concentration and groundwater elevations for selected El Rio wells are shown in Figures 4.4-2 through 4.4-7. The graphs show a number of occasions where rising nitrate concentrations correspond with falling groundwater elevations. A representation of monthly groundwater recharge totals in the basins near the wells, and the periods when wells were active (as opposed to being activated just to obtain a sample), would provide a more complete representation of operational conditions for each well. While these variables may help explain the nitrate variability recorded in individual wells, they are not included as groundwater elevation was selected as the metric to represent water quality in the Forebay.

El Rio well #4, located near the southern end of the northeastern margin of the El Rio Recharge Facility, records nitrate concentrations above the MCL more frequently than the other O-H production wells. Figure 4.4-2 shows that many of the higher nitrate concentrations in Well #4 are associated with periods of declining groundwater levels. Over the past 20 years nitrate in this well has commonly exceeded the MCL even when groundwater levels were greater than +20 ft msl. This well was constructed in 1955 and is screened from 100 to 277 ft below land surface. A replacement for well #4 was drilled in fall 2016 and the older well is slated for destruction.

Nitrate concentrations in El Rio well #5 rarely exceeded 45 mg/l prior to 1991, as shown on Figure 4.4-3. In the following decade high nitrate was recorded during periods of falling groundwater levels, even though groundwater levels remained more than +40 ft msl. In 2013 groundwater levels in this well fell below +20 ft msl, and since that time nitrate concentrations greater than 60 mg/l have commonly been recorded. The screened interval in this well begins at 135 ft below land surface.

Nitrate trends in El Rio well #6 are similar to those in the adjacent well #5, with no nitrate problems prior to 1991, but with periods of elevated nitrate in the 1990s (Figure 4.4-4). This well has recorded relatively few samples exceeding the MCL in the recent drought years. This well is screened from 149 to 277 ft below land surface.

Well #11, located at the far southern extent of the El Rio facility, experienced high nitrate concentrations between 1989 and 1991, then produced groundwater below the MCL for nitrate until 2009 (Figure 4.4-5). In late 2013 nitrate concentrations rose above the MCL again, and have increased since then to a recent high of 147 mg/l. Groundwater level measurements are rare since 2002 because of problems with the sounder access tube, but groundwater levels were likely around sea level in December 2013 when nitrate was recorded above the MCL. El Rio well #2A, the only other active UAS well in the southern portion of the facility, records a similar increase in nitrate concentration in recent years (Figure 4.4-6). The MCL was exceeded in January 2015 when groundwater levels were about -15 ft msl.

Shorter record sets exist for the three newer wells at El Rio, all of which were constructed in 2001 or later. Well #15 is located near the northwestern edge of the facility, is screened from 140 to 310 ft below land surface, and never recorded nitrate concentrations greater than 35 mg/l. Well #16 is located along the eastern margin and screened from 115 to 340 ft below land surface. This well tends to record high nitrate when groundwater levels fall below +20 ft msl, and recently recorded nitrate greater than 160 mg/l when groundwater levels were lower than +30 ft msl, as shown on Figure 4.4-7. Well #17 has only been active since 2014 but has not recorded nitrate concentrations above the MCL. This well is screened from 150 to 290 ft below land surface.

Nitrate loading to the Forebay has decreased over the past decade with the construction of a large sanitary sewer collection system that eliminated most septic systems from the neighborhoods surrounding the El Rio facility. Ventura County managed this successful project, where more than 1,400 properties were connected to sewer from 2005 to 2011. Ongoing programs also exist to promote efficient irrigation and fertilizer practices among area growers. These educational programs are conducted regularly by the University of California Cooperative Extension, the Ventura County Farm Bureau and various agricultural product suppliers or manufacturers. On such active program is the Ventura County Agricultural Irrigated Lands Group (VCAILG), an effort coordinated by the Farm Bureau in response to monitoring requirements administered by the Los Angeles Regional Water Quality Control Board. VCAILG is working to identify areas of degraded water quality in shallow aquifers and modify agricultural practices to prevent further degradation, to the extent they are related to agriculture.

4.4.1 Management Objective

SGMA specifically references the containment of contaminant plumes as a primary consideration for water quality impacts associated with groundwater overdraft. Contaminant plumes have generally not been identified on the Oxnard coastal plain. Areas prone to contamination by specific compounds, such as nitrate, however, have been recognized. The Forebay is one such area that periodically contains elevated nitrate concentrations in shallow groundwater. Nitrate contamination in UAS wells in and surrounding the Forebay has forced some well owners to blend water with other sources (such as groundwater from deeper aquifers). Other wells belonging to mutual water companies have been shut down and customers now rely on United's O-H system or the City of Oxnard for their potable water supply. Increased reliance on LAS wells is not a favored alternative on the Oxnard coastal plain, as overdraft conditions are generally more pervasive in the aquifers of the LAS than in the UAS.

The well field for United's O-H water system is located in the Forebay, as are a number of UAS wells operated by several mutual water companies that supply drinking water to the residents of the El Rio community. Extensive records of both water quality and groundwater levels exist for a number of production wells in the southern Forebay. Nitrate concentrations in some wells tend to increase when groundwater levels fall below certain elevations, allowing groundwater elevation to be used as a proxy metric for nitrate (water quality). Therefore, the management objective for "degraded water quality" is assumed, for this evaluation, to be maintaining groundwater elevations sufficiently high in the

Forebay to prevent future increases in nitrate concentrations above the MCL (45 mg/L as nitrate) in El Rio-area supply wells screened in the UAS.

4.4.2 Metrics

The assumed primary metric for determination of whether minimum thresholds are being achieved for degraded water quality are groundwater levels measured in the UAS of the Forebay. As discussed above, maintaining groundwater levels within the UAS of the Forebay above a threshold level should prevent nitrate concentrations from increasing above the MCL.

4.4.3 Data Sources

When water is delivered to the public, the SWRCB-Division of Drinking Water (DDW) enforces minimum monitoring requirements to assure that delivered water is free of chemical and biological contaminants. Testing requirements vary depending on the number of people served by the system and a system's vulnerability to contamination, as determined by the DDW. United regularly collects samples from the wells supplying the O-H potable water system, with sampling frequency exceeding the minimum DDW requirements. Nitrate is sampled weekly when wells record nitrate concentrations approaching the MCL. Water purveyors throughout California are required to report results of all water analyses to the DDW, and United regularly obtains water quality records for Ventura County wells from the DDW for integration into United's water quality database.

United routinely samples additional production wells and dedicated monitoring wells in the Forebay. Other wells are sampled annually by staff from the Groundwater Resources Section of the Water Resources Division of the Ventura County Watershed Protection District (VCWPD). Some other well owners occasionally share sample results directly with United. All available water quality records are archived by United.

Groundwater elevations are also routinely measured in area wells. Both United and the Groundwater Resources Section of the VCWPD maintain active monitoring programs. Cities and the larger mutual water companies also commonly measure their wells, either by hand or with pressure transducers suspended in the wells. These groundwater level records are commonly shared among agencies, and VCWPD staff uploads records to CA DWR as part of the California Statewide Groundwater Elevation Monitoring (CASGEM) program. Most of the groundwater levels measured and recorded are static levels, but pressure transducers allow documentation of groundwater levels in a well under both static and pumping conditions.

Water quality monitoring serves to document both typical conditions and the variability of groundwater quality in areas of groundwater recharge and areas of groundwater production near specific land uses. Groundwater level monitoring in the Forebay allows the mapping of the table across the basin, allowing visual representation of groundwater flow directions and gradients.

4.4.4 Minimum Threshold

Nitrate concentrations and their correlation with groundwater levels are variable among the El Rio production wells, with the up-gradient and shallower wells being more likely to record high nitrate concentrations. El Rio wells #5 and #16 commonly produce groundwater exceeding the MCL for nitrate when groundwater levels decline to +20 ft msl. Therefore, an elevation of +20 ft msl in the UAS in the Forebay is selected as the minimum threshold for water quality for this evaluation. Minimum thresholds were not developed in this evaluation for degraded water quality in the LAS in the Forebay, or in either aquifer system (UAS or LAS) in the remainder of the Oxnard Plain or Pleasant Valley basins, because a linkage between groundwater use (or elevation) and degradation of water quality has not been established in these areas to date.

4.4.5 Discussion

Saline intrusion has long been recognized as the primary water quality threat in the Oxnard Plain basin, and the severity of that threat is directly related to overdraft conditions within the basin. Other widespread and pervasive water quality problems have not been directly associated with groundwater overdraft. Elevated nitrate concentrations in public supply wells in the Forebay is, however, recognized as a recurring problem, most notably in time of drought.

Despite programs to reduce nitrate loading to groundwater, a number of wells in the Forebay continue to record nitrate concentrations above the MCL. The nitrate loading is believed to be associated with land use practices, and wells with screens near the water table tend to record the highest nitrate concentrations (United, 2008). While nitrate impacts to area wells are variable and may worsen during periods of depressed groundwater levels associated with overdraft and drought, these impacts are more closely associated with land use practices than groundwater overdraft.

4.4.6 Conclusions and Recommendations

Various water quality problems associated with groundwater overdraft have been identified in production wells across the Oxnard coastal plain, but a number of these problems are limited to specific wells or specific aquifers. Elevated concentrations of TDS, sulfate, chloride, iron or manganese are not uncommon among wells in southern Ventura County, and water quality in some wells tends to deteriorate with falling groundwater levels. In many cases use of the well continues as water quality remains acceptable for the intended use. Secondary health standards for potable water are in place for a number of salts, but a primary health standard exists for nitrate. In the Forebay it is not uncommon for UAS wells to exceed this health standard during times of drought, with the highest nitrate concentrations commonly observed in the shallowest wells. United's UAS production wells that supply groundwater for delivery to the southern Oxnard Plain where saline intrusion continues to be a problem are affected by high nitrate. Elevated nitrate concentrations commonly persist during times of drought, and also may exist seasonally when groundwater extraction exceeds groundwater recharge at the El Rio Recharge Facility.

Elevated nitrate concentrations in UAS wells of the southern Forebay are associated with declining groundwater elevations more strongly than other water quality issues on the Oxnard coastal plain, with the exception of seawater intrusion, which is a separate sustainability indicator identified by CA DWR. Other water quality issues might be identified as reasonable sustainability indicators for groundwater quality, but groundwater levels in United's O-H wells are the El Rio Recharge Facility serve as a reasonable metric for sustainability for the purposes of this analysis.

4.5 LAND SUBSIDENCE

The potential relationship between subsurface fluid extractions (e.g., groundwater and hydrocarbons) and inelastic land subsidence (subsidence) has been known for several decades. A detailed discussion of the geomechanics associated with subsidence are beyond the scope of this document; however, other publications describe the geomechanics associated with subsidence (e.g., Poland and others, 1984; Poland and Davis, 1969) and its effects (e.g., USGS, 1999, 2016). Subsidence associated with fluid withdrawals includes the permanent compaction of fine-grained sediments due to the increase in the effective stress caused by the fluid removal.

The specific causes of subsidence in the Oxnard Plain and Pleasant Valley basins are believed to include groundwater extraction, hydrocarbon extractions (i.e., petroleum and natural gas), and tectonic movement (Borcher and others, 2014). Borcher and others (2014, p. 67-69) relied heavily on information contained in a USGS report (Hanson and others, 2003) in their summary of land subsidence processes and amounts in the Oxnard Plain.

CA DWR (2014) prepared a summary document dealing with recent, historical, and future subsidence potential for groundwater basins included in CA DWR Bulletin 118. The stated intent of the document was to provide screening-level information with respect to subsidence. The Oxnard Plain basin is listed with a medium-high potential for future subsidence with neighboring Pleasant Valley basin assigned a low potential despite the evidence of subsidence reported by previous researchers and data included in the CA DWR's own report (2014).

Hanson and others (2003) contained geodetic information on subsidence in the Oxnard Plain and Pleasant Valley basins—shown on Figure 4.5-1—that was previously published in Hanson (1994) and is summarized in Table 4.5-1. Tectonic uplift in the bedrock areas north and east of the Oxnard Plain and subsidence in the alluvial deposits underlying the Oxnard Plain account for benchmark differentials.

Table 4.5-1. Reported Magnitudes and Rates of Subsidence at Selected Benchmarks in the Oxnard Plain and Pleasant Valley Basins

Time Period	Benchmark E584	Benchmark Tidal 3	Benchmark Z583 (tectonic activity)	Benchmark Z901	Numerical flow modeling (Hanson, 2003)
1939-1978	2.6 ft	0.5 ft	0.17 ft 0.004 ft/yr		
1939-1960	1.6 ft 0.07 ft/yr	0.25 ft			
1960-1992					
1960-1978	1 ft 0.06 ft/yr			0.5 ft 0.02 ft/yr	
1891-1993					3 ft in Southern Oxnard Plain
1891-1993					5 ft in Las Posas basin

Notes: Benchmark data from Hanson, 1994.

ft = feet
ft/yr = feet per year

Hanson and others (2003) also used a USGS regional groundwater flow model as a tool to simulate subsidence due to groundwater withdrawal within the model domain, shown on Figure 4.5-2. The Pleasant Valley basin and a portion of the Oxnard Plain basin that have historically experienced the greatest amount of groundwater extraction, not surprisingly, gave the greatest simulated subsidence values that were generally in the range of 2 to 5 ft over the 1891-1993 time period (Table 4.5-1).

The Ventura County General Plan (2013) contains a section on subsidence within the hazards analysis discussion. The plan acknowledges that:

"The U.S. Coast and Geodetic Survey have monitored this situation since the 1930's. Up to 1965, one large area was subject to subsidence of between 0.04 and 0.05 feet per year. A single point located at Hueneme Road and Highway 1 has dropped 1 1/2 feet in just 21 years. Records to 1968 show a dozen benchmarks that indicate that the ground may have settled a foot in a fifteen to twenty-year period."

Unfortunately the appendix does not itemize which benchmarks were being referenced nor does it provide information for the post 1968-present time period. A map of subsidence zones in the 2013

General Plan—shown on Figure 4.5-3—is based on "…figures from the 1973 Hazards appendix and were not updated due to a lack of geodetic survey data in the locations of potential subsidence."

While not directly applicable to the Oxnard Plain and Pleasant Valley basins, Sylvester (1997) reports on tectonic activity (aseismic growth) associated with the nearby Ventura Avenue Anticline. Between 1978 and 1997, the crest of this geological structure rose 40 mm (0.131 ft, ~0.007 ft/yr) relative to its flanks. This rise exemplifies the potential magnitude of tectonic-caused changes in land surface elevation in the study area.

Hanson (1994) describes the likelihood of three potential causal factors for subsidence on the Oxnard Plain: groundwater extraction, oil and gas production, and tectonic activity. Groundwater declines of 50 to 100 ft over the past 90 to 100 years are cited as indirect evidence of the potential for groundwater-extraction induced subsidence. Oil and gas field operations including the extraction of brines, oil, and natural gas are summarized to be sufficient to account for 1.5-2.0 ft of subsidence. As a complicating factor, the geologic environment is also tectonically active and the author opines that a benchmark on the southern edge of the Oxnard Plain (Z 583) suggests 0.17 ft of tectonic-caused subsidence from 1939 to 1978 (Hanson, 1994).

4.5.1 Management Objective

The Oxnard Plain and Pleasant Valley basins lack a network of extensiometers or a geodetic monitoring network adequate to assess subsidence rates across the basins. Groundwater elevation is proposed as a proxy metric for rate of subsidence for this sustainability indicator. It is recognized that the hydrologic record for the Oxnard Plain area has been punctuated by exceptional drought periods, sometimes lasting 2 to 5 years or longer, that are indicated in the hydrologic record by extreme low groundwater elevations. It is well known that low groundwater levels can be the causal force that initiates the compaction of fine-grained deposits. The propagation of compaction to, or near, the land surface can result in subsidence. However, once the fine-grained sediments have been compacted, there is a very low probability for additional subsidence unless the groundwater elevations decline below the historical lows. Therefore, the management objective for land subsidence in this evaluation is assumed to be the prevention of groundwater levels falling below historic lows for a period of time sufficient to allow further permanent compaction of fine-grained sediments.

4.5.2 Metrics

In the absence of a routinely monitored network or geodetic stations or extensiometers, groundwater elevation has been selected as the proxy metric to be used for land subsidence. It is not currently possible to differentiate between subsidence in the Oxnard Plain and Pleasant Valley basins resulting from groundwater extractions, oil and gas removal, or tectonic activity.

4.5.3 Data Sources

Data sources for historical land subsidence consist of the reports referenced throughout this section, and groundwater level measurements contained in United's groundwater elevation database.

4.5.4 Minimum Threshold

Figures 4.2-1 and 4.2-2 show historic-low groundwater levels measured in the UAS and LAS for all of the PLSS sections in the study area. Accordingly, the assumed minimum thresholds for the reduction of groundwater storage sustainability indicator are assumed for this evaluation to be historic low groundwater elevations commonly observed during past drought periods:

- -100 ft msl in the UAS in both the Oxnard Plain (including Forebay) and Pleasant Valley basins;
- -150 ft msl in the LAS in the Oxnard Plain (including Forebay) basin;
- -200 ft msl in the LAS in Pleasant Valley basin.
- Historic lows in a few PLSS sections have occasionally been slightly lower than these assumed minimum thresholds; however, such data outliers were not incorporated into development of the assumed assumed minimum thresholds.

4.5.5 Discussion

The assumed minimum thresholds associated with each BMO can be categorized into UAS and LAS groups. The UAS minimum thresholds are associated with higher groundwater elevations than the LAS minimum thresholds. This difference is a direct by-product of the much lower groundwater elevations historically associated with the LAS.

4.5.6 Conclusions and Recommendations

The use of the assumed minimum thresholds defined for this indicator are thought to adequately protect the land use on overlying parcels within the Oxnard Plain and Pleasant Valley groundwater basins from excessive rates of land subsidence. However, it is recognized that the use of groundwater elevation as a proxy for land subsidence potential does not address subsidence that may be associated with the other casual factors (i.e., oil and gas extraction and tectonic activity). If additional refinement of the subsidence causal factors are deemed to be necessary, then other, more sophisticated monitoring programs (e.g., extensiometers, interferometric synthetic aperture radar [InSAR], light detection and ranging [LIDAR] analyses, or expanded geodetic measurements) would be required.

4.6 SURFACE WATER DEPLETION

The GSP regulations identify surface water depletion as a sustainability indicator in recognition that surface water and groundwater exchanges occur in many groundwater basins. The language in §354.28.(c)(6) of the rule states that the minimum threshold for this indicator should be defined by the magnitude of surface water depletion that is induced by groundwater pumping, but only to the extent that pumping causes adverse impacts on beneficial uses of surface water. In general, adverse impacts potentially can occur where there is hydraulic coupling (i.e., no unsaturated zone exists) between a surface water body and the water table. Accordingly, such a condition usually occurs in surface water bodies that are predominantly perennial in nature, whereas ephemeral streams are characterized by predominantly decoupled conditions because these streams flow only in response to stormflows and/or artificial inflows from sources such as drainage systems and wastewater discharges. The occurrence of coupled versus decoupled stream/aquifer systems fundamentally defines where the potential for adverse impacts can arise from pumping; perennial reaches are the only stream reaches that receive sustained groundwater discharge over long time periods. Furthermore, if the water body is separated from the pumped aquifer(s) by one or more confining units, then groundwater pumping effects on the water body will be reduced, if they occur at all.

In the Oxnard Plain basin, the primary surface water bodies are the Santa Clara River, Revolon Slough, McGrath Lake (near the mouth of the Santa Clara River), Ormond Beach wetlands, and Mugu Lagoon wetlands (Calleguas Creek partly overlies the Oxnard Plain and Pleasant Valley basins, and is discussed further below).

- **The Santa Clara River** bounds the northern side of the Oxnard Plain basin and the Forebay. Within the study area, it is perennial only in the reach extending downstream of the Forebay, from approximately U.S. Highway 101 to the mouth of the river (Figure 2.1-1). Historical observations from the 1800s indicate that the reach lying along the north side of the Forebay (extending upstream of U.S. Highway 101 to the Santa Paula basin) has always been ephemeral (Beller and others, 2011), except for flowing conditions during portions of extremely high rainfall years. The locations of the typically perennial and ephemeral reaches correspond to the presence and absence, respectively, of the Semi-perched aquifer and the underlying confining unit that separates this aquifer from the UAS.
- **Revolon Slough** carries water discharged from tile drains beneath agricultural fields, and the slough may, in places, receive a small influx of groundwater from the Semi-perched aquifer, which is not pumped for groundwater use. Insufficient information is available to identify the nature or magnitudes of any such groundwater baseflow from the Semi-perched aquifer into the slough.
- **McGrath Lake, Ormond Beach wetlands, and Mugu Lagoon wetlands** consist of fresh- to brackish-water that is hydraulically connected to, and largely fed by, the regional Semi-perched aquifer, similar to the Santa Clara River. These water bodies are located just inland from coastal dunes; McGrath Lake is approximately 1 mile south from the mouth of

the Santa Clara River, the Ormond Beach wetlands lie between Mugu Lagoon and Port Hueneme, and the Mugu Lagoon wetlands surround the tidally influenced Mugu Lagoon.

In the Pleasant Valley basin, the primary surface water bodies are Arroyo Las Posas and Conejo Creek, which converge and become Calleguas Creek.

- **Arroyo Las Posas** enters the Pleasant Valley basin from the adjoining East Las Posas basin. This stream is usually perennial in its most downstream reach within the East Las Posas basin, then fully infiltrates its baseflow shortly after entering the Pleasant Valley basin. As described by Bachman (2016), baseflow in Arroyo Las Posas is a mixture of natural dry-weather flows, discharges from wastewater treatment plants, discharge from dewatering wells in Simi Valley, and agricultural tail waters. The terminus of the baseflow originally occurred in the East Las Posas basin, but in the early 1990s began to move downstream as the East Las Posas groundwater basin began to fill with water as a result of higher baseflow contributions from Simi Valley. Bachman (2016) reports that the Arroyo Las Posas baseflow entering the Pleasant Valley basin has infiltrated along a 1,400-foot long reach of the creek at the northern margin of the Pleasant Valley basin. Bachman (2016) also estimated that the next 5,500 ft of stream channel can infiltrate some or all of the storm flow that crosses into the Pleasant Valley basin during an individual storm event. In this area, the Semi-perched aquifer is absent and surface water in Arroyo Las Posas readily percolates into the underlying regional aquifer system (Hopkins, 2008). In summary, this creek's hydrologic role in the basin is as a source of recharge to the underlying regional aquifer system.
- **Conejo Creek** is perennial in the adjoining upstream Santa Rosa basin, and remains perennial over its entire reach within the Pleasant Valley basin. A major source of water to Conejo Creek is wastewater discharge from the City of Thousand Oaks Hill Canyon Wastewater Treatment Plant located just upstream of the Santa Rosa basin. The Camrosa Water District operates a diversion structure near Highway 101, but maintains a minimum of 6 cfs of flow in the creek below its diversion structure for habitat maintenance purposes. Visual inspections (using Google Earth) indicate that at least a portion of this 6 cfs dry-weather flow reaches the mouth of Conejo Creek (where it joins Arroyo Las Posas to form Calleguas Creek). The Semi-perched aquifer and its underlying confining unit are thought to be present beneath Conejo Creek, given that this creek remains perennial (unlike the nearby Arroyo Las Posas, whose wastewater-discharge sourced flows entering the basin fully infiltrate to groundwater because of the absence of the Semi-perched aquifer and underlying confining units). Shallow groundwater is thought to be a minor source, if at all, of the perennial flow in Conejo Creek, and the creek is separated from the pumped aquifers of the UAS and LAS by the likely presence of the Semi-perched aquifer and underlying Semi-perched aquitard.
- **Calleguas Creek** extends from the confluence of Arroyo Las Posas and Conejo Creek downstream to the Pacific Ocean at the Mugu Lagoon. Visual inspections (using Google Earth) suggest that Calleguas Creek is perennial in this reach, with potentially increasing

flows in the downstream direction. The sources of water to Calleguas Creek are a minimum flow of 6 cfs by Camrosa below its diversion structure on Conejo Creek; discharges from a wastewater treatment plant operated by the Camarillo Sanitary District next to Conejo Creek; and inflows from agricultural field tile drains and from the Revolon Slough, which enters Calleguas Creek just downstream of the boundary between the Pleasant Valley and Oxnard Plain basins. The Semi-perched aquifer is present throughout this area, but insufficient information is available to identify whether (and how much) shallow groundwater discharge from the Semi-perched aquifer might also be providing a portion of the perennial flow in Calleguas Creek. Shallow groundwater is thought to be a minor source, if at all, of the perennial flow in the creek, and the creek is separated from the pumped aquifers of the UAS and LAS by the presence of the Semi-perched aquifer.

4.6.1 Management Objective

Management objectives are not assumed in this evaluation for these water bodies because of the physical relationships between their perennial reaches, the Semi-perched aquifer, and the deeper aquifers (UAS and LAS) that are the source of groundwater supplies for the region. Specific details for each water body are as follows:

- **Santa Clara River.** The location of the perennial reach (from approximately U.S. Highway 101 downstream to the river's mouth) coincides with the location of the "clay cap" that separates the Semi-perched aquifer from the underlying UAS across in much of the Oxnard Plain basin. The river reach extending along the Forebay (immediately upstream of U.S. Highway 101) is ephemeral and coincides with the area where the clay cap and Semi-perched aquifer are absent. Based on the available historical accounts of river flow conditions and the geologically-controlled physical relationships that dictate where the river is perennial versus ephemeral, neither the UAS nor the LAS is hydraulically connected to the river's perennial reach in the Oxnard Plain. Accordingly, measurable surface water depletion is not expected to occur in the perennial reach of the Santa Clara River (downstream from U.S. Highway 101) as a result of groundwater pumping from the UAS or LAS.
- **Revolon Slough.** The primary source of water in Revolon Slough is understood to be discharge from tile drains beneath agricultural fields. Revolon Slough is not in direct hydraulic communication with the UAS or the LAS. Therefore, surface water depletion is not expected to occur in the slough as a result of groundwater extraction from the UAS or LAS.
- **McGrath Lake, Ormond Beach wetlands, and Mugu Lagoon wetlands.** These water bodies occur where the Semi-perched aquifer is present. They are not hydraulically connected to either the UAS or the LAS. Accordingly, measurable surface water depletion is not expected to occur in these water bodies as a result of groundwater pumping from the UAS or LAS.

- **Arroyo Las Posas.** This creek's baseflow and a portion of its storm flow infiltrate to the deeper underlying water table in the Pleasant Valley basin. The Semi-perched aquifer and underlying aquitard are absent beneath this creek. Because Arroyo Las Posas is not perennial in the Pleasant Valley basin and lies above (is not hydraulically connected to) the water table, measurable surface water depletion is not expected to occur as a result of the groundwater pumping that occurs from the UAS and LAS.
- **Conejo Creek and Calleguas Creek.** Both of these creeks lie in portions of the Pleasant Valley basin where the Semi-perched aquifer likely is present. Additionally, most wells in the Pleasant Valley basin are completed in the LAS; the small number of UAS wells in the basin are perforated in basal units of the UAS that are predominantly comprised of fine-grained sediments. Accordingly, because Conejo Creek and Calleguas Creek are not hydraulically connected directly to the pumped aquifers in the Pleasant Valley basin, measurable surface water depletion is not expected to occur in either creek as a result of groundwater extraction from the UAS or LAS.

4.6.2 Metrics

Management objectives and minimum thresholds for the Surface Water Depletion sustainability indicator are not being established because each local stream is not hydraulically connected directly to the pumped aquifers (the UAS and LAS) in the Oxnard Plain, Forebay, and Pleasant Valley basins. Accordingly, no metrics are assumed in this evaluation for the Surface Water Depletion sustainability indicator.

4.6.3 Data Sources

The primary sources of information along the Santa Clara River are 1) surface and subsurface geologic mapping of the presence and absence of the Semi-perched aquifer and underlying Semi-perched aquitard (Turner, 1975), and 2) historical references that have been compiled into a detailed descriptive historical summary of the region's development and the characteristics of the river and riverbank by the San Francisco Estuary Institute (SFEI; Beller and others, 2011). The understanding of conditions along Arroyo Las Posas is derived from streamflow data in the East Las Posas basin (Bachman, 2016), surface and subsurface geologic mapping, and groundwater elevation data. For the other local streams (Revolon Slough, Conejo Creek, and Calleguas Creek), little to no quantitative data are available to identify the exact direction and magnitude of any groundwater/surface water discharges that might be occurring.

4.6.4 Minimum Threshold

Management objectives, metrics, and minimum thresholds for the Surface Water Depletion sustainability indicator are not being established because each local stream is not hydraulically connected directly to the pumped aquifers (the UAS and LAS) in the Oxnard Plain, Forebay, and Pleasant Valley basins.

4.6.5 Discussion

A detailed historical report by Beller and others (2011) provides substantial information indicating that the current locations of the perennial and ephemeral reaches of the Santa Clara River have always been present naturally, including at the time the region was first settled. As discussed on page 81 of that report, beginning around the communities of Montalvo and Saticoy, early observers reported the Santa Clara River to be intermittent and often completely dry during the summer. An observer in 1872-73 at Saticoy described the river as running for another half mile and then being dry for the next 7 or 8 miles. At the present-day Highway 101 crossing, an observer in August 1868 described the river as “some water flowing where we crossed it, and quite a large body a few miles above.” Fifteen years later, in June 1883, another observer described a “wide sandy bed where an emaciated stream reposes till revived by winter rains.” Variably flowing conditions were observed at the river’s mouth during the 1800s, with an early October 1855 description of “an insignificant stream with but an inch or so of water in its channel” and “nearly dry during the summer” in September 1857.

The SFEI report (page 81) summarized these and other observations into the following interpretation and general understanding of predevelopment flow conditions from below Santa Paula down to the river’s mouth (Beller and others, 2011):

> While most other historical accounts do describe the presence of some summer water in this reach, almost without exception they also mention the limited amount of water present (as opposed to the Santa Paula reach where the river had abundant summer water). Just above Saticoy, near where Crespi described watering his mounts in the “very shallow” river in 1769, Freeman (1930) remarked that surface water “begins to disappear into the gravels beneath the Oxnard Plain,” and an 1889 depiction of the river late in the dry season in the same area described it “loitering along its sandy bed as if it were loth to reach the sea” (Earnes 1889). Also near Saticoy, General Land Office surveyor Henry Hancock reported in June 1853 a “current near 6 miles per hour and average depth 9 inches,” indicating that by late summer flow would have been extremely shallow or nonexistent. Cooper’s interpretation of the Saticoy-Montalvo area as summer dry is supported by USGS (1903a) historical mapping and Crespi’s earlier observations that “no trees are to be seen nearby” in the area (Crespi and Brown 2001), indicating limited summer water availability.
>
> Below the Montalvo (Highway 101) bridge and closer to the river mouth, early descriptions also indicate that while the river was likely perennial in most years, surface water was not as abundant as in perennial reaches upstream, and flowed shallowly over the Oxnard Plain. Surface water was perennially found where the zone of artesian water intersected the river in this lower reach (Lippincott ca 1930). Johnson (1855a) recorded that in early October, the river was “an insignificant stream, with but an inch or so of water in its channel.” This sentiment was echoed by numerous observers, who described minimal surface flow from

> Saticoy to the ocean: what Seward ([1883]1937) called "an emaciated stream." Davidson (1864) wrote that the river was "nearly dry during the summer, and terminates in lagoons and marshes," while a traveler crossing the river near its mouth (presumably the Montalvo crossing) in late August 1868 wrote that "There was some water flowing where we crossed it, ,and quite a large body a few miles above" (*Daily Alta California* 1868). Bowers (1879, in Benson 1997) called the river a "somewhat rapid stream" near the mouth in late October.

Pages 94 through 100 of the SFEI report discuss that a significant riparian area was historically present along the south side of the river from the Highway 101 crossing to the river's mouth, and also east of Santa Paula. No mention of such a riparian habitat is made between Highway 101 and Santa Paula. Traveling near Saticoy, Crespi observed in 1769 that "Though no trees are to be seen nearby, a great deal of trees was visible afar off where we thought the shore must be close by." Cooper (1887) described a grove in 1872-73 as beginning three to four miles west of Saticoy, either just above or just below the modern-day bridge crossing for Highway 101. Cooper called this riparian habitat the West Grove, as opposed to the East Grove that was located near Santa Paula. The SFEI report (Beller and others, 2011) interprets that this naming affirms the discontinuity of the riparian forest along the river. Just above the Highway 101 crossing, a newspaper columnist (*Daily Alta California* 1868) described "a low bottom to the left moist and good for crops of various kinds" in contrast to the scrubby, drier land on the valley floor. The SFEI report also notes that West Grove is mostly absent in 20th century images of the lower river because of agricultural reclamation, with the forest mostly gone by 1927. See Figure 3.47 from the SFEI report for map views and schematic cross sections that compare channel and habitat conditions near the river's mouth (about 3.5 miles downstream of the Highway 101 crossing) for three different time periods the early 1800s, the year 1927, and the year 2005. As shown in the cross sections, the most dramatic changes to the river occurred prior to 1927, and the extent of shrubs and small trees was actually greater in 2005 than in the early 1900s.

4.6.6 Conclusions and Recommendations

As discussed previously, management objectives, metrics, and minimum thresholds for the Surface Water Depletion sustainability indicator are not being established because the perennial reaches of each local stream arise from the existence of a Semi-perched aquifer and underlying aquitard, which hydraulically separate the perennial stream reaches from the UAS and LAS, which are the deeper pumped aquifers in the Oxnard Plain, Forebay, and Pleasant Valley basins. Additionally, in the case of the Santa Clara River, the locations of its perennial and ephemeral reaches appear to be unchanged from the years when the region was first settled; instead, the locations of these reaches arise from natural conditions (primarily geologic controls), rather than from the modern-day pumping of groundwater from the deeper UAS and LAS aquifers.

5 SUSTAINABLE YIELD

As defined by the SGMA, "'Sustainable yield means the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result" (CA DWR, 2016). Undesirable results are assumed to occur if the groundwater sustainability indicators fail to meet or exceed the minimum thresholds. For the evaluation described in this report, assumed minimum threshold groundwater elevations developed for each sustainability indicator (Section 4) were grouped by aquifer or aquifer system (UAS and LAS) and by location in the study area, then the highest applicable minimum threshold at each location was selected as the target groundwater level. This approach allows a single sustainability indicator (i.e., "lowering groundwater levels") to be used to evaluate performance of different pumping scenarios, while ensuring that management objectives for the five other sustainability indicators are met. This greatly simplifies the evaluation process, and potentially could make future monitoring efforts more efficient and effective.

5.1 TARGET GROUNDWATER LEVELS

Quantitative assumed minimum thresholds developed in Section 4 for seawater intrusion, land subsidence, degraded water quality, and reduction of groundwater storage were used to develop the comprehensive target groundwater levels assumed for this evaluation; the target groundwater levels are shown on Figures 5.1-1 and 5.1-2, and are summarized in Table 5.1-1. Minimum thresholds for the "surface water depletion" indicator were not established for this evaluation because local surface-water bodies are fed by a local perched aquifer that is minimally influenced by pumping from the regional aquifers used for water-supply. It is assumed for this evaluation that if groundwater elevations can be maintained at or above the target groundwater levels under most circumstances, then minimum thresholds will be met and management objectives likely achieved under most circumstances.

5.2 METHOD

United has constructed a numerical groundwater flow model to simulate and forecast groundwater flow in the aquifers underlying the Oxnard coastal plain. The United model incorporates a revised hydrostratigraphic conceptual model and improved horizontal and vertical resolution compared to the previous USGS model for the region (Hanson and others, 2003). The United model is still being updated, tested, and reviewed; however, based on calibration results to date and initial review by an expert panel, it appears to be a capable tool for this preliminary evaluation. The United model was used to forecast groundwater level responses to simulated changes in pumping rates, in order to evaluate some hypothetical pumping scenarios that could result in sustainable yield (i.e. maintain groundwater elevations above target groundwater levels discussed in Section 5.1).

Table 5.1-1. Assumed Minimum Thresholds and Target Groundwater Levels

Area	Aquifer System	Assumed Minimum Threshold for Each Sustainability Indicator (feet NGVD29)						Target Groundwater Level[a] (feet NGVD29)
		Lowering Groundwater Levels	Reduction of Groundwater Storage	Seawater Intrusion	Degraded Water Quality	Land Subsidence	Surface Water Depletion	
Forebay	UAS	---	-100	---	+20	-100	---	**+20**
	LAS	---	-150	---	---	-150	---	**-150**
Oxnard Plain basin (excluding Forebay)	UAS	---	-100	---	---	-100	---	**-100**
	LAS	---	-150	---	---	-150	---	**-150**
Pleasant Valley basin	UAS	---	-100	---	---	-100	---	**-100**
	LAS	---	-200	---	---	-200	---	**-200**
Seawater Intrusion Management Area	UAS	---	-100	+6	---	-100	---	**+6**
	LAS	---	-150	+18.5	---	-150	---	**+18.5**

Notes: --- = Not applicable

[a] Target groundwater levels represent the highest of the minimum thresholds, and represent the lowest that groundwater elevations could be without causing undesirable results. Groundwater elevations can be higher than the target groundwater levels without causing undesirable results.

5.2.1 Model Development

Development of the United model began with considerable effort to review and update the hydrostratigraphic conceptual model for the Oxnard Plain (including the Forebay), Pleasant Valley, and Mound groundwater basins, in order to explicitly represent the aquifers and aquitards 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 compared to the USGS model, which is a two-layer model representing the UAS and the LAS each as single layers. In addition, the geometry of some faults and folds was adjusted in the conceptual model during preparation 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, which represent the seven aquifers and six aquitards that are recognized in the model area. The current active domain of the United model includes the Oxnard Plain (including the Forebay), Pleasant

Valley, Mound, and West Las Posas basins, part of the Santa Paula basin, as well as the submarine (offshore) outcrop areas of the principal aquifers that underlie these basins. The extent and boundary conditions for model layers 3 and 9, which represent the Oxnard and Fox Canyon aquifers, are shown on Figures 5.2-1 and 5.2-2. There are small variations in the extent of each model layer, corresponding to variations in extent of each aquifer; however, layers 3 and 9 are considered representative of the overall approach to model construction. The current 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 across the active model domain, as follows:

- The eastern margin of the active model domain in 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 margin of the active model domain in Pleasant Valley basin consists of a no-flow boundary with the Santa Rosa basin, due to negligible cross-sectional area for groundwater flow from the Santa Rosa basin to the Pleasant Valley basin.
- The northeastern boundary of the active model domain currently terminates just inside Santa Paula basin, and is simulated as a general-head boundary.
- The northern margin 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 (including the Hueneme and Fox Canyon aquifers) is simulated to occur within the San Pedro outcrop north of the model boundary.
- The southeastern margin of the active model domain coincides with the contact between Holocene alluvial fill deposits and poorly permeable 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 margin of the active model domain extends offshore to the submarine outcrop areas of the Mugu aquifer and San Pedro Formation. 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 United 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 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.

- The model calibration period also was a time of major changes in groundwater management in Ventura County, including the establishment of FCGMA and the efforts of the 1980s to reduce pumping in the UAS.
- Reporting of various data, including groundwater level measurements and pumping records, became more detailed and extensive starting in the early- to mid-1980s.

A number of aquifer tests and slug tests were performed within the modeled area by United and the USGS. Review of the aquifer test results indicates that the hydraulic conductivities for the aquifers of the UAS typically range from 100 to 300 ft per day, and those in the LAS generally range from 10 to 50 ft per day. The inferred hydraulic conductivity values from the tabulated aquifer tests were used to set the range of initial aquifer parameters in the model. The aquifer parameters were adjusted during calibration, as described below.

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 improved fit based on manual and automated calibration simulations. The most sensitive parameter influencing calibration of simulated to measured hydraulic heads is hydraulic conductivity; this parameter is typically also subject to the greatest variability and uncertainty. Therefore, hydraulic conductivity commonly received the greatest degree of adjustment during model calibration. The vertical to horizontal anisotropy ratio is generally set to 0.1 (1:10) throughout the model. However, the vertical anisotropy ratio in the layers representing the aquifers of the UAS in the Forebay is 0.5 (1:2), to represent increased hydraulic communication between the UAS and the LAS in this area.

Results of calibration indicate that the model is well calibrated throughout most of the Forebay area, Oxnard Plain basin, and Pleasant Valley basin. The model is not as well calibrated yet in the Mound basin and the northeast area of the Pleasant Valley basin, and the West Las Posas basin conceptual model is in development at this time (calibration has not yet been attempted in this basin). However, these areas are of minor relevance for modeling the effects of pumping on groundwater levels that affect the sustainability indicators of primary concern in the Oxnard Plain and Pleasant Valley basins.

In 2016, 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 the widely used MODFLOW pre- and post-processor, Groundwater Vistas; and,
- John Porcello, of GSI Water Solutions, 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 (spreading 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 three-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 groundwater level changes and scatter plots of the groundwater-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 groundwater 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. In mid-2016, pumping, climatic, and groundwater-level data for the period from January 2013 through December 2015 were incorporated into the model. The model was able to simulate groundwater-level changes observed in the Oxnard Plain and Pleasant Valley basins during this period, which included a drought of comparable duration and magnitude to the drought ending in 1990. United is planning to complete the model documentation in 2017, and can share the documentation with interested parties at that time.

5.2.2 Simulation Approach for Sustainable Yield Evaluation

The overall approach for using the groundwater model to evaluate effects of hypothetical pumping scenarios on groundwater levels and potential sustainable yield consisted of simulating reduced pumping rates in the Oxnard Plain and Pleasant Valley basins, then determining the extent to which target groundwater levels were achieved under each scenario. Seawater intrusion has historically been (and continues to be) the most pressing groundwater sustainability challenge within the study area. Achieving management objectives for seawater intrusion by raising groundwater elevations (as a result of simulated pumping reductions) to target groundwater levels in the seawater intrusion management area was anticipated to raise groundwater elevations above target groundwater levels elsewhere in the Oxnard Plain and Pleasant Valley basins, thereby achieving the management objectives for other sustainability indicators. Modeling results were reviewed to determine the degree to which assumed minimum thresholds for all sustainability indicators established in Section 4 were met, not just those for seawater intrusion.

The modeled base period for the hypothetical pumping scenarios was January 1985 through December 2015 (31 years). Each pumping scenario consisted of 1985 through 2015 boundary conditions and aquifer stresses (e.g., recharge and extractions), with extractions under each pumping scenario reduced proportionately relative to reported extractions from 1985 through 2015. Reported pumping rates in the study area and rainfall amounts (at Oxnard Airport) during 1985 through 2015 are shown on Figure 5.2-3, illustrating the range in groundwater usage and climatic variability that occurred during this period. Forecasting of future climatic conditions, land use, and changes in water sources in the study area was beyond the scope of this initial effort. Therefore, this approach is, in effect, an evaluation of the reduction in pumping that would have been required to achieve sustainable yield in the study area during the period from 1985 through 2015.

The scenarios that were simulated include:

- **Base Case Scenario**—This scenario used reported pumping rates to simulate, to the extent feasible, measured groundwater levels (and their changes) during the period from 1985 through 2015. These simulated groundwater levels were used as the basis for comparing potential impacts of the subsequent hypothetical pumping scenarios rather than measured groundwater levels, because the model provides discrete results for head (groundwater level) in each aquifer, during every month, across the entire study area. Because the measured data do not provide a consistent data set on a regular frequency and at the same group of wells, nor data specific to individual aquifers, the simulated hydraulic heads provide more useful baseline information for the subsequent evaluations of sustainable yield under the assumed hypothetical pumping scenarios.

- **Scenario A**—Simulated pumping rates in the Oxnard Plain (excluding the Forebay) and Pleasant Valley basins were reduced by 50 percent in both the UAS and the LAS compared to 1985 through 2015 rates. This scenario comprises the simplest approach to raising groundwater elevations to achieve target groundwater levels (minimum thresholds)--a uniform reduction in pumping. However, this approach does not focus pumping reductions in areas where groundwater elevations are typically the farthest below target groundwater levels (i.e., the southern part of the Oxnard Plain basin, where seawater intrusion has historically been greatest). Therefore, it was anticipated that this scenario would likely result in simulated groundwater elevations rising to levels well above target groundwater levels in some areas, while failing to achieve them in other areas. It was apparent during early tests of this approach that 20 and 40 percent uniform pumping reductions would not come close to achieving the target groundwater levels across much of the seawater intrusion management area. Consequently, a 50-percent reduction was selected for Scenario A to demonstrate the relative merits and limitations of this approach. Simulated reductions in pumping were not applied to the Forebay, due to its distance (more than 3 miles) from areas where groundwater quality has been impaired by seawater intrusion. Continued operation of groundwater recharge and pumping operations by United in the Forebay is expected to be a key factor to eventually achieving sustainable yield in the Oxnard Plain and surrounding basins.
- **Scenario B**—Simulated pumping rates for wells screened solely in the LAS in the Oxnard Plain (excluding the Forebay) and Pleasant Valley basins were reduced by 75 percent compared to 1985 through 2015 rates, while pumping rates for wells screened in the UAS were unchanged from historical rates (no reduction). Pumping rates for wells that are screened across both the UAS and the LAS were also left unchanged from historic rates (these wells make up a relatively small proportion of total pumping in the Oxnard Plain basin). Scenario B focused on reducing pumping solely in the LAS because measured groundwater levels in most of the UAS are currently closer to the target groundwater levels than are groundwater levels in the LAS. Furthermore, despite the presence of an aquitard between the UAS and LAS, vertical conductance between these aquifer systems was anticipated to allow a modest groundwater-level response in the UAS as a result of large-scale reductions in pumping from the LAS. Consequently, reducing pumping solely in the LAS could potentially achieve target groundwater levels in both aquifer systems, with a

smaller overall reduction in pumping rate (resulting in a higher sustainable yield value) than if pumping were reduced equally in both the UAS and LAS.

- **Scenario C**—Simulated pumping rates for all wells (UAS and LAS) within the assumed seawater intrusion management area were reduced by 100 percent (no pumping), while pumping rates for all other wells in the Oxnard Plain (including the Forebay) and Pleasant Valley basins remained at historic rates (no reductions). The goal of this scenario was to determine whether target groundwater levels could be achieved with a complete pumping moratorium in the area where seawater intrusion has been and continues to be the greatest concern, while pumping continued at historic rates elsewhere in the study area. Initial results from this scenario (discussed further in Section 5.3) indicated that this approach would not result in groundwater elevations rising to target levels, and necessitated development of Scenario D.
- **Scenario D**—Simulated pumping rates for all wells (UAS and LAS) within the seawater intrusion management area were reduced by 100 percent, pumping rates for LAS wells throughout the remainder of the Oxnard Plain (excluding the Forebay) and Pleasant Valley basins were reduced by 70 percent, and pumping rates for UAS wells throughout the remainder of the Oxnard Plain and Pleasant Valley basins continued at historic rates (no reduction). The intent of this scenario was to determine whether a combination of eliminating pumping in the seawater intrusion management zone and significantly reducing pumping from the LAS could more effectively achieve target groundwater levels compared to Scenario B, which assumed some pumping would continue in the seawater intrusion management area.
- **Scenario E**—Simulated pumping rates for all wells (UAS and LAS) within the seawater intrusion management area were again reduced by 100 percent, pumping rates for LAS wells in the remainder of the Oxnard Plain (excluding the Forebay) and Pleasant Valley basins were reduced by 75 percent, and pumping rates for UAS wells outside of the seawater intrusion management area were ***increased*** by 50 percent above historic rates. The intent of this scenario was to take advantage of the fact that groundwater levels in the UAS in the northwestern part of the Oxnard Plain basin have historically been well above target levels much of the time, and likely would rise farther if LAS pumping were reduced in the Oxnard Plain and Pleasant Valley basins. Therefore, pumping could potentially be increased in the UAS (raising the sustainable yield) while still achieving target groundwater levels.

Table 5.3-1, below, summarizes the annual average groundwater extraction rates assumed under each modeled scenario, by individual basin and as the sum for all three modeled basins. Also shown, for reference purposes, is the sum of annual average groundwater and surface water use for the modeled basins combined, including:

- Reported pumping from wells (varies by pumping scenario);
- Imports from the State Water Project (26,600 AF/yr); and

- Delivery of diverted surface water from the Santa Clara River and Conejo Creek (17,700 AF/yr).

The quantity of surface water imported or diverted to the basins and used for municipal, agricultural, or industrial purposes is not input directly into the groundwater flow model. However, surface water imports indirectly influence actual and modeled groundwater pumping rates and agricultural return flows. The percent reductions in groundwater use and total water use (groundwater plus surface water imports and diversions) assumed in each scenario—compared to the base case—are shown in the right-hand column of Table 5.2-1.

5.2.3 Assumptions and Limitations

An important assumption for the approach used in this evaluation is that it is based on climatic conditions in the study area during the period from 1985 through 2015. Development of independent forecasts of future climatic conditions was beyond the scope of the current effort. However, forecasting of future climatic conditions is encouraged as the FCGMA's groundwater sustainability planning efforts continue, to provide a more accurate assessment of hydrologic inputs and outflows that could affect the water balance in the study area during the groundwater sustainability planning window.

Other key assumptions applied to the modeling effort include:

- Reported groundwater withdrawals (pumpage from wells) during the period from 1985 through 2015 are repeated, or reduced proportionally from historic withdrawal rates (i.e., no wells were assumed to be destroyed, and no new wells were assumed to be drilled); and
- The sole approach considered for achieving sustainable yield for this evaluation was to modify pumping rates in the UAS and/or LAS.

Other pumping distributions are theoretically possible that could potentially increase sustainable yield to a modest degree (i.e., achieve minimum thresholds with smaller pumping reductions), or new water-supply enhancement or mitigation projects could be constructed to specifically address one or more groundwater sustainability indicators (e.g., injection or extraction barriers in areas vulnerable to seawater intrusion). Consideration of new projects and detailed evaluation of the numerous potential distributions of pumping distributions are beyond the scope of this effort, but may be undertaken by the FCGMA as their groundwater sustainability planning efforts continue. This evaluation also assumes no reductions in surface-water deliveries from the Santa Clara River resulting from climate change or increased in-stream flow requirements. Such reductions would likely cause a corresponding reduction in forecasted sustainable yield of the Oxnard Plain and Pleasant Valley basins.

Table 5.2-1. Summary of Pumping Rates Assumed for Each Modeled Scenario

Scenario	Average Groundwater Extractions (AF/yr)				Average Combined Groundwater and Surface Water Use (AF/yr)	Percent Reduction Compared to Base Case (Groundwater / Total Water)
	Oxnard Plain	Forebay	Pleasant Valley	Sum		
Base Case (no changes in pumping from 1985-2015 rates)	54,200	24,000	20,800	**99,000**	**143,000**	**0% / 0%**
Scenario A (50% reduction in pumping from UAS and LAS in Oxnard Plain [excluding the Forebay] and Pleasant Valley basins)	27,300	24,000	10,400	**61,700**	**105,000**	**38% / 27%**
Scenario B (75% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basin, no reduction in UAS pumping)	30,500	24,000	6,100	**60,600**	**104,000**	**39% / 27%**
Scenario C (100% reduction in pumping in seawater intrusion management area, no reductions in remainder of basins)	44,700	24,000	20,600	**89,300**	**133,000**	**10% / 7%**
Scenario D (no pumping in seawater intrusion management area, 70% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basin, no reduction in UAS pumping)	28,900	24,000	7,000	**59,900**	**104,000**	**39% / 27%**
Scenario E (no pumping in seawater intrusion management area, 75% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basin, 150% increase in UAS pumping)	38,600	24,100	6,600	**69,300**	**113,000**	**30% / 21%**

5.3 RESULTS

Model results were evaluated by comparing forecasted groundwater elevations for each simulated pumping scenario to the target groundwater levels described in Section 5.1 (corresponding to assumed minimum thresholds assumed for each sustainability indicator in Section 4). Results are illustrated using the time-series hydrographs shown on Figures 5.3-1 through 5.3-4. These hydrographs compare target groundwater levels to simulated groundwater elevations under each pumping scenario in the Oxnard aquifer (representative of the UAS) and the Fox Canyon aquifer (representative of the LAS) at wells near Port Hueneme and Mugu Lagoon—where seawater intrusion problems are most pronounced—and in the eastern Oxnard Plain basin near the boundary with the Pleasant Valley basin. In addition, time series hydrographs are shown for the Semi-perched aquifer and the Oxnard aquifer at a well in the northwest Oxnard Plain basin adjacent to the perennial reach of the Santa Clara River (between U.S. Highway 101 and the coast). The locations for these wells are shown on Figures 5.2-1 and 5.2-2. Detailed inspection of model results indicated that forecasted groundwater elevations in the Mugu aquifer were typically within a few inches to a few feet of those in the Oxnard aquifer, and that forecasted groundwater elevations in the Hueneme and Grimes Canyon aquifers were within a few feet of those in the Fox Canyon aquifer. Therefore, to conduct the evaluations efficiently, results for only the Oxnard and Fox Canyon aquifers are described in this report, but can be applied to the other aquifers in the UAS and LAS, respectively.

Maps showing groundwater elevations forecasted by each scenario during December 2012 are provided on Figures 5.3-5 through 5.3-16; in each scenario, forecasted groundwater elevations at this time approximate common fall-season lows for the period from 1995 through 2012, which is representative of typical climatic and hydrogeologic conditions in the Oxnard Plain and Pleasant Valley basins. This period is referred to as "typical" subsequently in this report. Forecasted groundwater elevations during the first 10 years of the simulation period (1985 through 1994) are anomalously low due to the higher pumping rates occurring in the region from 1985 through 1990 and the exceptional drought that persisted through 1990. Similarly, forecasted groundwater elevations during the last three years of the simulation period (2013 through 2015) are anomalously low due to the current exceptional drought. Forecasted groundwater elevations throughout the study area as of December 2012 are influenced by low precipitation that year; therefore, they are slightly lower than average long-term seasonal-low groundwater elevations for the period from 1995 through 2012, and represent a conservatively low estimate of "typical" groundwater levels.

Comparisons of model results to each of the six SGMA sustainability criteria are provided below.

5.3.1 Lowering Groundwater Levels

This section summarizes model-forecasted impacts to groundwater levels resulting from the base-case and the reduced-pumping model scenarios. The time-series hydrographs shown on Figures 5.3-1 through 5.3-4 and the groundwater level contour maps shown on Figures 5.3-5 through 5.3-16 indicate that although each of the reduced-pumping model scenarios results in groundwater elevations that are higher than historic lows, and are mostly higher than target groundwater levels, assumed minimum thresholds for seawater intrusion are only achieved consistently by Scenarios D and E. Details regarding forecasted groundwater elevations in the seawater intrusion management area under each scenario are provided below.

5.3.1.1 Base-Case Scenario

Groundwater levels resulting from the base-case pumping scenario are similar to measured groundwater elevations in the study area from 1985 through 2015. This similarity was expected, as the model is calibrated to (and assumes a repetition of) 1985 through 2015 climatic conditions, pumping, and recharge rates. As noted previously, the groundwater levels simulated by the base-case scenario are used for comparing potential impacts of the subsequent hypothetical pumping scenarios.

Inspection of Figures 5.3-1 through 5.3-4 indicates that for most of the simulation period, simulated groundwater elevations for the base-case scenario are generally above the target groundwater levels, including in the seawater intrusion management area in the Oxnard aquifer at Port Hueneme (except during droughts), but are below target groundwater levels in the Fox Canyon aquifer at Port Hueneme and in both aquifers at Mugu Lagoon. These model results are generally in close agreement with groundwater elevation measurements at Port Hueneme-area well 01N22W20J07S, and Mugu Lagoon-area wells 01N21W29B03S and 01N21W28D01S; however, the model tends to underpredict measured groundwater elevations in the Fox Canyon aquifer at well 01N22W20J04S (Port Hueneme) by 10 ft or more during non-drought periods, and by less than 10 ft during drought periods. This tendency does not negatively impact this evaluation to a significant degree, because groundwater elevations in the Mugu Lagoon area are generally lower than those near Port Hueneme; therefore, forecasted groundwater elevations in the Mugu Lagoon area are generally the limiting factor for determining whether each scenario achieves its management objectives.

The base-case-scenario model results for the Port Hueneme and Mugu Lagoon areas are also consistent with analytical results that indicate increasing salinity near Mugu Lagoon and periods of both increasing and decreasing salinity at Port Hueneme (United, 2016). When groundwater elevations near the coast are below target groundwater levels for an extended period, seawater can intrude laterally into the aquifer; when groundwater elevations are above target groundwater levels, a seaward hydraulic gradient occurs, preventing seawater from intruding further inland. Figures 5.3-1 and 5.3-2 indicate that groundwater elevations are consistently below target groundwater levels in the Fox Canyon aquifer at Port Hueneme and in both aquifers near Mugu Lagoon; this condition allows landward seawater intrusion to occur. Figure 5.3-1 indicates that modeled (and measured) groundwater elevations at well 01N22W20J07S, which is screened in the UAS, fluctuate from below sea level during extended droughts to well above sea level during more typical climatic and hydrogeologic conditions (i.e., 1995 through 2012). These fluctuations in groundwater elevation tend to allow seawater intrusion during droughts, and reverse or halt seawater intrusion during average to wet periods.

Figures 5.3-5 and 5.3-6 support the observation that a landward hydraulic gradient, which promotes seawater intrusion, is present in the Oxnard aquifer at Mugu Lagoon, and in the Fox Canyon aquifer at both Port Hueneme and Mugu Lagoon, under typical climatic and hydrogeologic conditions. Groundwater elevations decline during drought conditions (e.g., fall 2015, as shown on Figures 4.3-1 and 4.3-2) compared to typical conditions, causing an increase in landward hydraulic gradients in each aquifer and thereby exacerbating seawater intrusion. Figure 5.3-5 shows that during a typical water year, groundwater elevations in the UAS are lowest in the southeast Oxnard Plain basin approximately three miles north from Mugu Lagoon. East-trending hydraulic gradients that occur in both the UAS and the LAS along the coast between Port Hueneme and Mugu Lagoon cause seawater that intrudes the aquifers at Port Hueneme during drought years to migrate southeastward down the coast toward Mugu Lagoon during average to wet years. Figure 5.3-6 shows that during a typical water year, groundwater elevations in the LAS are lowest in the southeast Oxnard Plain basin approximately three miles north from Mugu Lagoon and in the northwest Pleasant Valley basin near the Camarillo Airport. These groundwater depressions in the UAS and LAS in the southeast Oxnard Plain are the primary causes for continued seawater intrusion in the Mugu Lagoon area.

5.3.1.2 SCENARIOS A THROUGH E

Pumping Scenario A, which assumes a 50 percent reduction in UAS and LAS pumping in the Oxnard Plain basin (excluding the Forebay) and the Pleasant Valley basin, is forecasted to result in groundwater elevations that are typically 10 to 85 ft higher in the seawater intrusion management area, and 10 to 40 ft higher in the central Oxnard Plain, than those simulated in the base case scenario. Groundwater elevations in the UAS in the seawater intrusion management area are forecasted to remain above target groundwater levels most of the time (except during exceptional droughts), but below target groundwater levels in the LAS nearly all of the time (Figures 5.3-1 and 5.3-2). Figure 5.3-7 indicates seaward hydraulic gradients, which would halt or reverse seawater intrusion, occur in the UAS at Port Hueneme and Mugu Lagoon under typical conditions. However, Figure 5.3-8 indicates landward gradients, which can exacerbate seawater intrusion, occur in the LAS at Port Hueneme and Mugu Lagoon under typical conditions.

Pumping Scenario B, which assumes a 70 percent reduction in LAS pumping throughout the Oxnard Plain basin (excluding the Forebay) and the Pleasant Valley basin, and no reduction in UAS pumping, is forecasted to result in groundwater elevations that are 10 to 120 ft higher in the seawater intrusion management area, and 15 to 80 ft higher in the central Oxnard Plain, than those simulated in the base case scenario. Groundwater elevations in the UAS throughout the seawater intrusion management area, and in the LAS near Port Hueneme, are forecasted to remain above target groundwater levels most of the time (except during exceptional droughts). However, groundwater elevations in the LAS near Mugu Lagoon are forecasted to remain below target groundwater levels most of the time (Figures 5.3-1 and 5.3-2). Figure 5.3-9 indicates seaward hydraulic gradients, which would halt or reverse seawater intrusion, occur in the UAS at Port Hueneme and Mugu Lagoon under typical conditions. However, Figure 5.3-10 indicates landward gradients, which can exacerbate seawater intrusion, occur in the LAS at Mugu Lagoon under typical conditions.

Pumping Scenario C, which assumes no pumping in the seawater intrusion management area (but allows pumping to continue at historical rates throughout the remainder of the study area), is forecasted to result in groundwater elevations that are 5 to 60 ft higher in the seawater intrusion management area, and 5 to 20 ft higher in the central Oxnard Plain, than those simulated in the base case scenario. Groundwater elevations in the UAS in the Port Hueneme area are forecasted to remain above target groundwater levels most of the time (except during exceptional droughts), but below target groundwater levels nearly all of the time in the LAS at Port Hueneme and in both the UAS and LAS at Mugu Lagoon (Figures 5.3-1 and 5.3-2). Figure 5.3-11 indicates seaward hydraulic gradients, which would halt or reverse seawater intrusion, occur in the UAS at Port Hueneme, but not at Mugu Lagoon under typical conditions. Figure 5.3-12 indicates landward gradients, which can exacerbate seawater intrusion, occur in the LAS at Port Hueneme and Mugu Lagoon under typical conditions.

Pumping Scenario D, which assumes no pumping in the seawater management area and a 70 percent reduction in LAS pumping throughout the Oxnard Plain basin (excluding the Forebay) and the Pleasant Valley basin, but no reduction in UAS pumping in the Oxnard Plain or Pleasant Valley basins, is forecasted to result in groundwater elevations that are 10 to 130 ft higher in the seawater intrusion management area, and 20 to 120 ft higher in the central Oxnard Plain, than those simulated in the base case scenario. Groundwater elevations in the UAS throughout the seawater intrusion management area, and in the LAS near Port Hueneme, are forecasted to remain above target groundwater levels most of the time (even through most drought periods). However, groundwater elevations in the LAS near Mugu Lagoon are forecasted to remain slightly below target groundwater levels some of the time (Figures 5.3-1 and 5.3-2). Figure 5.3-13 indicates seaward hydraulic gradients, which would halt or reverse seawater intrusion, occur in the UAS at Port Hueneme and Mugu Lagoon under typical conditions. Figure 5.3-14 indicates nearly flat gradients occur in the LAS at Port Hueneme and Mugu Lagoon under typical conditions, suggesting that the rate of seawater intrusion would be negligible.

Pumping Scenario E, which assumes no pumping in the seawater management area, a 75 percent reduction in LAS pumping throughout the Oxnard Plain (excluding the Forebay) and Pleasant Valley basins, and a 50 percent ***increase*** in UAS pumping in the Oxnard Plain (excluding the Forebay) and Pleasant Valley basins, is forecasted to result in groundwater elevations that are 10 to 130 ft higher in the seawater intrusion management area, and 10 to 120 ft higher in the central Oxnard Plain, than those simulated in the base case scenario, similar to Scenario D. Groundwater elevations in the UAS throughout the seawater intrusion management area, and in the LAS near Port Hueneme, are forecasted to remain above target groundwater levels most of the time (even through most drought periods). However, groundwater elevations in the LAS near Mugu Lagoon are forecasted to remain slightly below target groundwater levels some of the time (Figures 5.3-1 and 5.3-2). Figure 5.3-15 indicates seaward hydraulic gradients, which would halt or reverse seawater intrusion, occur in the UAS at Port Hueneme and Mugu Lagoon under typical conditions. Figure 5.3-16 indicates nearly flat gradients occur in the LAS at Port Hueneme and Mugu Lagoon under typical conditions, suggesting that the rate of seawater intrusion would be negligible.

5.3.2 Reduction of Groundwater Storage

As discussed in Section 4.2, assumed minimum thresholds for reduction of groundwater storage were developed from historical low groundwater elevations throughout the period of record. Within the study area, historical groundwater lows occurred during the 1960s (when the pattern of groundwater withdrawals in the Oxnard Plain basin was very different from today, particularly in the UAS), in the early 1990s, and in 2015, depending on aquifer system and location. Because the base-case pumping scenario consists of a repeat of 1985 through 2015 pumping and climatic conditions in the study area, simulated groundwater elevations reflect a corresponding return to the 1990 and 2015 record low levels, as shown on Figures 5.3-1 through 5.3-4. However, simulated groundwater elevations do not reach the record low groundwater elevations observed at some wells in the 1960s. Therefore, the base-case scenario is likely to be partially effective at achieving assumed minimum thresholds for reduction of groundwater storage in the Oxnard Plain and Pleasant Valley basins.

Under Scenarios A, B, D and E, forecasted groundwater elevations in the UAS and LAS remain consistently higher than historic lows (due to the reduction in pumping), as shown on Figures 5.3-1 through 5.3-4. Therefore, these scenarios should be effective at achieving assumed minimum thresholds for reduction of groundwater storage in the Oxnard Plain and Pleasant Valley basins. Under Scenario C, forecasted groundwater elevations in the UAS and LAS approach historic lows at inland areas (Figure 5.3-4). Therefore, this scenario is considered likely to be only partially effective at achieving assumed minimum thresholds levels for reduction of groundwater storage in the Oxnard Plain and Pleasant Valley basins.

5.3.3 Seawater Intrusion

Seawater intrusion has historically been viewed as the greatest sustainability concern for groundwater underlying the Oxnard Plain and Pleasant Valley basins, and was a principal reason for formation of the FCGMA. Therefore, it was no surprise that seawater intrusion proved to be the key sustainability indicator in this evaluation. If, and only if, target groundwater levels in the seawater intrusion management area were achieved, then target groundwater levels in other areas of the basins were generally achieved as well under each pumping scenario.

Simulated groundwater elevations for the base-case scenario during typical water years are generally above the target groundwater levels in the seawater intrusion management area in the UAS at Port Hueneme, but are below target groundwater levels in the LAS at Port Hueneme and in both aquifer systems near Mugu Lagoon (Figures 5.3-1 and 5.3-2). Pumping from the LAS in the eastern Oxnard Plain basin and western Pleasant Valley basin has created a large cone of depression that extends to the coast (Figure 5.3-6), creating landward hydraulic gradients within the seawater intrusion management area that are greatest during droughts, but persist through average and wet years as well. Therefore, the base-case scenario, which repeats historic pumping and hydrogeologic conditions, is recognized to be generally ineffective at achieving assumed minimum thresholds for seawater intrusion, even though groundwater elevations in the UAS near Port Hueneme are above target groundwater levels during typical water years (Figures 5.3-1 and 5.3-5). Table 5.3-1 summarizes the relative effectiveness of each modeled pumping scenario at achieving target groundwater levels in the key areas of concern (near Port Hueneme and Mugu Lagoon) in the seawater intrusion management area. The period for averaging groundwater elevations shown on this table (2000 through 2012) was selected because the running-average rainfall during this timeframe was approximately equal to the long-term average rainfall, without occurrence of exceptionally dry or wet periods.

Forecasted groundwater elevations under Scenario D are generally above the target groundwater levels in the seawater intrusion management area in the UAS and LAS at Port Hueneme and at Mugu Lagoon, except during exceptional droughts (Figures 5.3-1 and 5.3-2). Therefore, this scenario is considered to be effective at achieving target groundwater levels for seawater intrusion, subject to monitoring and potential minor adjustment of pumping rates and locations.

Similar to Scenario D, forecasted groundwater elevations under Scenario E are generally above the target groundwater levels in the seawater intrusion management area in the UAS and LAS at Port Hueneme and in the UAS at Mugu Lagoon, except during exceptional droughts (Figures 5.3-1 and 5.3-2). Forecasted average groundwater elevations are slightly below target groundwater levels in the LAS at Mugu Lagoon, but landward hydraulic gradients are very small (Figure 5.3-16), likely resulting in negligible seawater intrusion rates in this area. Small adjustments in Scenario E pumping rates could be made to raise forecasted groundwater elevations in the LAS near Mugu Lagoon above the target groundwater level, without decreasing the overall assumed pumping rates in the Pleasant Valley and Oxnard Plain basins. Therefore, this scenario is considered to be effective at achieving assumed minimum thresholds for seawater intrusion, subject to monitoring and potential minor adjustment of pumping rates and locations.

Table 5.3-1. Effectiveness of Modeled Pumping Scenarios at Achieving Target groundwater levels in Seawater Intrusion Management Area

Scenario	2000-2012 Average Groundwater Elevation (feet NGVD29)						Effective at Achieving Target?
	Target[a]		Port Hueneme[b]		Mugu Lagoon[c]		
	UAS	LAS	UAS	LAS	UAS	LAS	
Base Case (no changes in pumping from 1985-2015 rates)	**+6**	**+18.5**	+9.3	-10.3	-7.4	-51.1	Only in UAS in Port Hueneme area
Scenario A (50% reduction in pumping from UAS and LAS in Oxnard Plain [excluding the Forebay] and Pleasant Valley basins)	**+6**	**+18.5**	+21.3	+14.2	+16.9	-2.8	UAS only
Scenario B (75% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basin, no reduction in UAS pumping)	**+6**	**+18.5**	+20.3	+20.9	+21.4	+14.3	All but LAS in Mugu Lagoon area
Scenario C (100% reduction in pumping in seawater intrusion management area, no reductions in remainder of basins)	**+6**	**+18.5**	+12.3	+0.3	+3.0	-20.8	Only in UAS in Port Hueneme area
Scenario D (no pumping in seawater intrusion management area, 70% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basin, no reduction in UAS pumping)	**+6**	**+18.5**	+20.6	+22.1	+23.1	+19.4	Yes
Scenario E (no pumping in seawater intrusion management area, 75% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basin, 150% increase in UAS pumping)	**+6**	**+18.5**	+16.7	+20.1	+20.3	+17.8	Yes, but marginal in LAS at Mugu Lagoon[d]

[a] Target groundwater levels, see Section 4.3.
[b] Represented by simulated groundwater elevations at wells 01N22W20J07S (Oxnard aquifer) and 01N22W20J04S (Fox Canyon aquifer).
[c] Represented by simulated groundwater elevations at wells 01N21W29B03S (Oxnard aquifer) and 01N21W28D01S (Fox Canyon aquifer).
[d] The average groundwater elevation in the LAS in the Mugu Lagoon area is slightly below the target groundwater level, but gradients are nearly flat, suggesting that seaward intrusion in this area could be halted with some minor adjustments to Scenario E pumping rates in this area.

5.3.4 Degraded Water Quality

Similar to the "reduction of groundwater storage" sustainability indicator, assumed minimum thresholds for degraded water quality were developed from historical groundwater elevations in the period of record. Historically, groundwater quality (in the UAS and LAS) in the Forebay area and in the Pleasant Valley basin has been problematic chiefly during extended drought periods, when groundwater levels are lowest. Because the base-case pumping scenario consists of a repeat of

1985 through 2015 pumping and climatic conditions in the region, simulated groundwater elevations reflect historic levels, and groundwater quality issues can be expected to recur. Therefore, the base-case scenario is considered to be ineffective at achieving target groundwater levels for reduction of groundwater storage in the Oxnard Plain and Pleasant Valley basins only part of the time.

Under Scenarios A, B, D and E, forecasted groundwater elevations in the UAS and LAS remain consistently higher than historic lows (due to the reduction in pumping). Therefore, these scenarios should be effective at achieving assumed minimum thresholds for avoiding degraded water quality in the Oxnard Plain and Pleasant Valley basins. Under Scenario C, forecasted groundwater elevations in the UAS and LAS approach historic lows at inland areas. Therefore, this scenario is considered likely to be only partially effective at achieving assumed minimum thresholds for avoiding degraded water quality in the Oxnard Plain and Pleasant Valley basins.

5.3.5 Land Subsidence

As discussed in Section 4.5 (and similar to the "reduction of groundwater storage" sustainability indicator), assumed minimum thresholds for land subsidence were developed from historical low groundwater elevations throughout the period of record. Within the study area, historical groundwater lows most commonly occurred during the 1960s (when the magnitude and distribution of groundwater withdrawals in the Oxnard Plain basin was very different from today, primarily from pumping in the UAS), 1990, and 2015, depending on aquifer system and location. Because the base-case pumping scenario consists of a repeat of 1985 through 2015 pumping and climatic conditions in the study area, simulated groundwater elevations reflect a corresponding return to the 1990 and 2015 record low levels. However, simulated groundwater elevations do not reach the record low groundwater elevations observed at some locations in the 1960s. Therefore, the base-case scenario is likely to be partially effective at achieving assumed minimum thresholds for land subsidence in the Oxnard Plain and Pleasant Valley basins.

Under Scenarios A, B, D and E, forecasted groundwater elevations in the UAS and LAS remain consistently higher than historic lows (due to the reduction in pumping). Therefore, these scenarios should be effective at achieving assumed minimum thresholds for avoiding degraded water quality in the Oxnard Plain and Pleasant Valley basins. Under Scenario C, forecasted groundwater elevations in the UAS and LAS approach historic lows at inland areas. Therefore, this scenario is considered likely to be only partially effective at achieving assumed minimum thresholds for avoiding degraded water quality in the Oxnard Plain and Pleasant Valley basins.

5.3.6 Surface Water Depletion

As discussed in Section 4.6, surface water flows are not affected by groundwater elevation changes in the UAS or LAS in the Oxnard Plain (including the Forebay) or Pleasant Valley basins to a significant degree, because each local stream is not hydraulically connected directly to these two pumped aquifer systems. Therefore, surface water depletion is not considered an applicable sustainability indicator for this evaluation.

5.4 DISCUSSION

Table 5.4-1 qualitatively summarizes the forecasted effectiveness of each pumping scenario at achieving the assumed minimum thresholds for each sustainability indicator in the Oxnard Plain and Pleasant Valley basins. Review of this table, and of the groundwater modeling results presented in Section 5.3, indicates that Scenarios D and E are forecasted to achieve assumed minimum thresholds for the applicable sustainability indicators most of the time (except during exceptional droughts). Average annual pumping rates under each of these scenarios range from 52,900 to 62,700 AF/yr in the Oxnard Plain basin (including the Forebay) and from 6,600 to 7,000 AF/yr in the Pleasant Valley basin. The combined annual average pumping rate for both basins ranges from 59,900 to 69,300 AF/yr under these scenarios, which would comprise a 30 to 39 percent reduction compared to the average annual pumping reported for the period from 1985 through 2015 (or a 21 to 27 percent reduction from average total water use, including surface water diversions and imports, reported for 1985 through 2015). This range of pumping rates defines the "sustainable yield" for the two basins (combined), under the assumptions regarding sustainability criteria, minimum thresholds, and future water-supply (including climatic) conditions as described in this report.

It should be noted that the range of potential sustainable yield values could change if other assumptions are made regarding minimum thresholds, distribution of pumping, forecasted climatic/hydrologic conditions, changes in surface water availability, and future water-supply or mitigation projects. As discussed in Section 5.2, reduction of pumping rates was the sole approach used to simulate how to potentially achieve target groundwater levels. This approach is most likely to provide sustainable-yield values at the lower end of the range of possible estimates; in contrast, assuming new water-supply development or water-quality mitigation projects would tend to increase sustainable yield. Because preparation of the FCGMA's GSPs for the Oxnard Plain and Pleasant Valley basins is still in progress, United staff felt it was premature at this time to attempt to develop and simulate modeling scenarios that involved major new water-supply projects. However, this evaluation also assumes no reductions in surface-water deliveries from the Santa Clara River resulting from climate change or increased in-stream flow requirements. Such reductions would likely cause a corresponding reduction in sustainable yield of the Oxnard Plain and Pleasant Valley basins.

Scenario E is notable in that it assumes increased pumping in the UAS compared to 1985-2015 average rates; this scenario yields the highest sustainable-yield values of the scenarios evaluated, except for the base-case. However, Scenario E likely would also be the most complex of these scenarios to implement, requiring new UAS supply wells and pipelines or canals to deliver it to fields or municipal/industrial users that formerly relied partially to completely on groundwater obtained from the LAS. Scenarios A through D, in contrast, simply assume reductions in pumping from certain aquifer systems in selected areas. Although such reductions require little effort to conceptualize, the resultant long-term effects on the economy, culture, and environment in the region would likely be large and complex. Analysis of such effects is beyond the scope of this evaluation, but should be considered in parallel with development and implementation of the FCGMA's GSPs.

To simplify the analysis to a level commensurate with the current incomplete status of the FCGMA's GSP, potential alternative climate scenarios, changes in land-use and water-supply conditions, and proposals for development of new projects that target specific groundwater sustainability concerns (e.g., United's proposed brackish-water treatment project, the City of Oxnard's recycled water initiatives, etc.) were not included in this analysis. However, the uncertainties associated with excluding these possible changes in future conditions does not limit the utility of the model for evaluating the overall changes in groundwater levels, or for comparing relative differences, of each pumping scenario that was simulated.

Table 5.4-1. Effectiveness of Each Modeled Scenario at Achieving Assumed Minimum Thresholds for Sustainability Indicators in Oxnard Plain (including the Forebay) and Pleasant Valley Basins

Scenario	Average Annual Pumping Rate (AF/yr)	Effectiveness at Achieving Assumed Minimum Thresholds for Sustainability Indicators						
		Lowering Groundwater Levels	Reduction of Storage	Seawater Intrusion		Degraded Water Quality	Land Sub-sidence	Surface Water Depletion
				Port Hueneme	Mugu Lagoon			
Base Case (no changes in pumping from 1985-2015 rates)	99,000	N/A	Partially	Partially	No	No	Partially	N/A
Scenario A (~50% reduction in pumping from UAS and LAS in Oxnard Plain [excluding the Forebay] and Pleasant Valley basins)	61,700	N/A	Yes	Partially	Partially	Yes	Yes	N/A
Scenario B (~75% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basins, no reduction in UAS pumping)	60,600	N/A	Yes	Yes	Partially	Yes	Yes	N/A
Scenario C (100% reduction in pumping in seawater intrusion management area, no reductions in remainder of basins)	89,300	N/A	Partially	Partially	No	Partially	Partially	N/A
Scenario D (no pumping in seawater intrusion management area, ~70% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basins, no reduction in UAS pumping)	59,900	N/A	Yes	Yes	Yes	Yes	Yes	N/A
Scenario E (no pumping in seawater intrusion management area, ~75% reduction in LAS pumping from Oxnard Plain [excluding the Forebay] and Pleasant Valley basins, ~150% increase in UAS pumping)	69,300	N/A	Yes	Yes	Yes	Yes	Yes	N/A

Notes:

N/A = Not applicable. As described in Section 4, lowering of groundwater levels is assumed in this evaluation to be the common metric used to establish each of the assumed minimum thresholds for the other five sustainability indicators, and surface-water flows do not appear to be affected by pumping from the UAS or LAS to a substantial degree.

“Partially” effective, for the purpose of this evaluation, means sufficient rises in groundwater to achieve target groundwater levels in a substantial fraction (at least one-fourth) of the study area, based on qualitative review of model results.

5.5 CONCLUSIONS

Based on the analyses and discussion presented above, the key conclusions of this evaluation are as follows:

1. Comprehensive target groundwater levels are used in this evaluation to represent the assumed minimum thresholds for each SGMA sustainability indicator, effectively comprising a single usable and effective metric for each aquifer (or aquifer system) and management area
2. As a result of past actions by the FCGMA, United, Calleguas Municipal Water District, cities and individual well owners, groundwater elevations in the UAS across much of the Oxnard Plain and Pleasant Valley basins have generally risen since the 1980s, and are near or above target levels much of the time, except in the vicinity of Mugu Lagoon. However, groundwater elevations in the LAS remain below target levels most of the time across much of the Oxnard Plain and Pleasant Valley basins (currently more than 150 ft below sea level in some areas). Therefore, groundwater elevations in the LAS are typically farther below target groundwater levels than are groundwater elevations in the UAS.
3. In the southern Oxnard Plain and Pleasant Valley basins, where groundwater elevations are historically lowest, target groundwater levels would need to be highest, primarily as a result of the assumed minimum thresholds for seawater intrusion. Therefore, prevention of seawater intrusion is a primary driver for pumping reductions aimed at achieving sustainable yield. When groundwater elevations rise sufficiently to limit or reverse seawater intrusion along the coast, they are typically higher than target groundwater levels and assumed minimum thresholds for the other sustainability indicators throughout the Oxnard Plain and Pleasant Valley basins under the reduced-pumping scenarios considered in this evaluation.
4. In order to achieve target groundwater levels with minimal cuts in pumping (maximizing sustainable yield), assumed pumping reductions were focused in the LAS rather than the UAS, and in both aquifer systems near the coast where seawater intrusion is known to enter the aquifers via the Hueneme and Mugu submarine canyons. Groundwater flow modeling conducted by United as part of this evaluation generally corroborated these potential approaches to achieving sustainable yield, with the following caveats:

- Reducing, or even eliminating, pumping solely in the area along the coast that has been impacted by past saline water intrusion (the assumed seawater intrusion management area) cannot, by itself, raise groundwater elevations in the LAS above target levels (thereby stopping seawater intrusion). Some pumping reductions are required further inland in the Oxnard Plain and Pleasant Valley basins in order to achieve target groundwater levels in the seawater intrusion management area.
- Although vertical hydraulic conductivity between the UAS and LAS is generally low, it is sufficient to allow significant movement of groundwater between the two aquifer systems over a large area. Therefore, rising groundwater levels in the LAS (resulting from reduced

pumping at wells screened in the LAS) would cause a corresponding, although muted, rise in groundwater levels in the UAS as the vertical gradient between the aquifer systems is reduced. Model results suggest that reducing pumping solely in the LAS would raise groundwater elevations in the UAS above target groundwater levels across most of the study area, with the exception of the assumed seawater intrusion management area. In fact, groundwater elevations in the UAS were forecasted to rise high enough above target levels under Scenarios D and E to allow ***increased*** pumping from the UAS in some areas. Model results showed that reducing pumping in the UAS by the same percentage as in the LAS caused UAS groundwater elevations near the coast to rise well above sea level, resulting in discharge of fresh groundwater from the UAS into the Pacific Ocean.

5. Assuming that sustainable yield would be achieved solely via reductions in pumping (no new sources of water supply), and that climatic conditions, land-use changes, or regulatory issues don't change the balance of water supply and demand substantially, this evaluation concludes that the combined sustainable yield for the Oxnard Plain (including the Forebay) and Pleasant Valley basins would be approximately 60,000 to 69,000 AF/yr. The low end of this range was arrived at under two pumping scenarios (B and D) that assumed reductions in pumping chiefly in the LAS, with elimination of both UAS and LAS pumping near the coast in one of these scenarios. The high end of this range was arrived at under only one pumping scenario (E), which assumed reductions in pumping in the LAS, elimination of both UAS and LAS pumping near the coast, and ***increased*** pumping from the UAS inland from the coast. Implementation of such a pumping scheme would increase sustainable yield, but likely would require construction of new UAS wells and conveyance infrastructure to take advantage of the increased water supply from the UAS.

This evaluation was performed to estimate the combined sustainable yield for the Oxnard Plain (including the Forebay) and Pleasant Valley basins. The purpose is to provide supporting information to United's management and Board of Directors in establishing groundwater management policies that are consistent with the mission of the agency. The analyses relied on simplifying assumptions about sustainability indicators that could possibly be incorporated into FCGMA's planned GSP, future pumping patterns and land uses in the study area, and future climatic and hydrologic conditions. During the GSP development process, the FCGMA could use different assumptions, or develop other pumping scenarios that would result in higher or lower sustainable yields. However, the range of sustainable yields resulting from this evaluation are in the same order of magnitude as "annual yield" estimated as part of the FCGMA's 2007 GMP update (100,000 AF/yr combined annual yield for the Oxnard Plain, Pleasant Valley, Santa Rosa, and West/East/South Las Posas basins). Therefore, unless development of new water-supply sources is assumed, it seems probable that the FCGMA's GSP, when completed, will include a sustainable yield estimate (or range of estimates) in the same order of magnitude as the range estimated in this evaluation, unless new water-supply projects are proposed.

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FIGURES

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Figure 2.1-1. Vicinity Map.

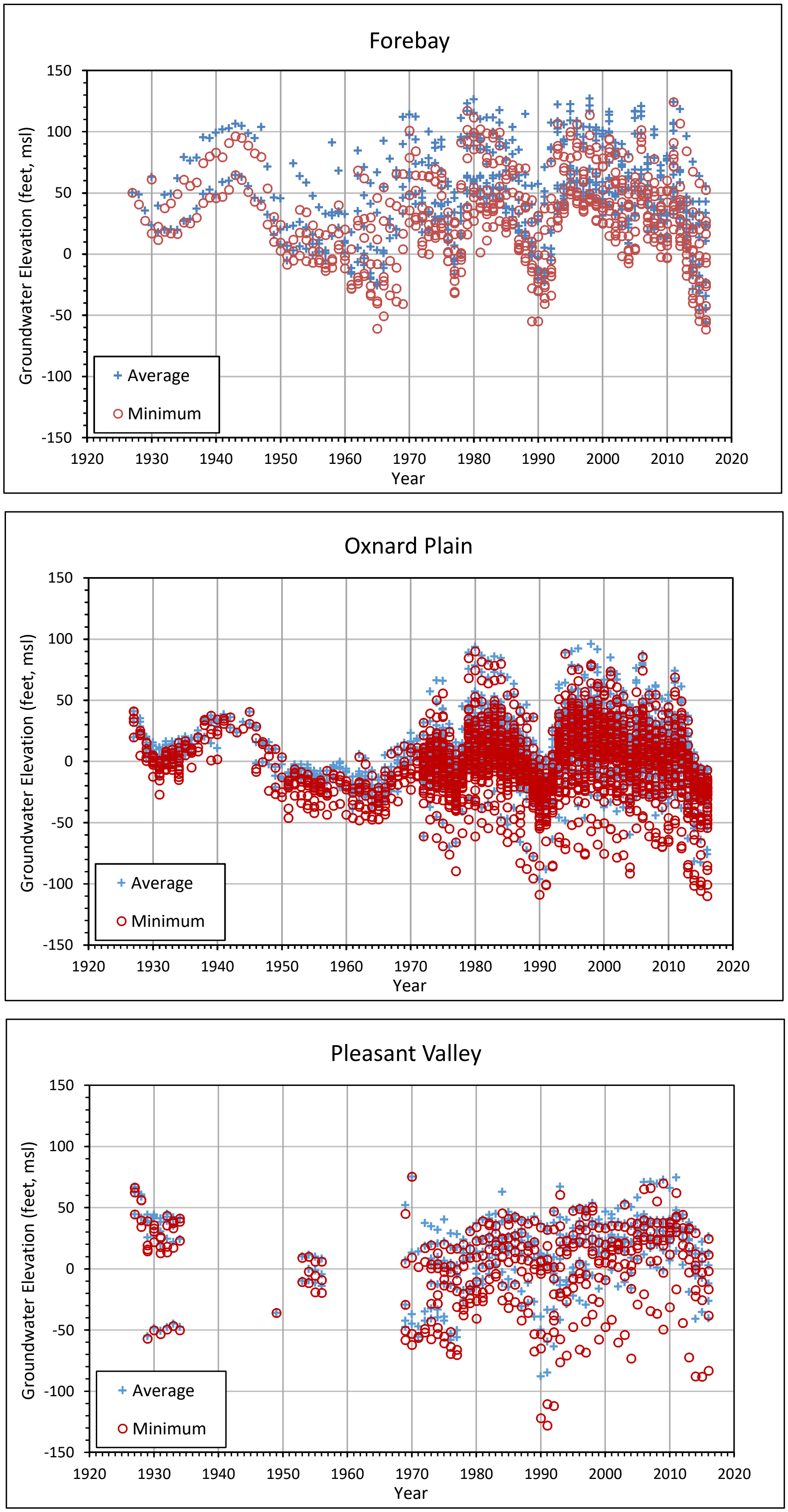


Figure 4.2-1. Average and Minimum of Reported Groundwater Elevations in the UAS for Each Public Land Survey System Section.

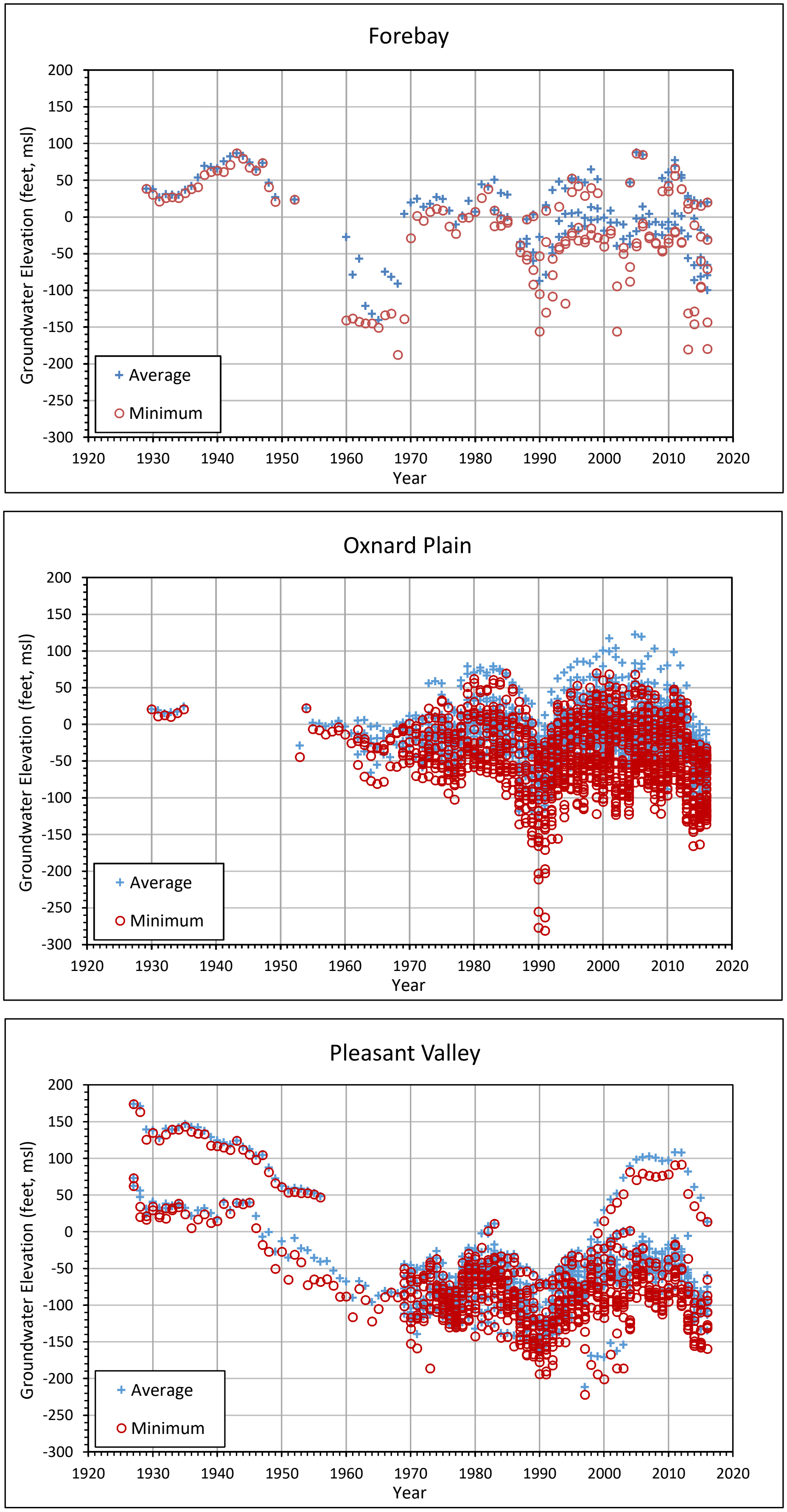


Figure 4.2-2. Average and Minimum of Reported Groundwater Elevations in the LAS for Each Public Land Survey System Section.

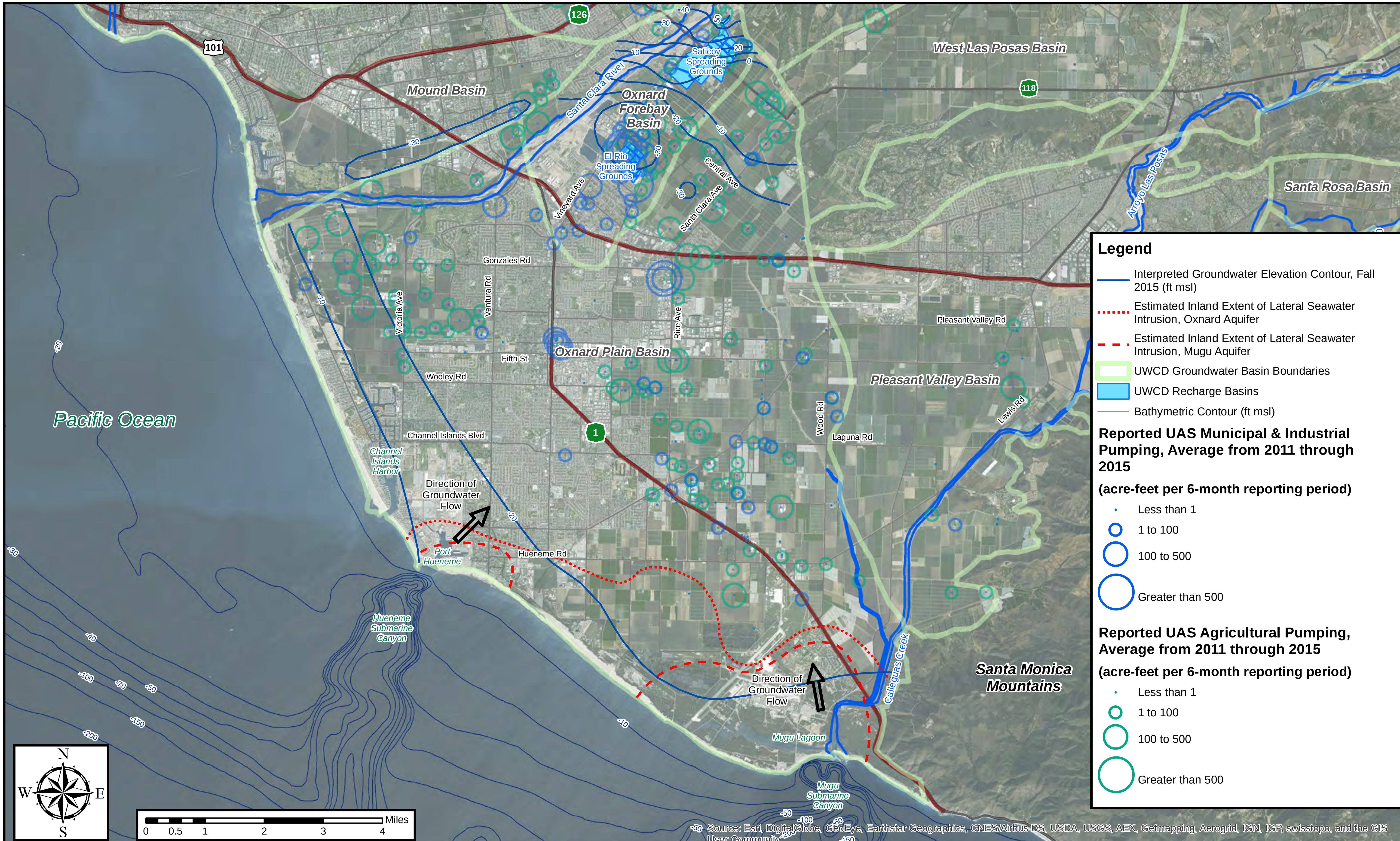


Figure 4.3-1. Seawater Intrusion Extents and Groundwater Elevations in the UAS as of Fall 2015.

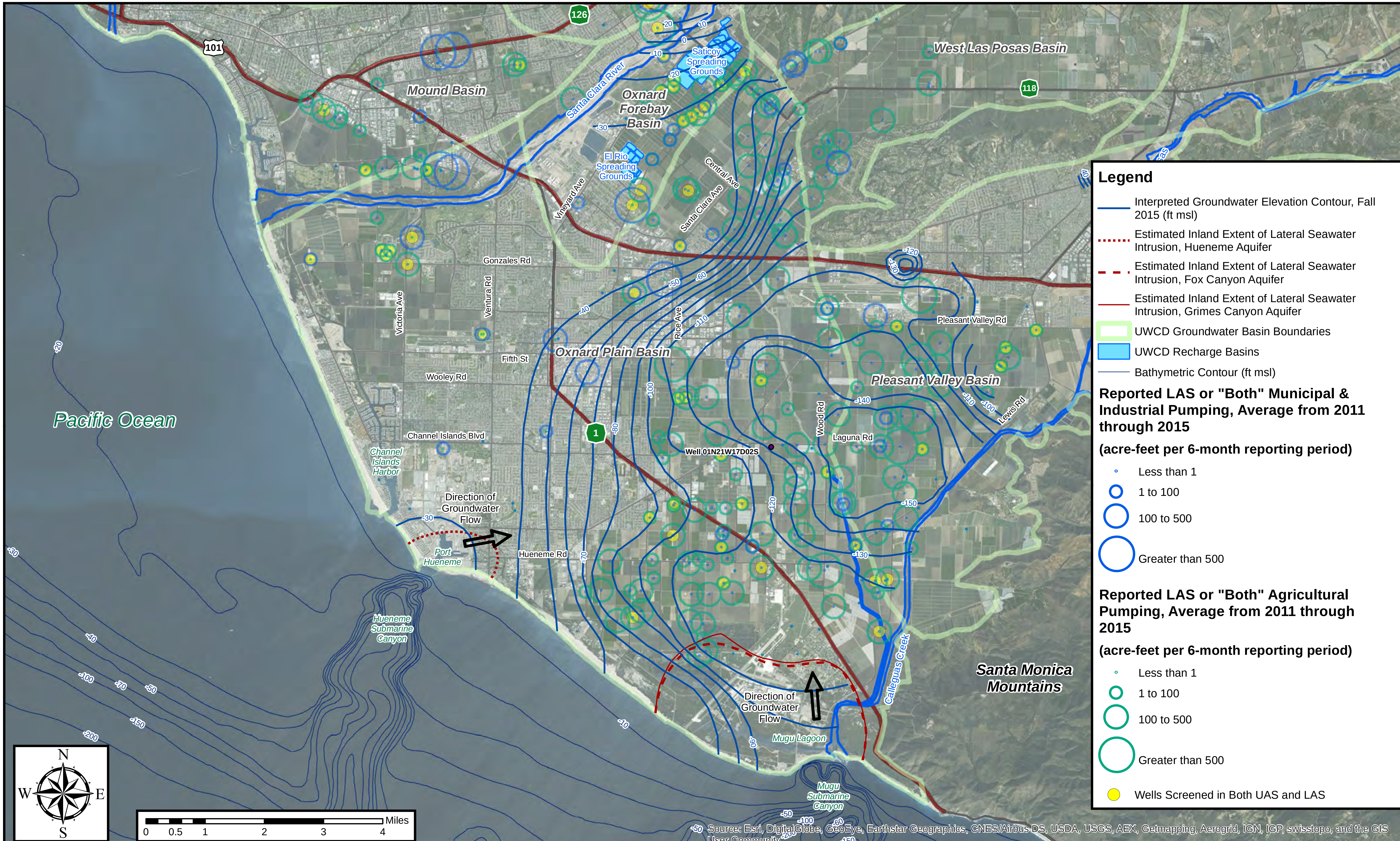


Figure 4.3-2. Seawater Intrusion Extents and Groundwater Elevations in the LAS as of Fall 2015.

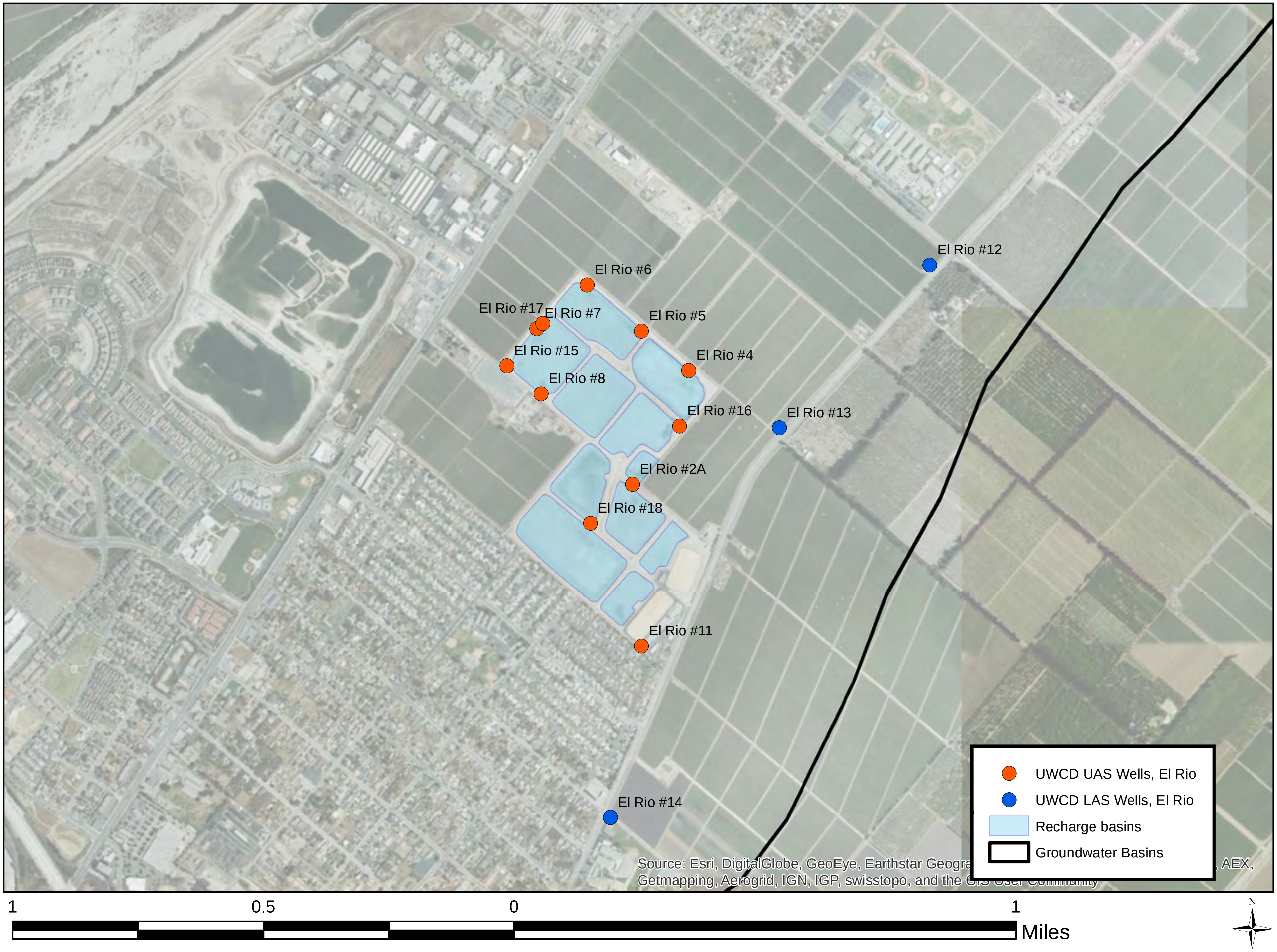


Figure 4.4-1. Map of Wells at El Rio Recharge Facility.

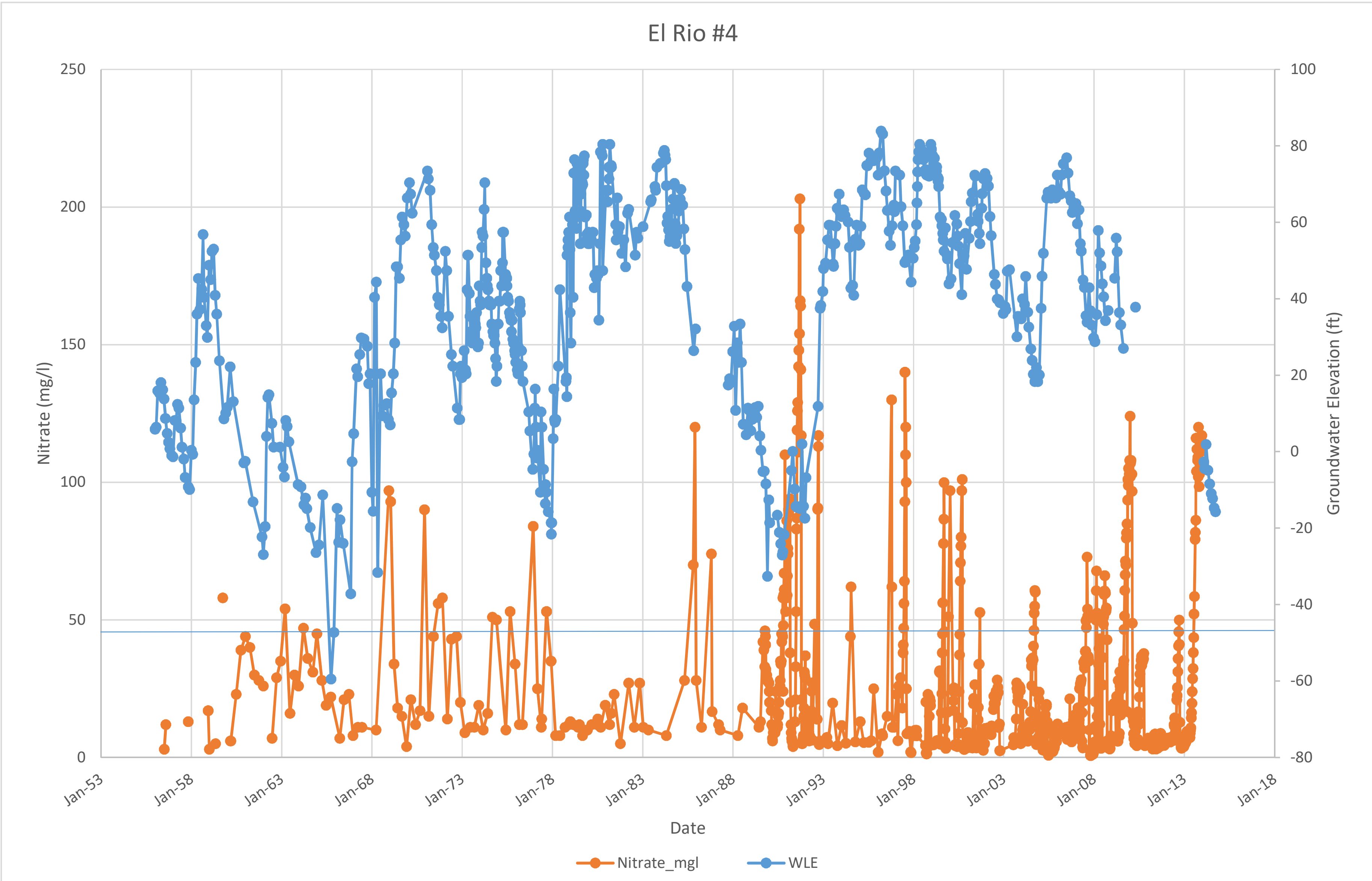


Figure 4.4-2. Time-Series Graphs of Nitrate Concentration and Groundwater Elevations at El Rio Well #4.

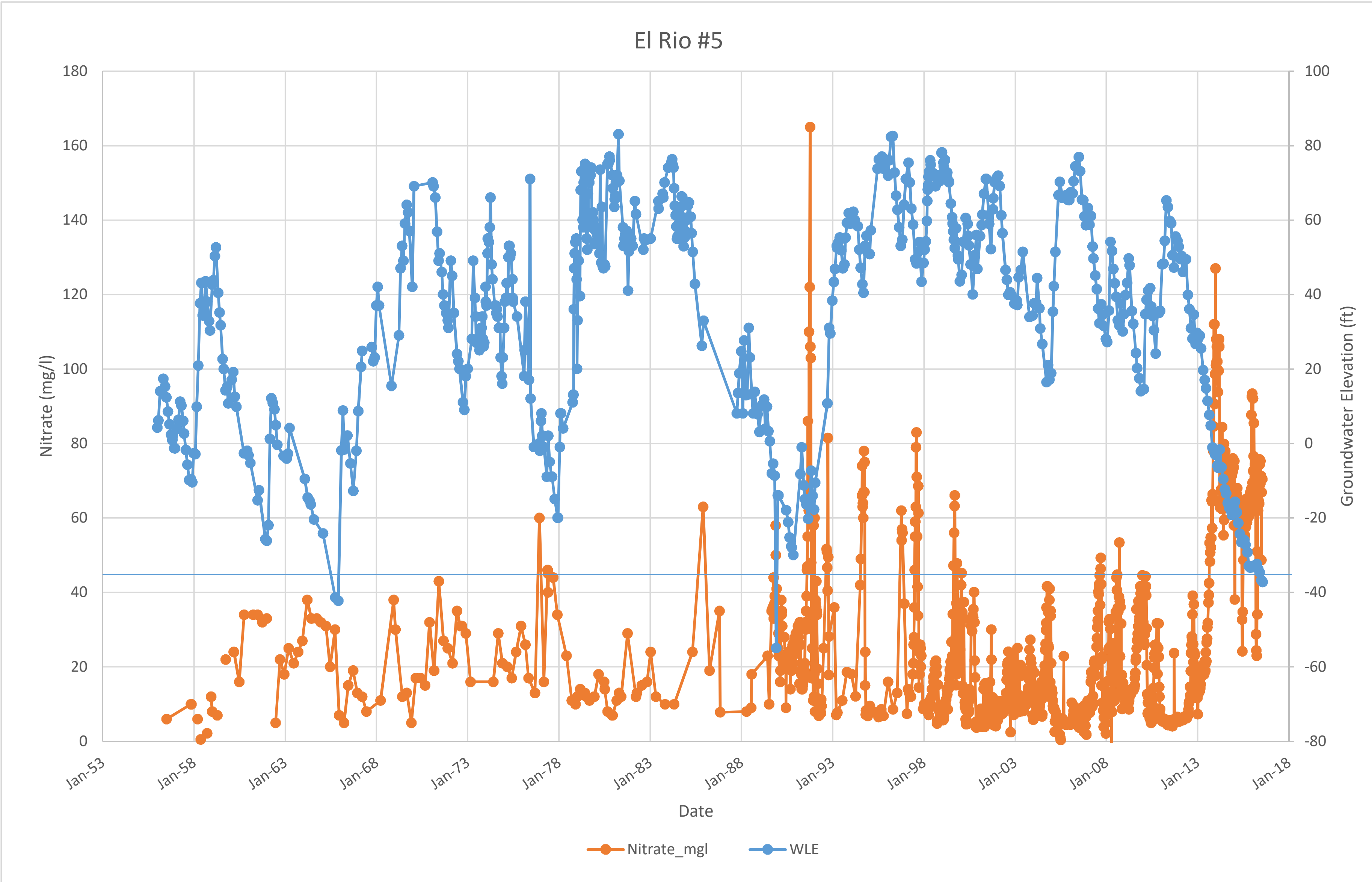


Figure 4.4-3. Time-Series Graphs of Nitrate Concentration and Groundwater Elevations at El Rio Well #5.

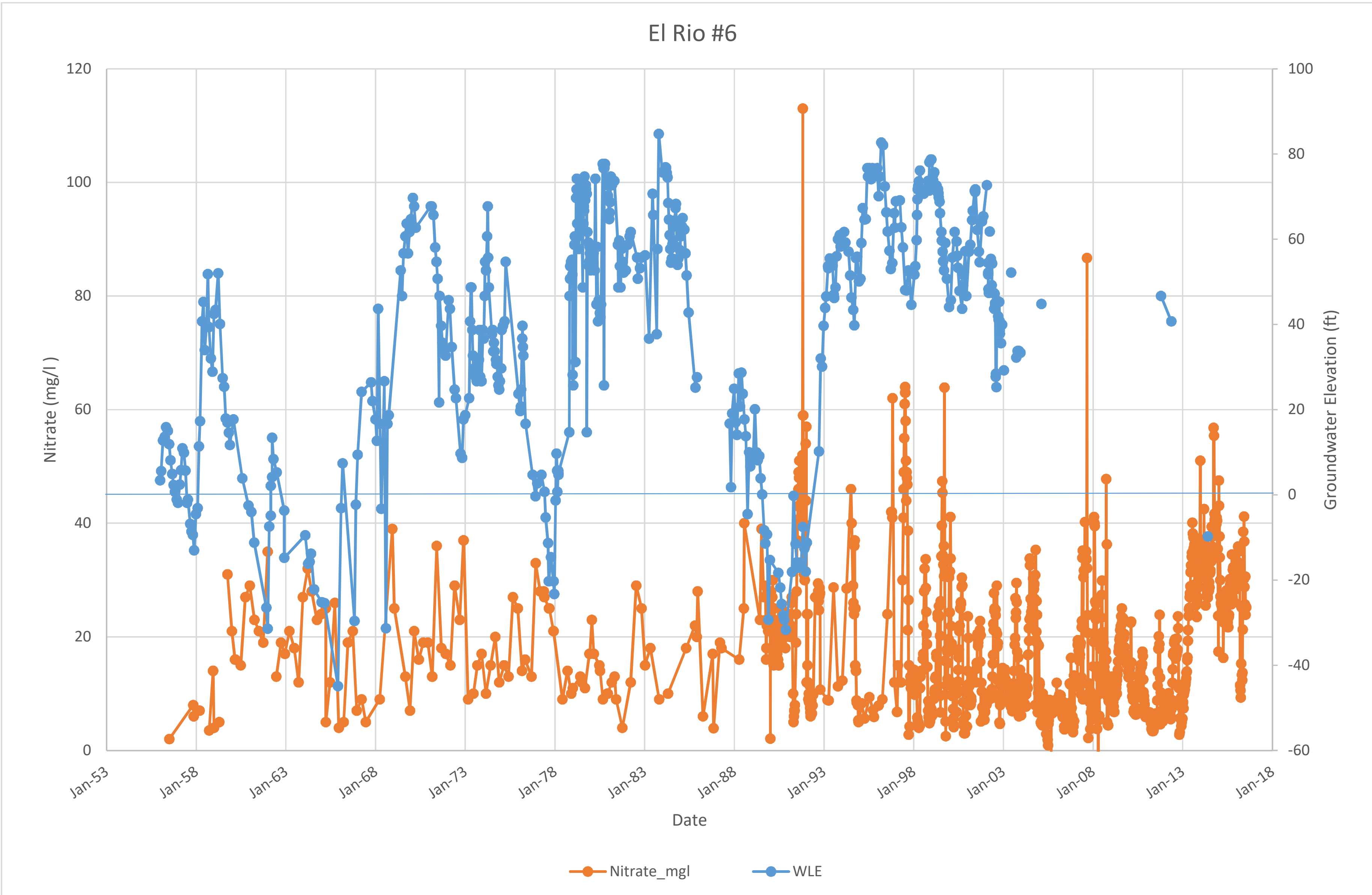


Figure 4.4-4. Time-Series Graphs of Nitrate Concentration and Groundwater Elevations at El Rio Well #6.

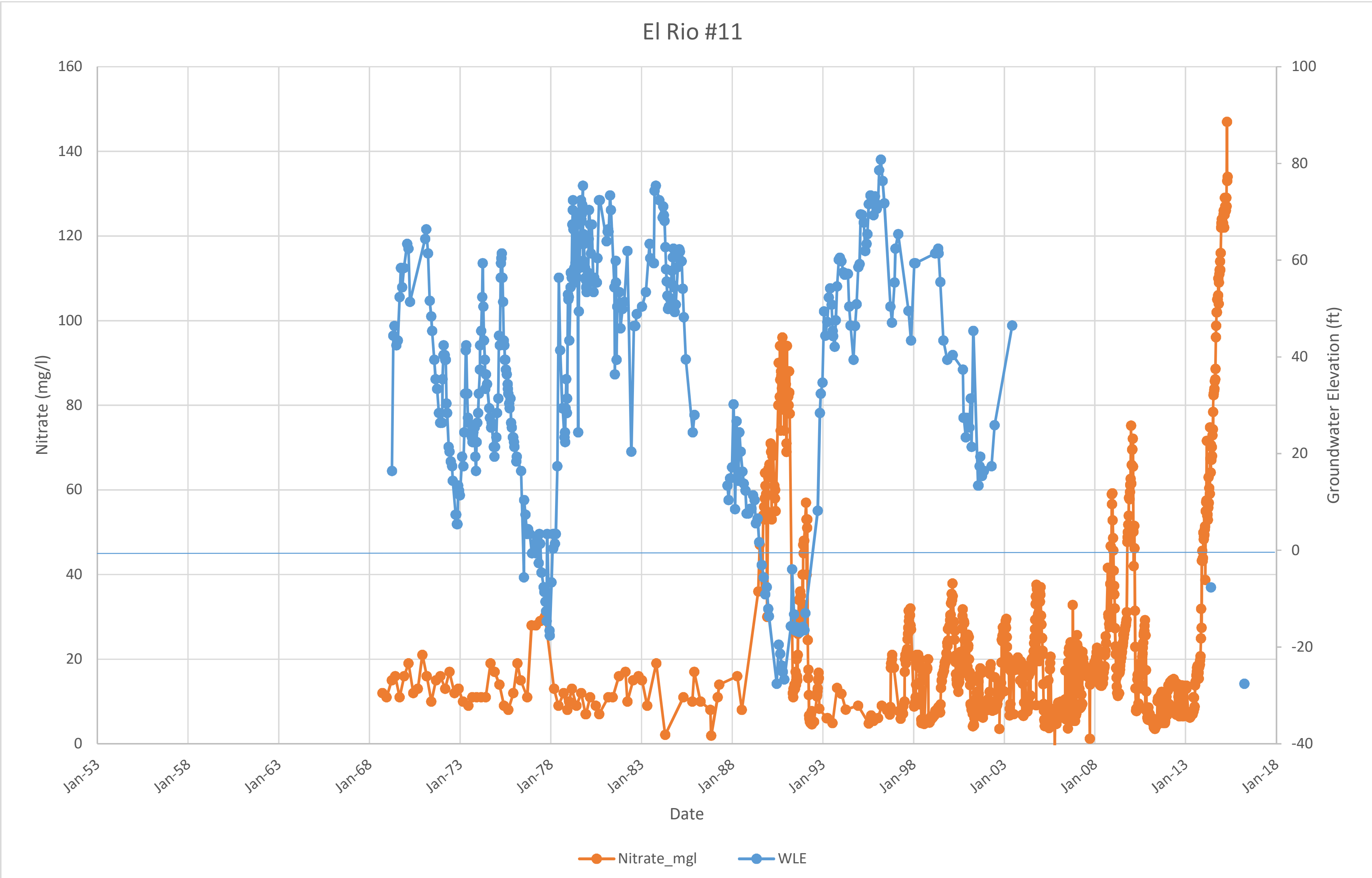


Figure 4.4-5. Time-Series Graphs of Nitrate Concentration and Groundwater Elevations at El Rio Well #11.

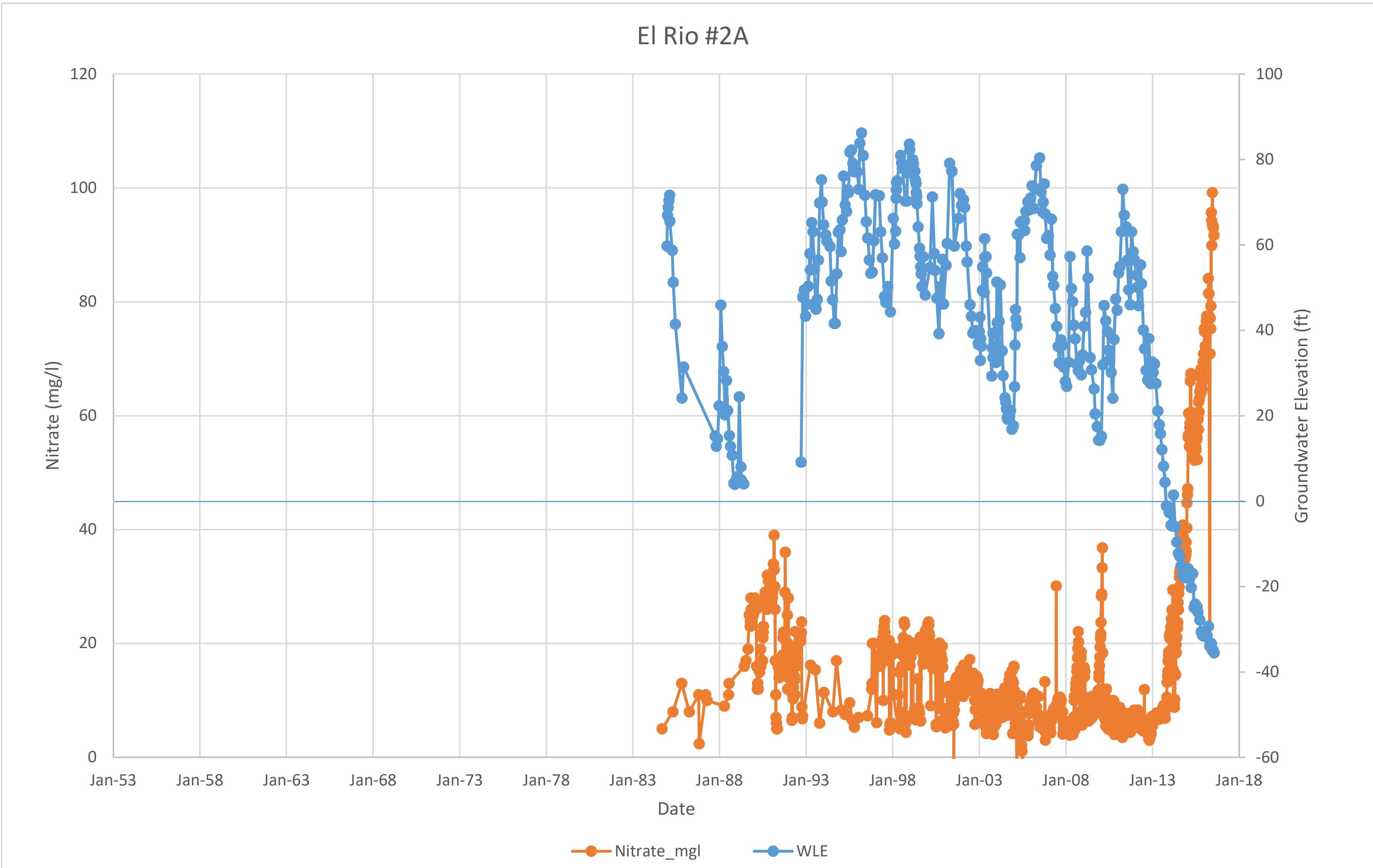


Figure 4.4-6. Time-Series Graphs of Nitrate Concentration and Groundwater Elevations at El Rio Well #2a.

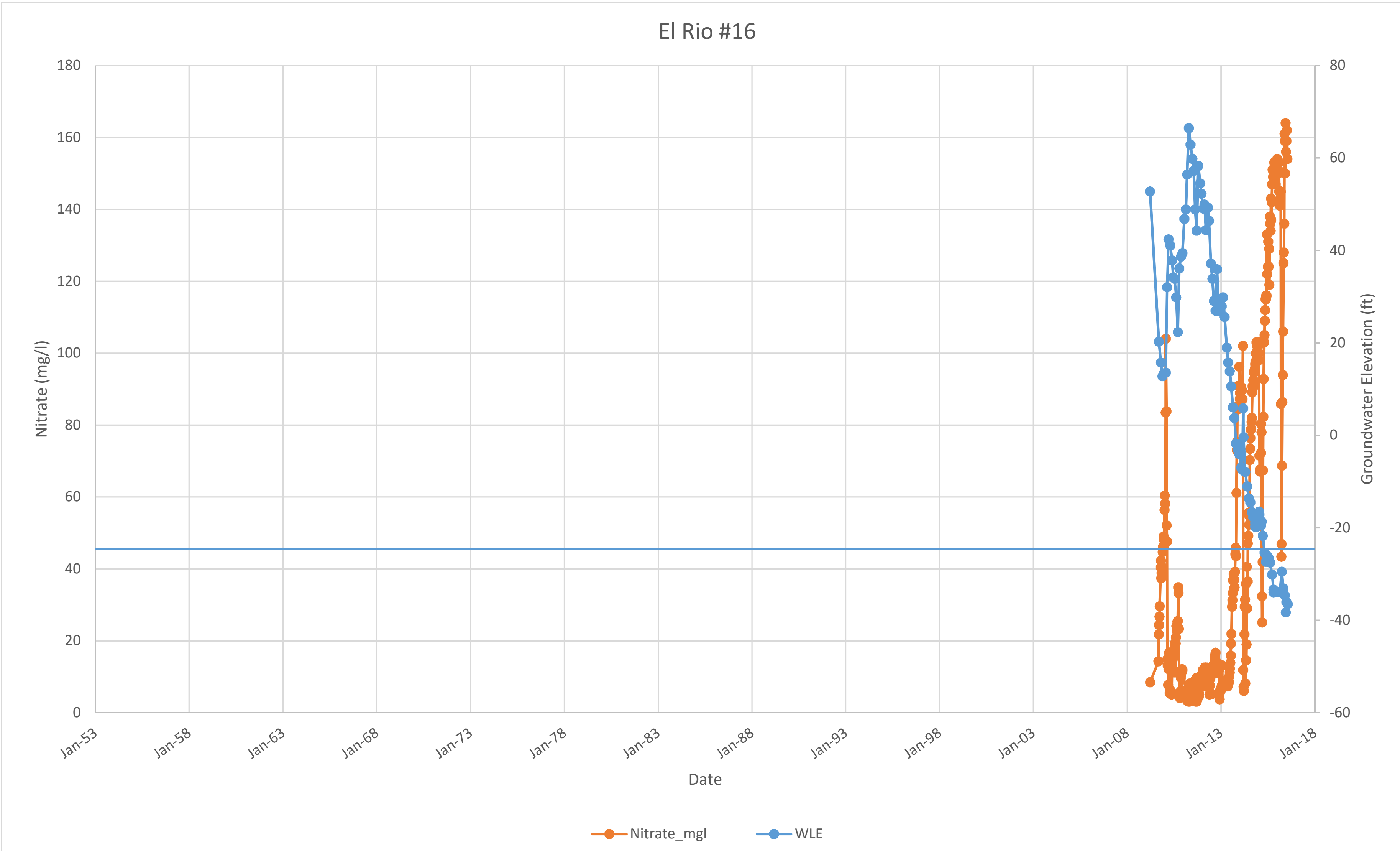


Figure 4.4-7. Time-Series Graphs of Nitrate Concentration and Groundwater Elevations at El Rio Well #16.

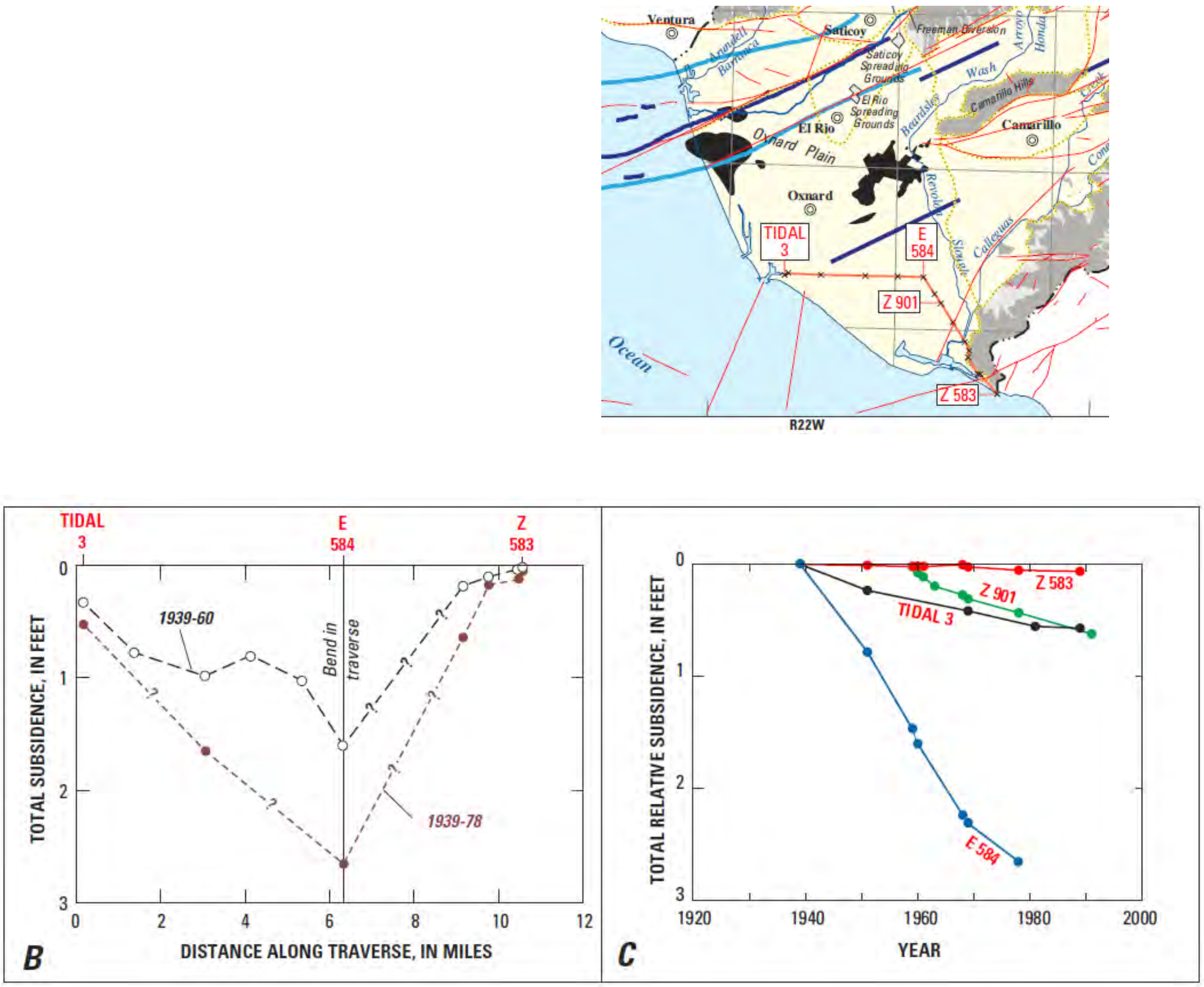


Figure 9. Subsidence in Oxnard Plain and Pleasant Valley, Santa Clara–Calleguas ground-water basin, Ventura County, California. ***A***, Geographic features. ***B***, Subsidence profile. ***C***, Subsidence of bench marks through time.

(from Hanson et al, 2003)

Figure 4.5-1. U.S. Geological Survey Graphs of Historical Subsidence in the Oxnard Plain and Pleasant Valley Basins.

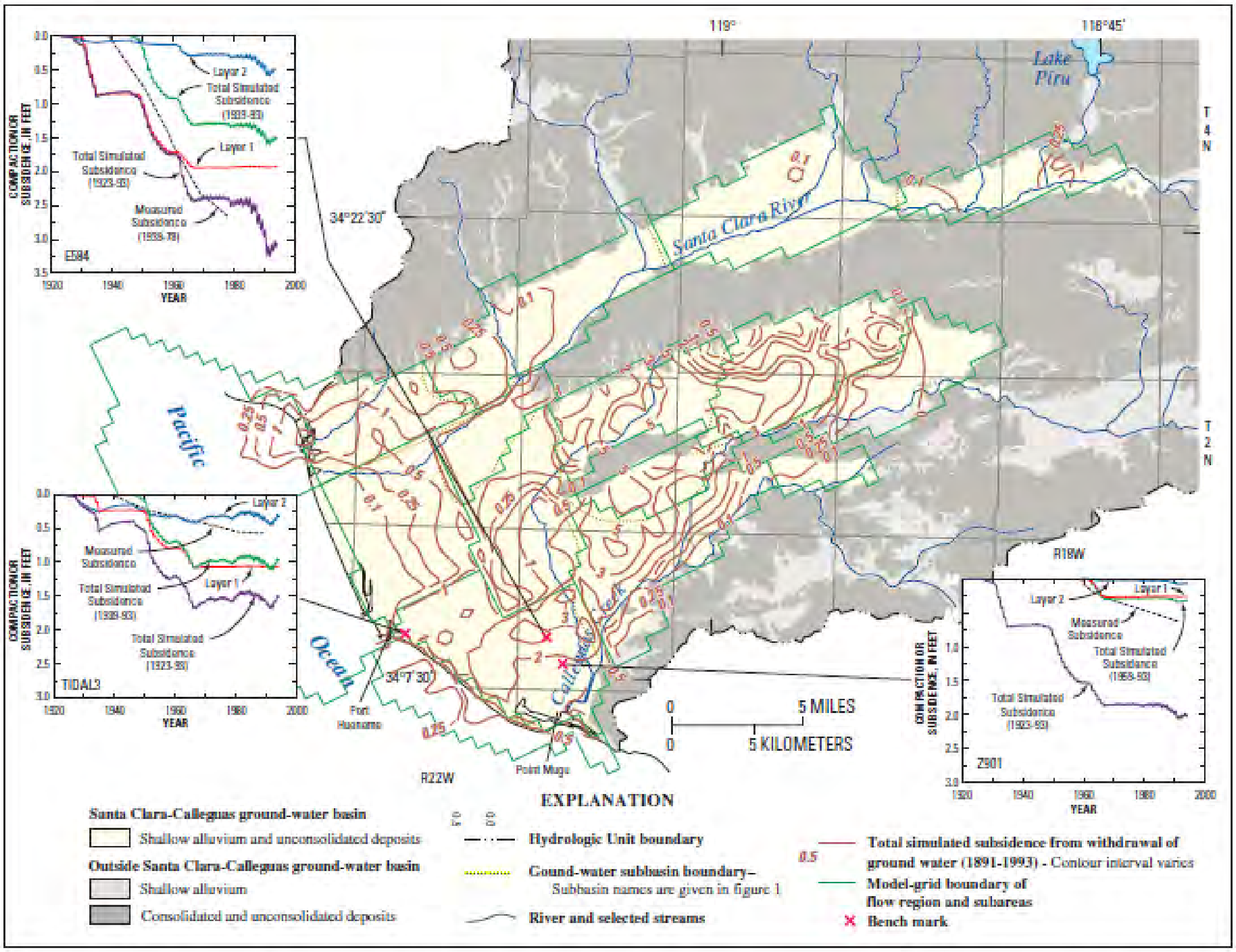
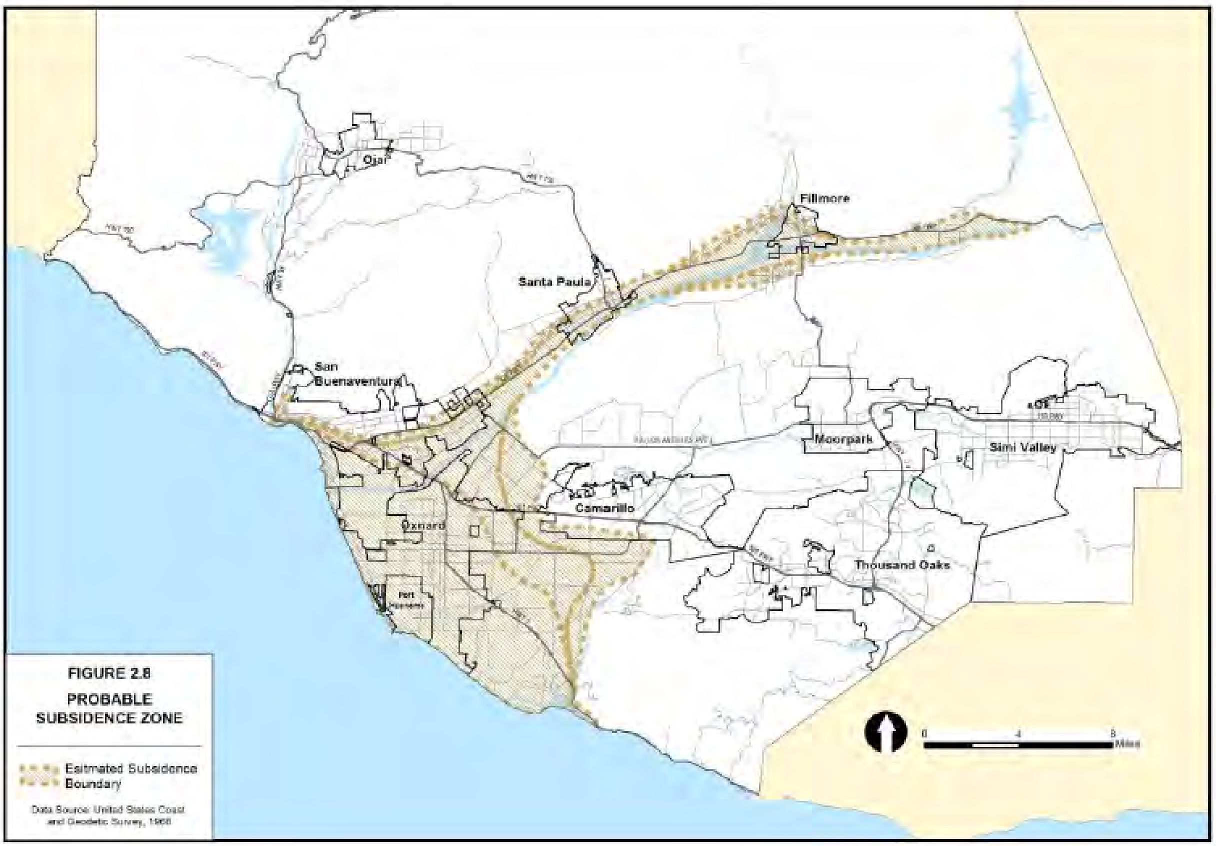


Figure 24. Simulated compaction owing to withdrawal of ground water, 1891–1993, in the Santa Clara–Calleguas ground-water basin, Ventura County, California, and locations of selected bench marks and related measured and simulated bench-mark trajectories.

(from Hanson et al, 2003)

Figure 4.5-2. U.S. Geological Survey Map of Simulated Historical Subsidence in the Oxnard Plain and Pleasant Valley Basins.



(from Ventura County General Plan, 2013)

Figure 4.5-3. Map of Ventura County's Estimated "Probable Subsidence Zone" in the Oxnard Plain and Pleasant Valley Basins.

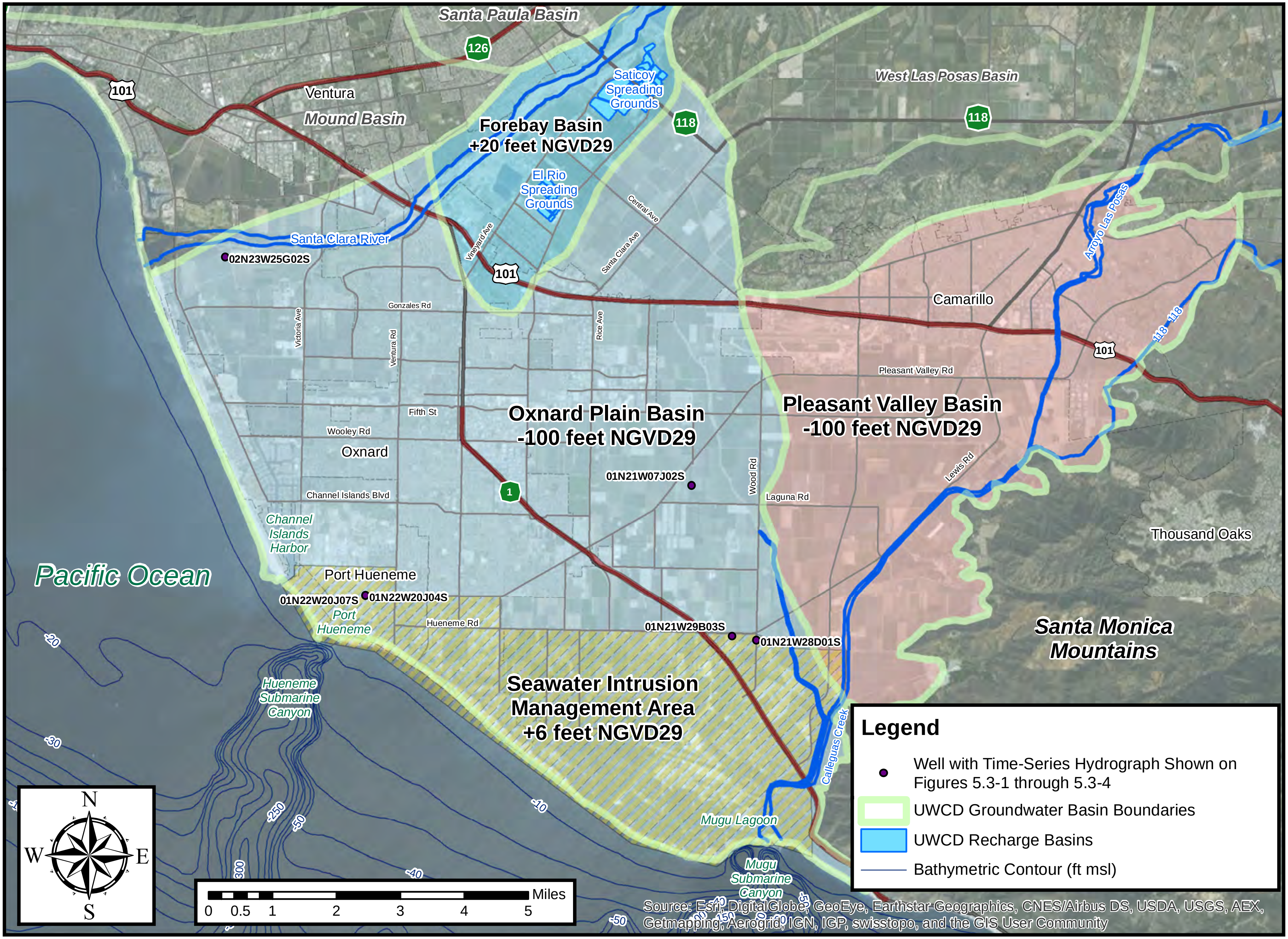


Figure 5.1-1. Target Groundwater Levels, UAS.

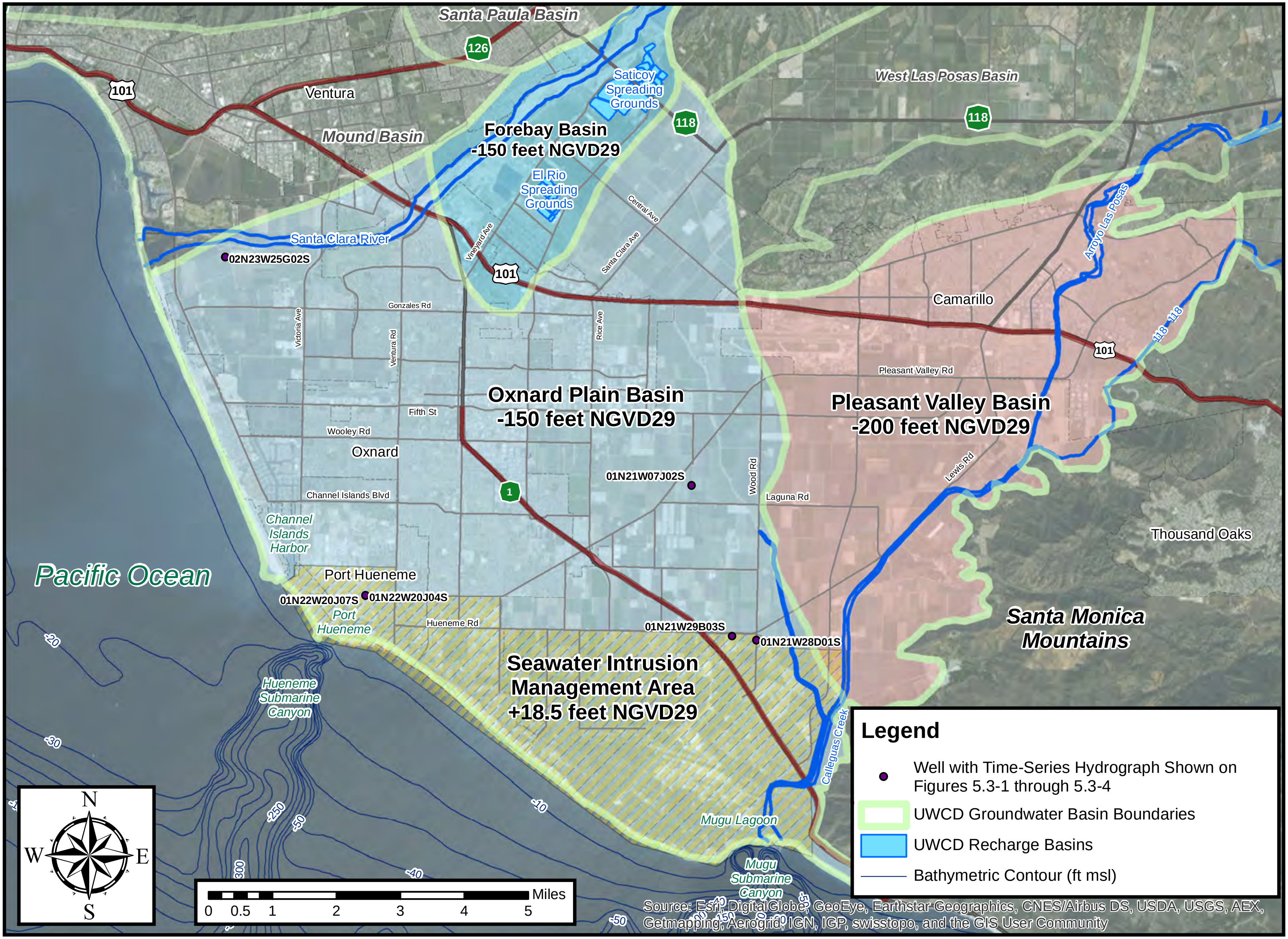


Figure 5.1-2. Target Groundwater Levels, LAS.

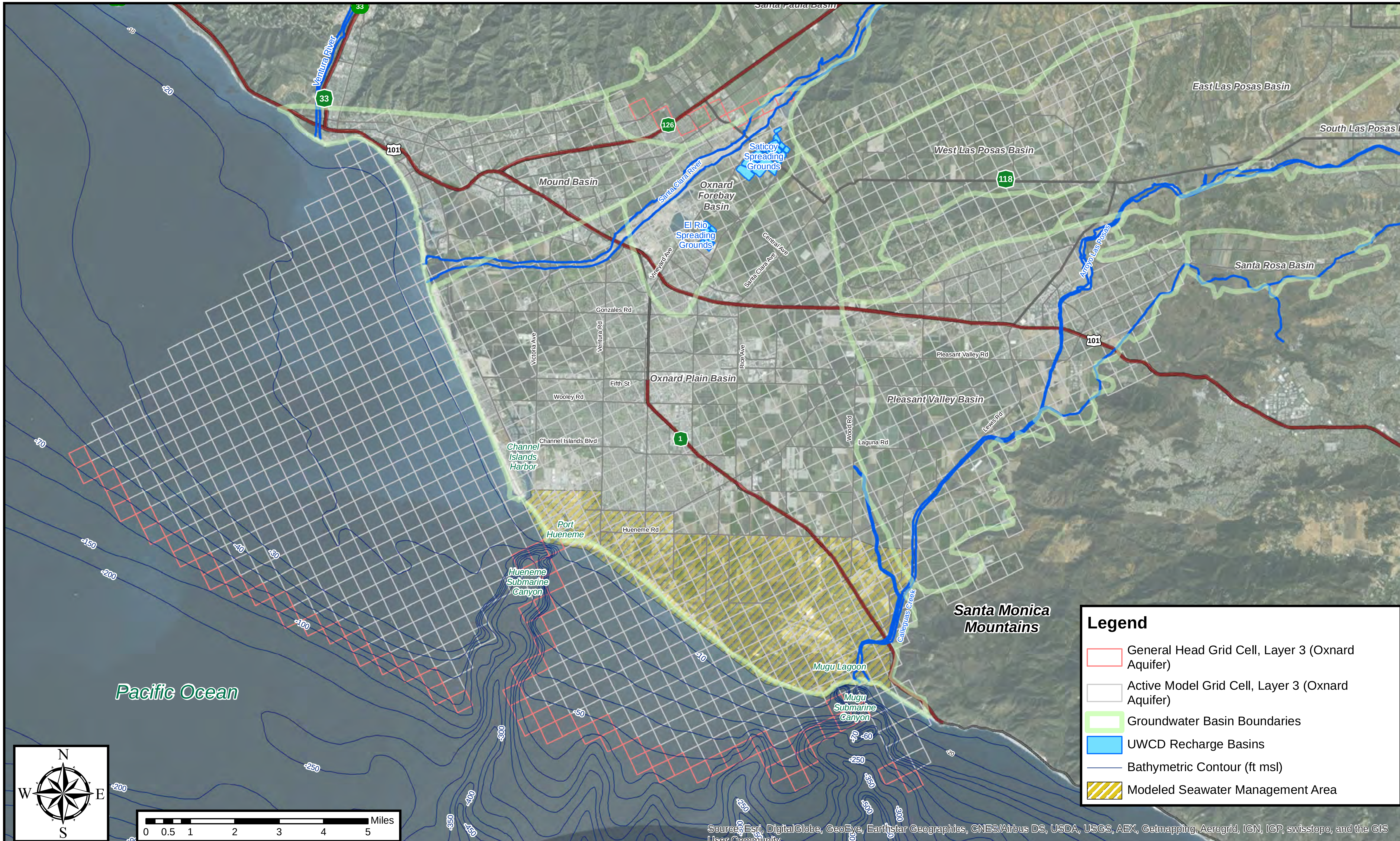


Figure 5.2-1. Active Model Grid Area, Layer 3 (Oxnard Aquifer).

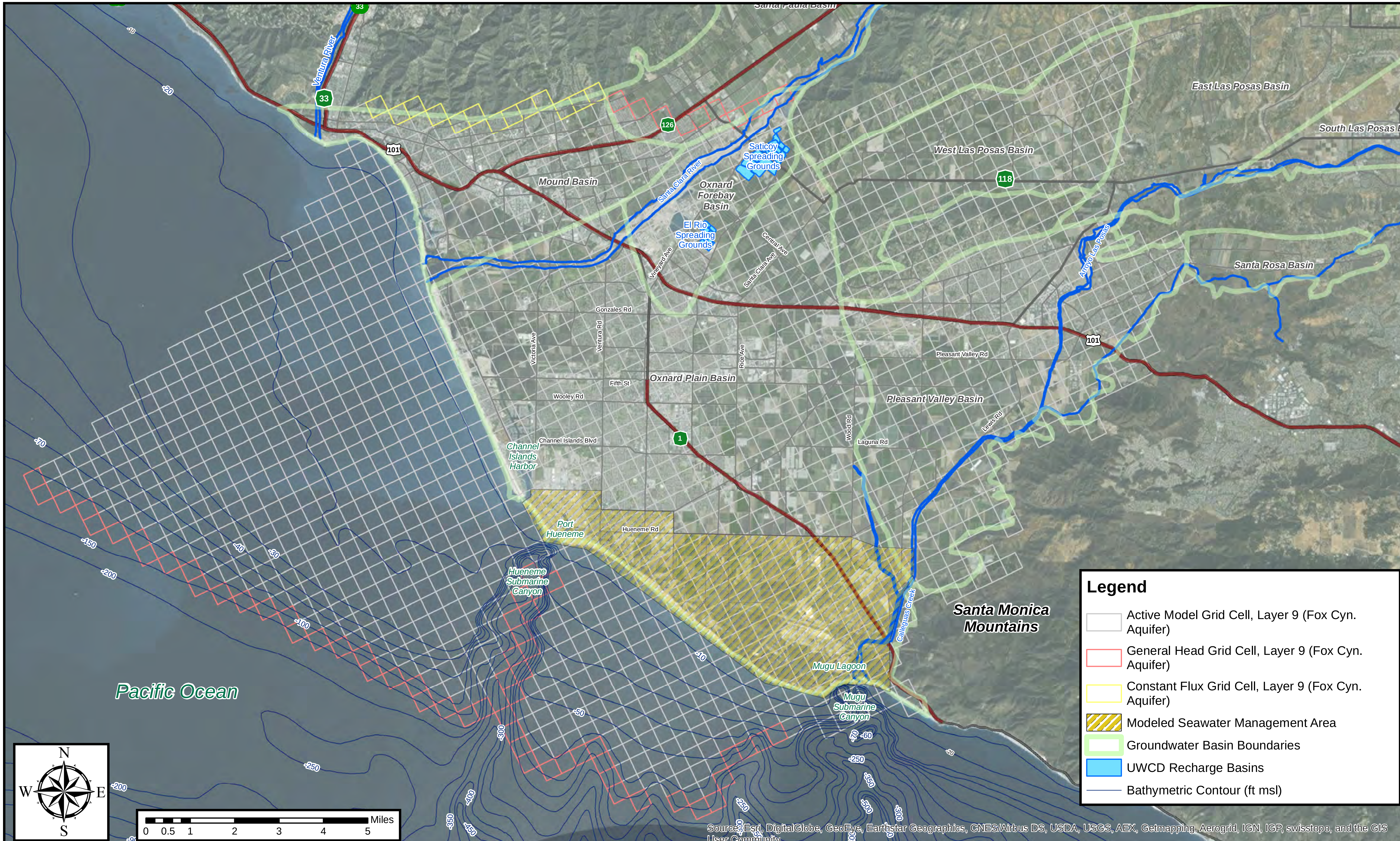


Figure 5.2-2. Active Model Grid Area, Layer 9 (Fox Canyon Aquifer).

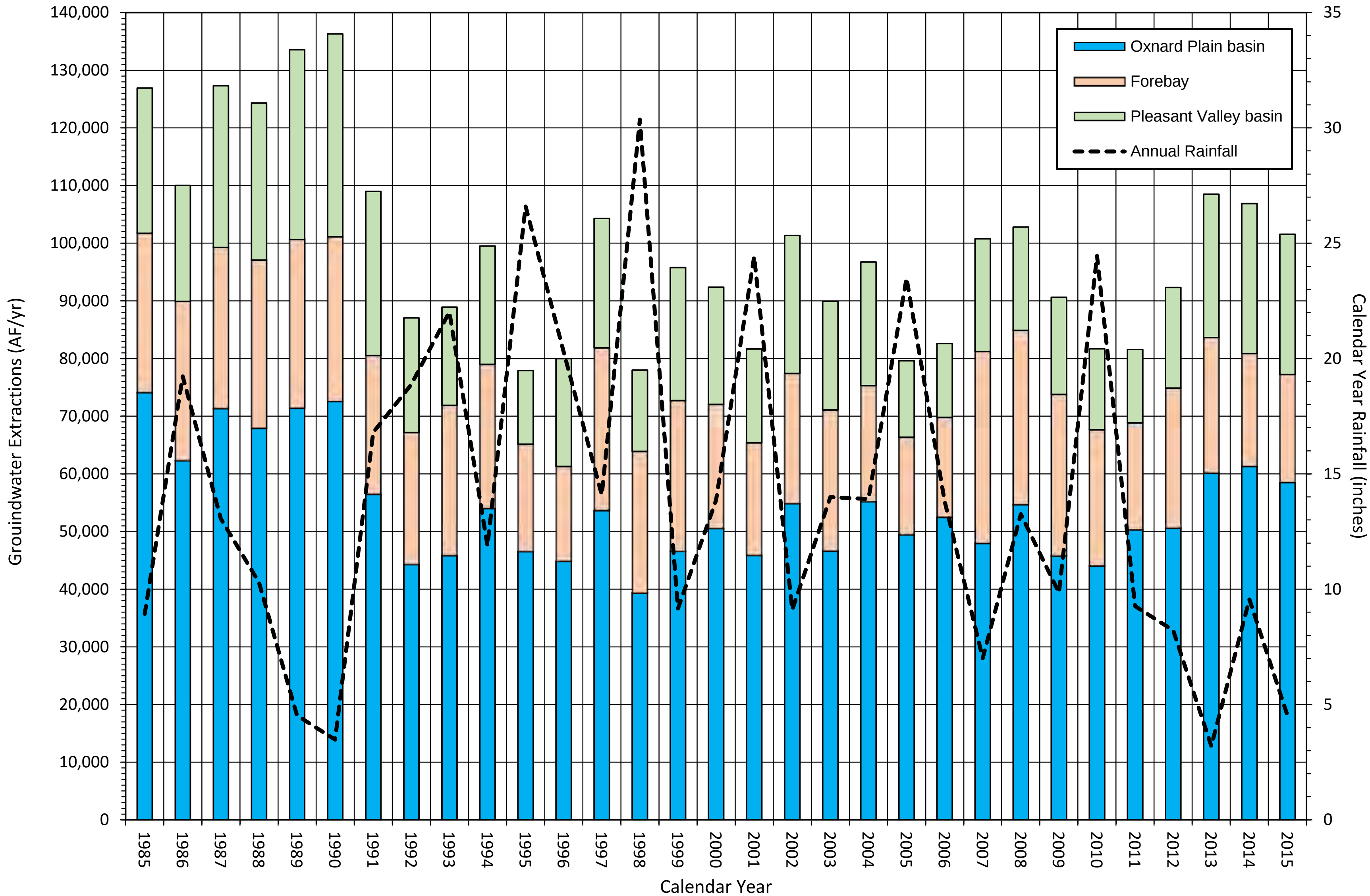
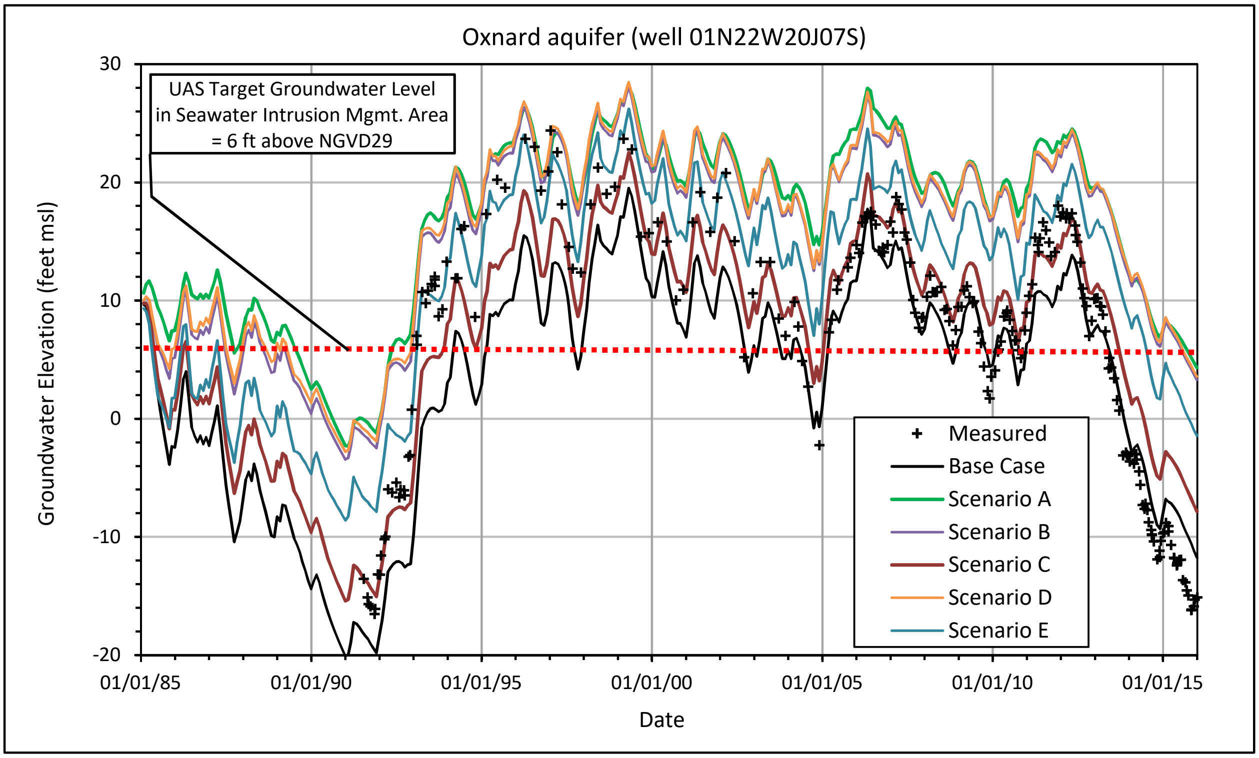


Figure 5.2-3. Annual Groundwater Extractions in Study Area and Rainfall Reported at Oxnard Airport, 1985-2015.



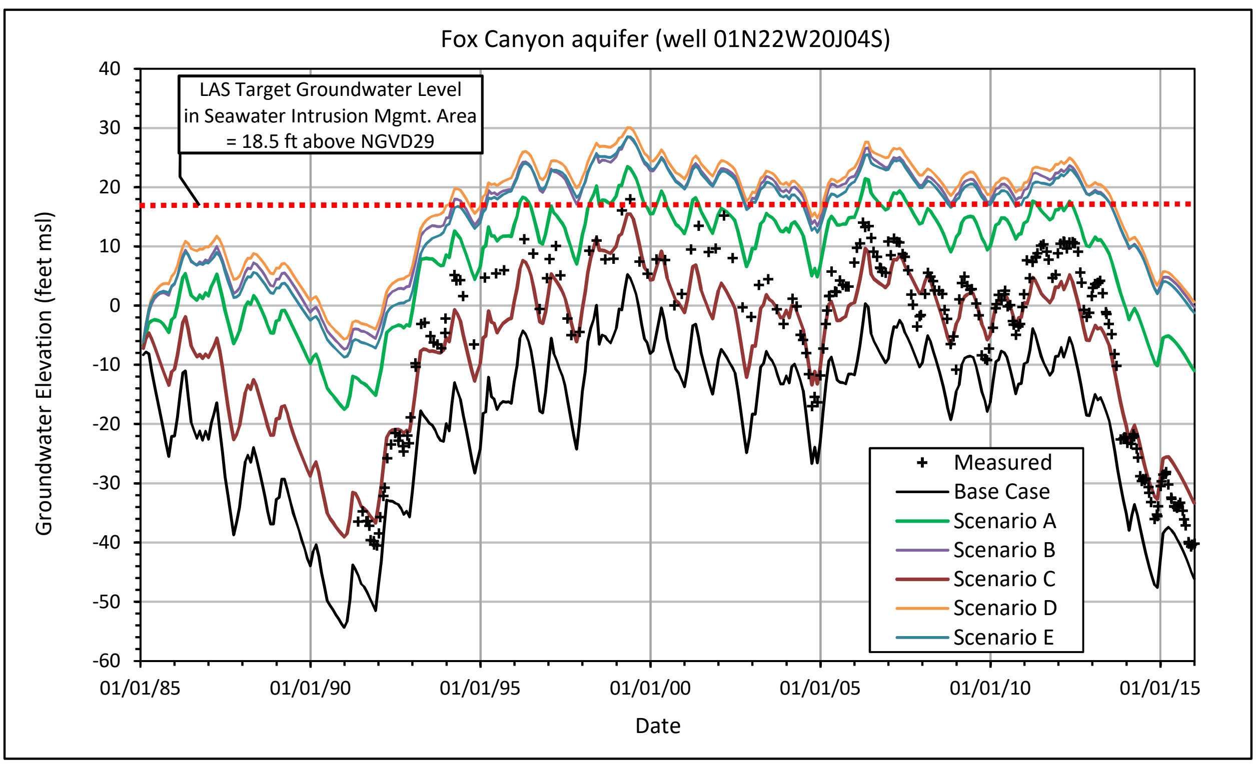
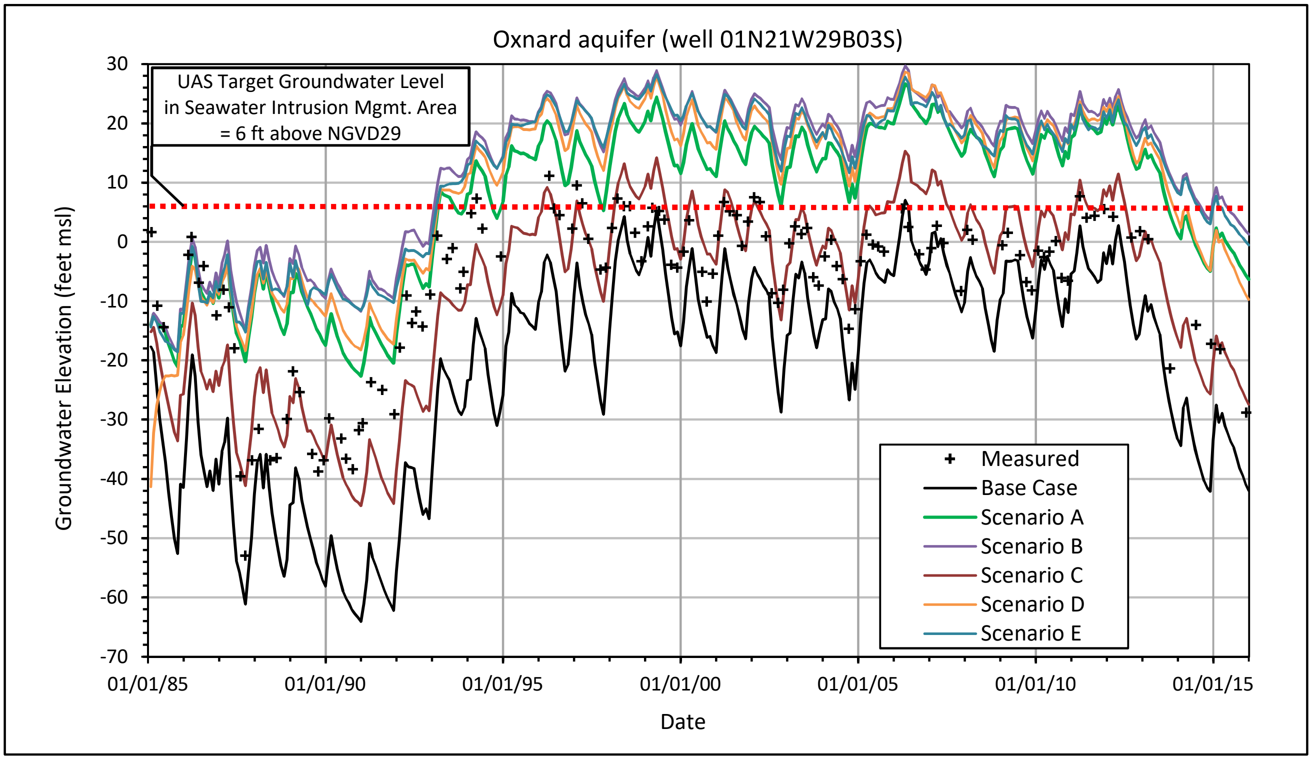


Figure 5.3-1. Time-Series Hydrographs of Simulated Groundwater Levels in Port Hueneme Area.



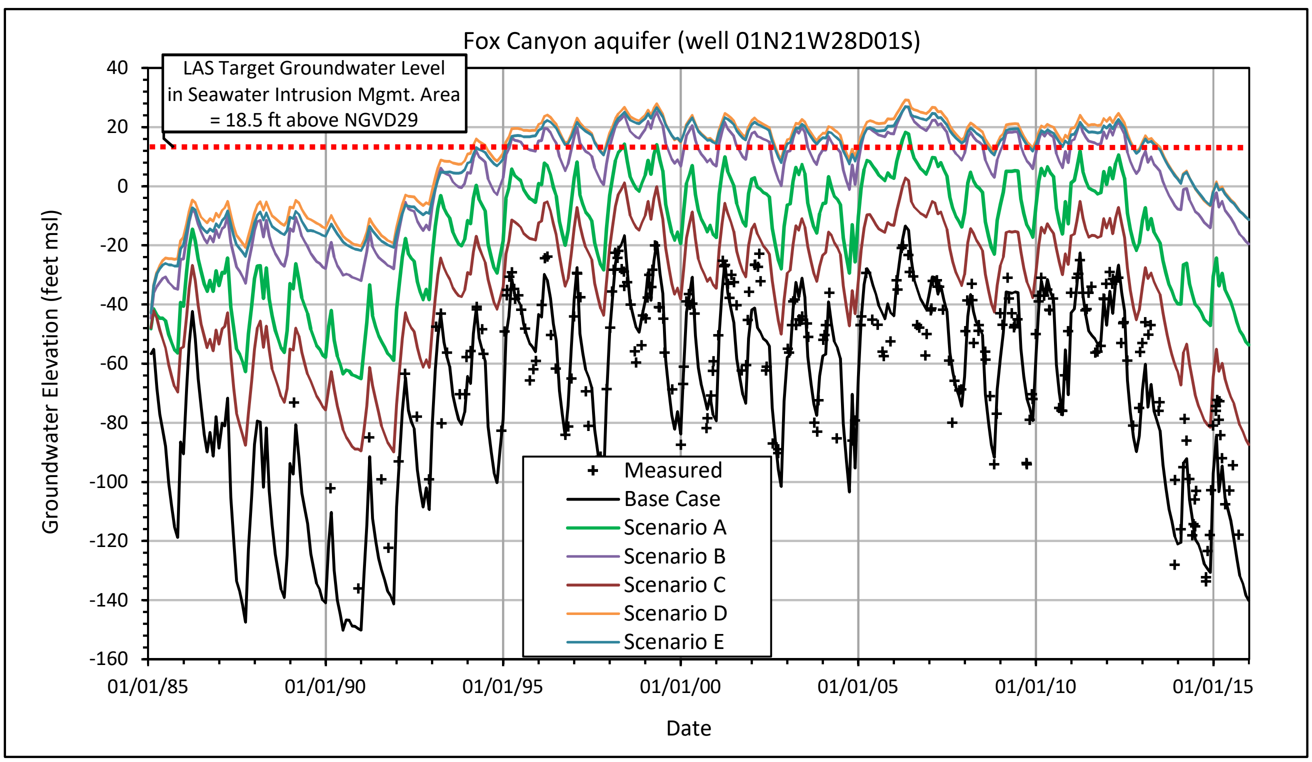


Figure 5.3-2. Time-Series Hydrographs of Simulated Groundwater Levels in Mugu Lagoon Area.

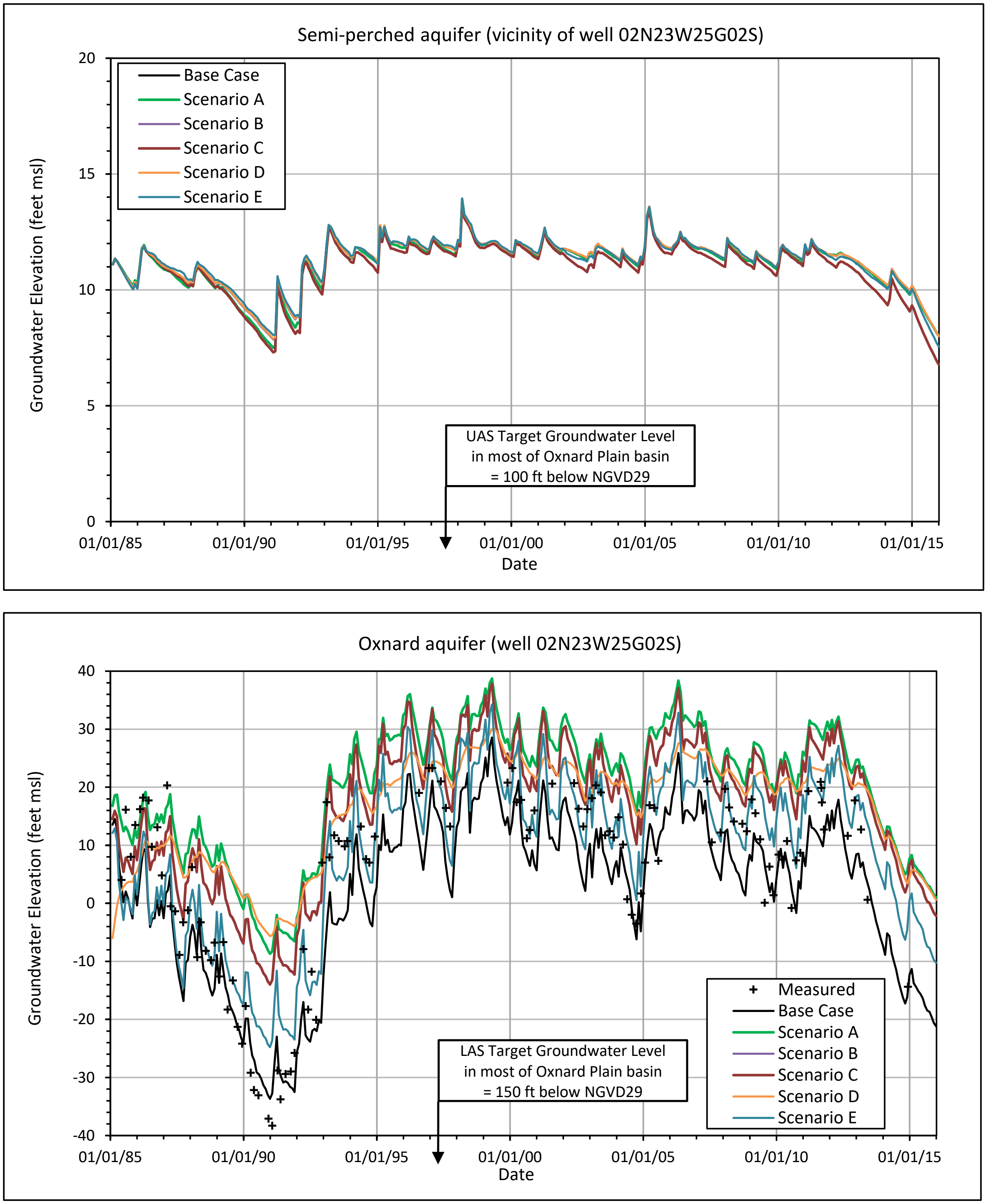
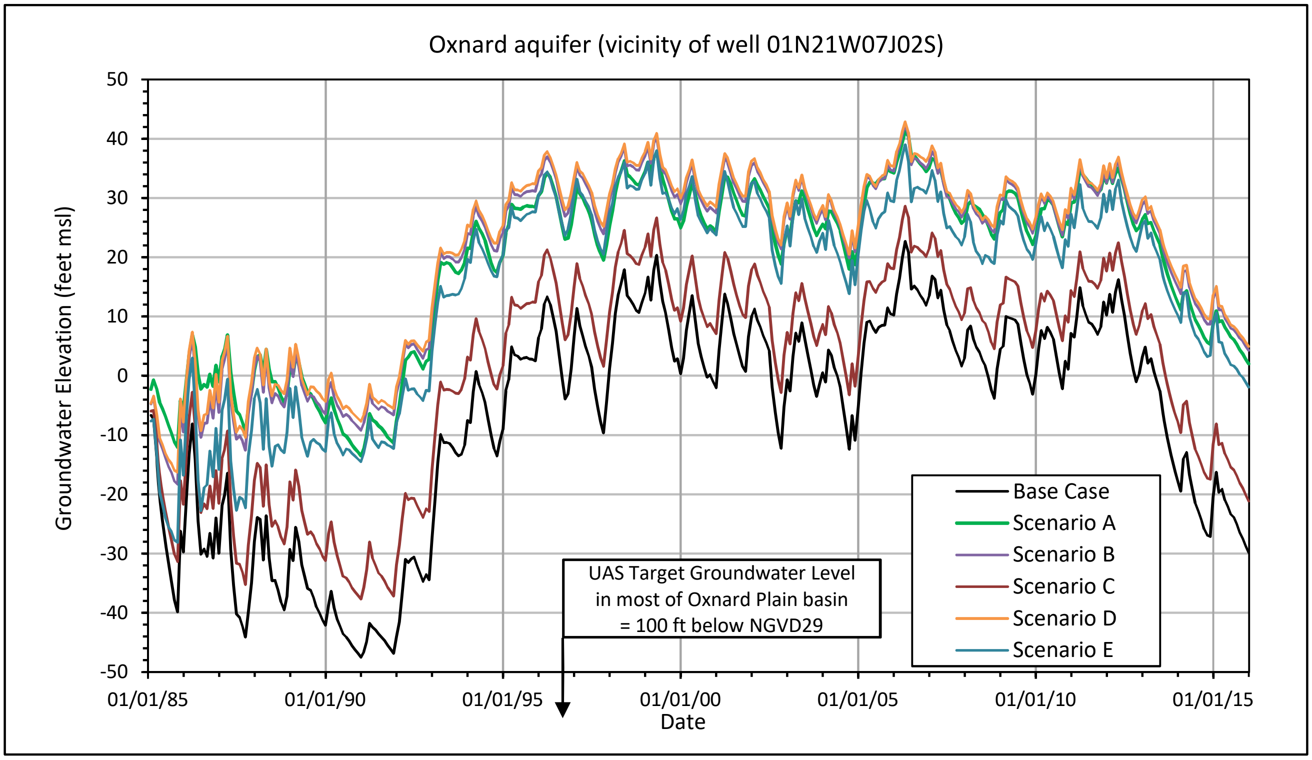


Figure 5.3-3. Time-Series Hydrographs of Simulated Groundwater Levels in Northwestern Oxnard Plain near Santa Clara River.



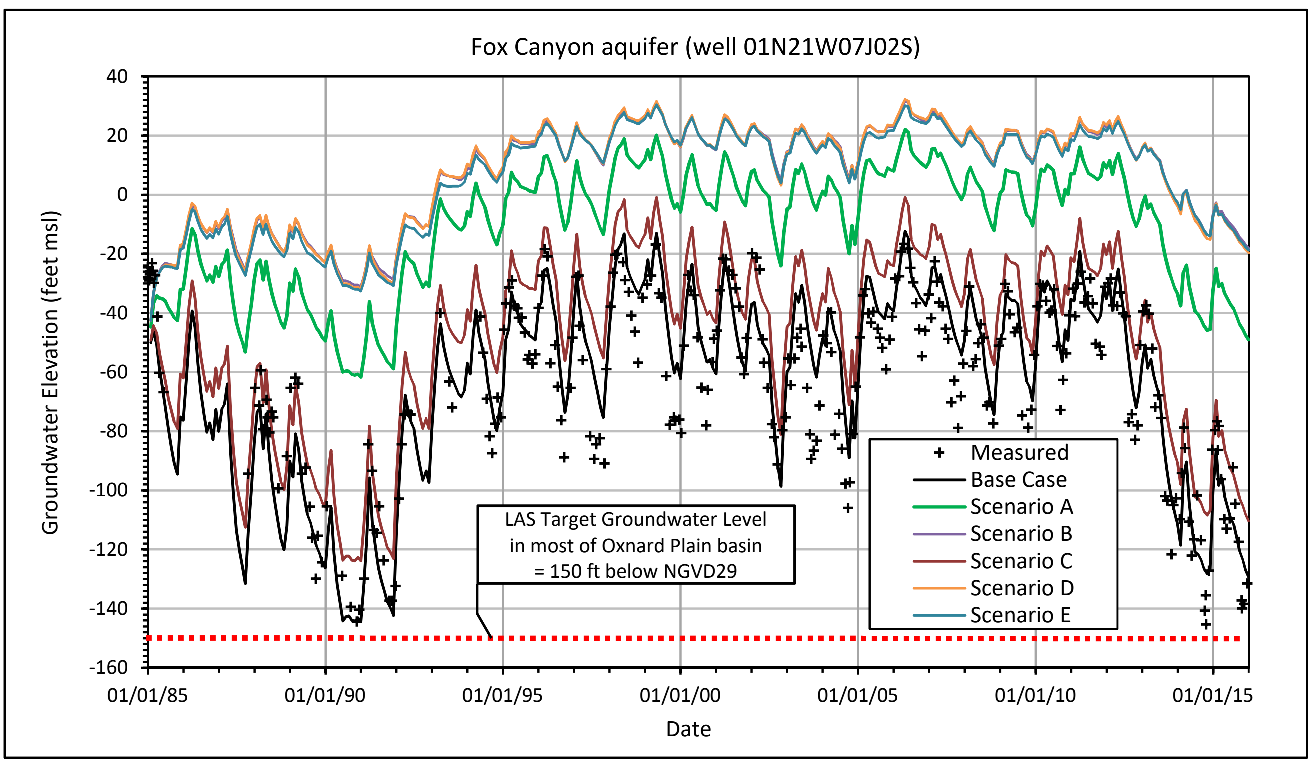


Figure 5.3-4. Time-Series Hydrographs of Simulated Groundwater Levels in Eastern Oxnard Plain Basin near Boundary with Pleasant Valley Basin.

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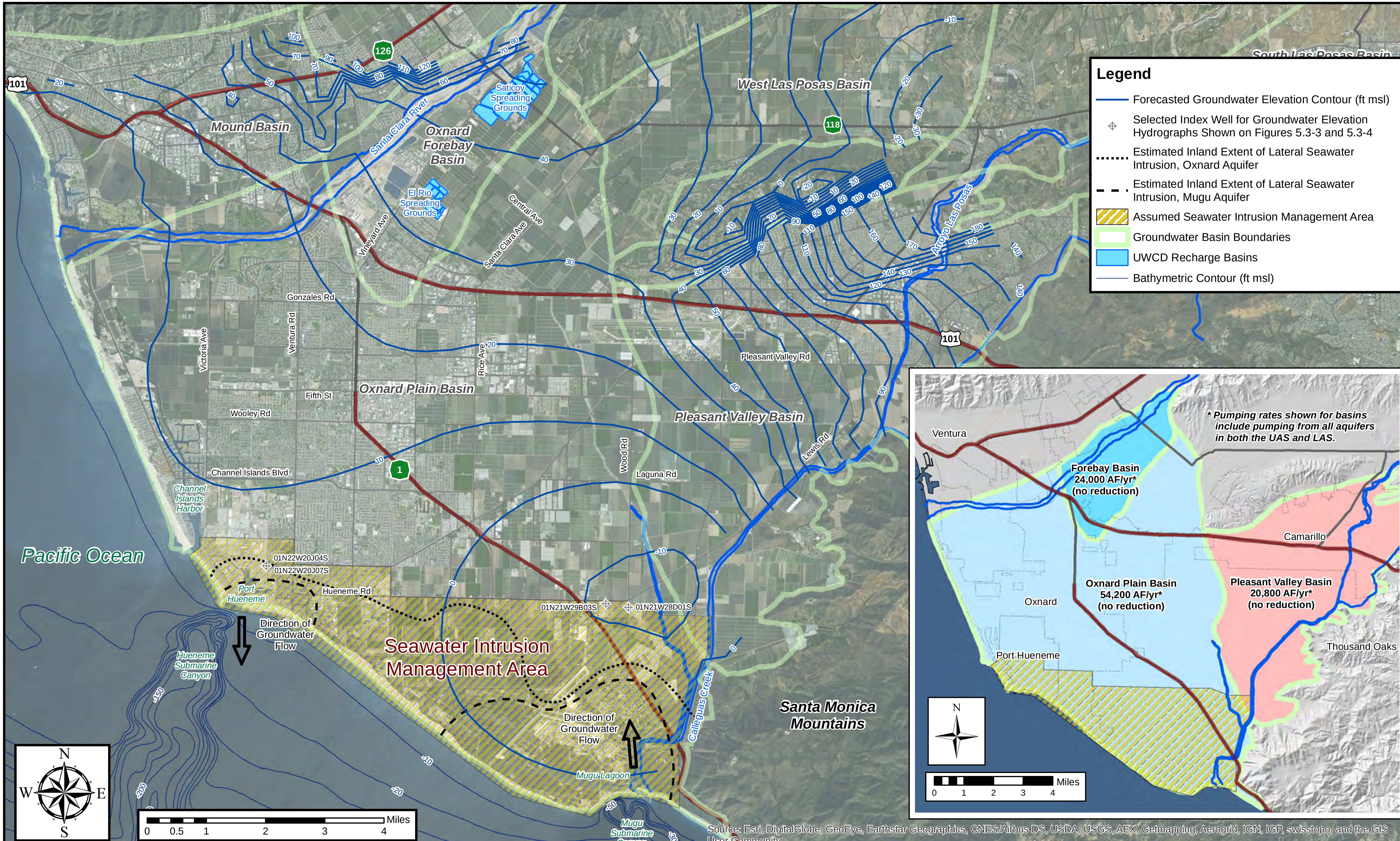

Figure 5.3-5. Simulated Groundwater Elevations in Oxnard Aquifer Under Base Case Pumping Scenario, Typical Water-Year Conditions.

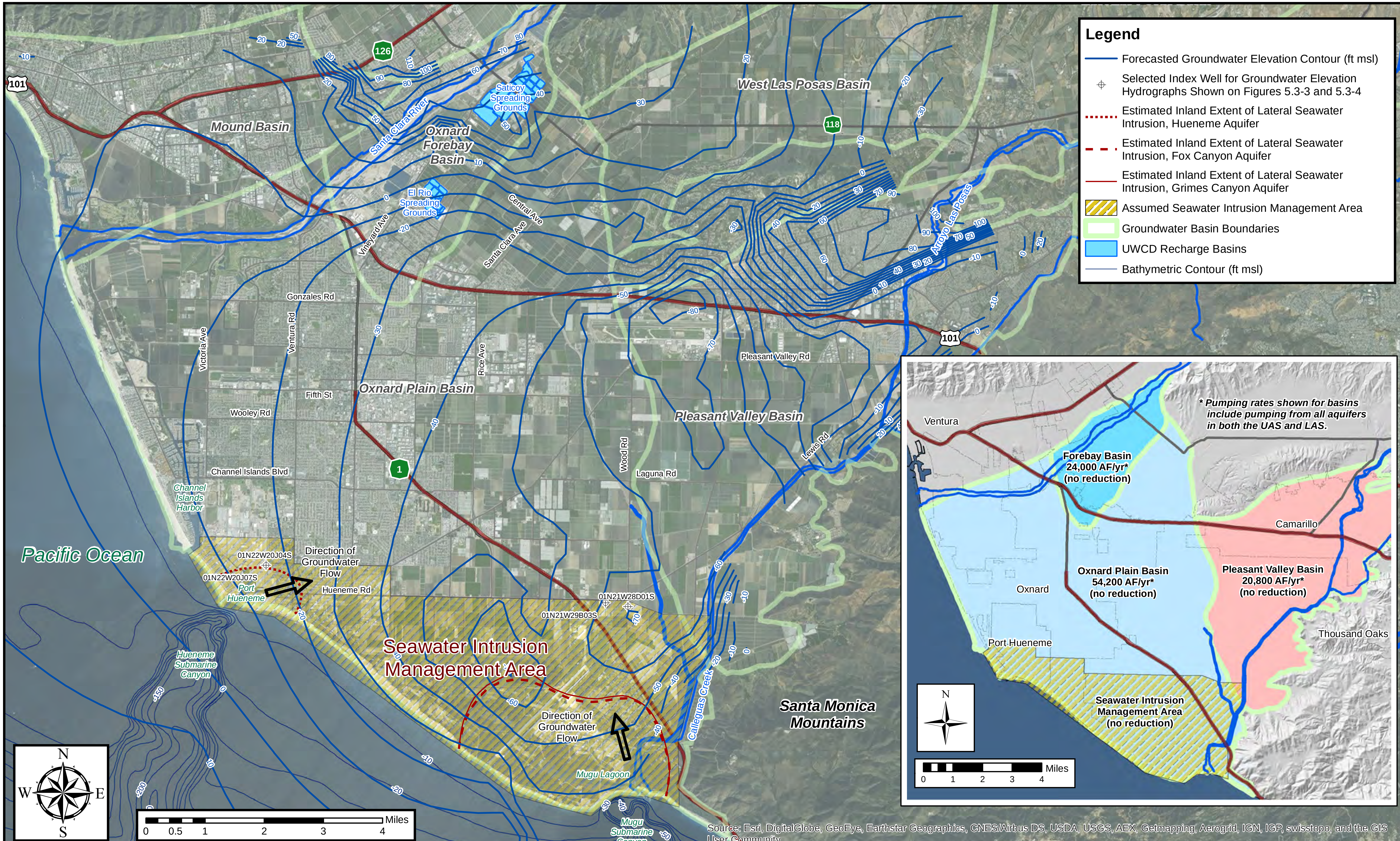

Figure 5.3-6. Simulated Groundwater Elevations in Fox Canyon Aquifer Under Base Case Pumping Scenario, Typical Water-Year Conditions.

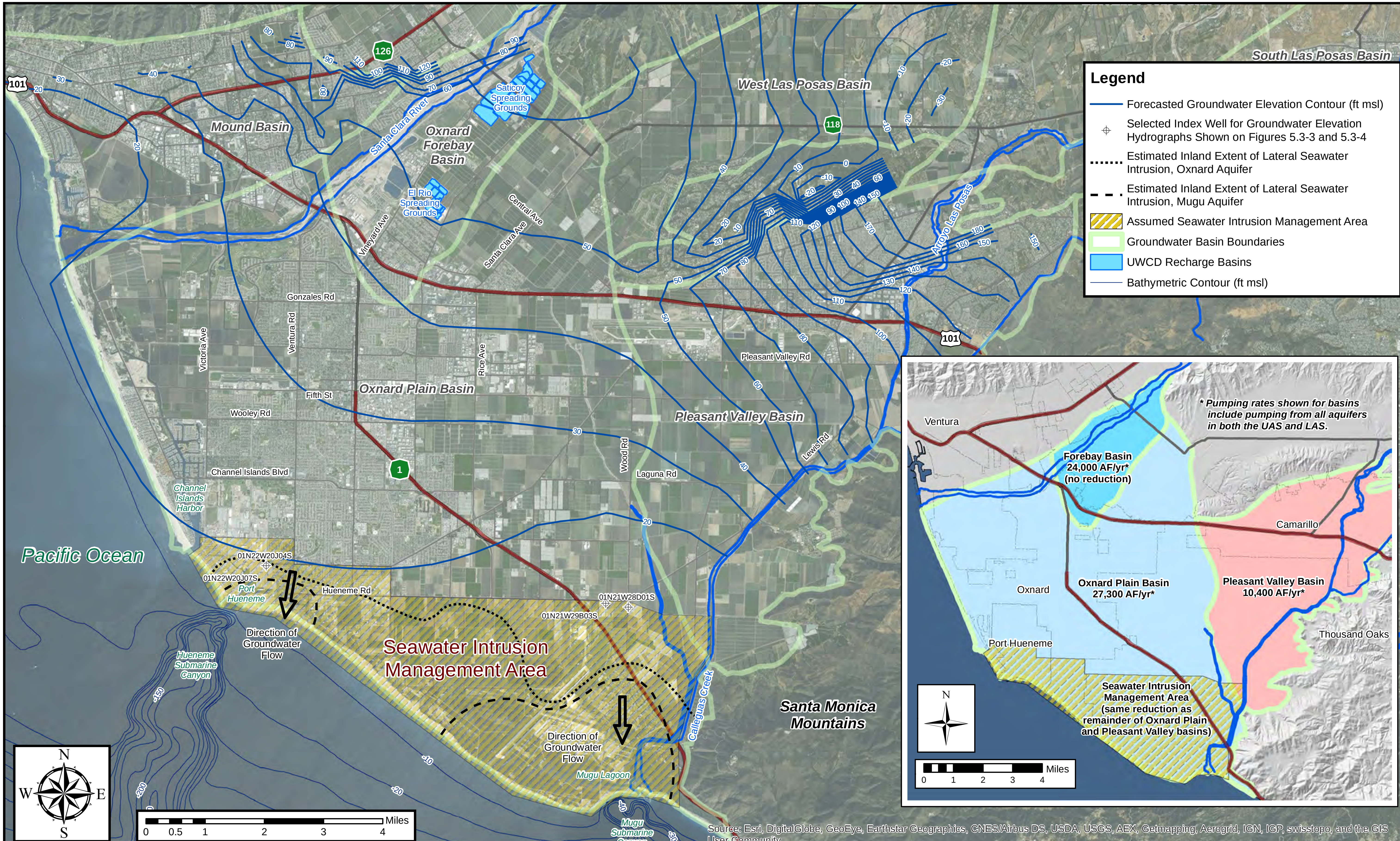

Figure 5.3-7. Simulated Groundwater Elevations in Oxnard Aquifer Under Scenario A, Typical Water-Year Conditions.

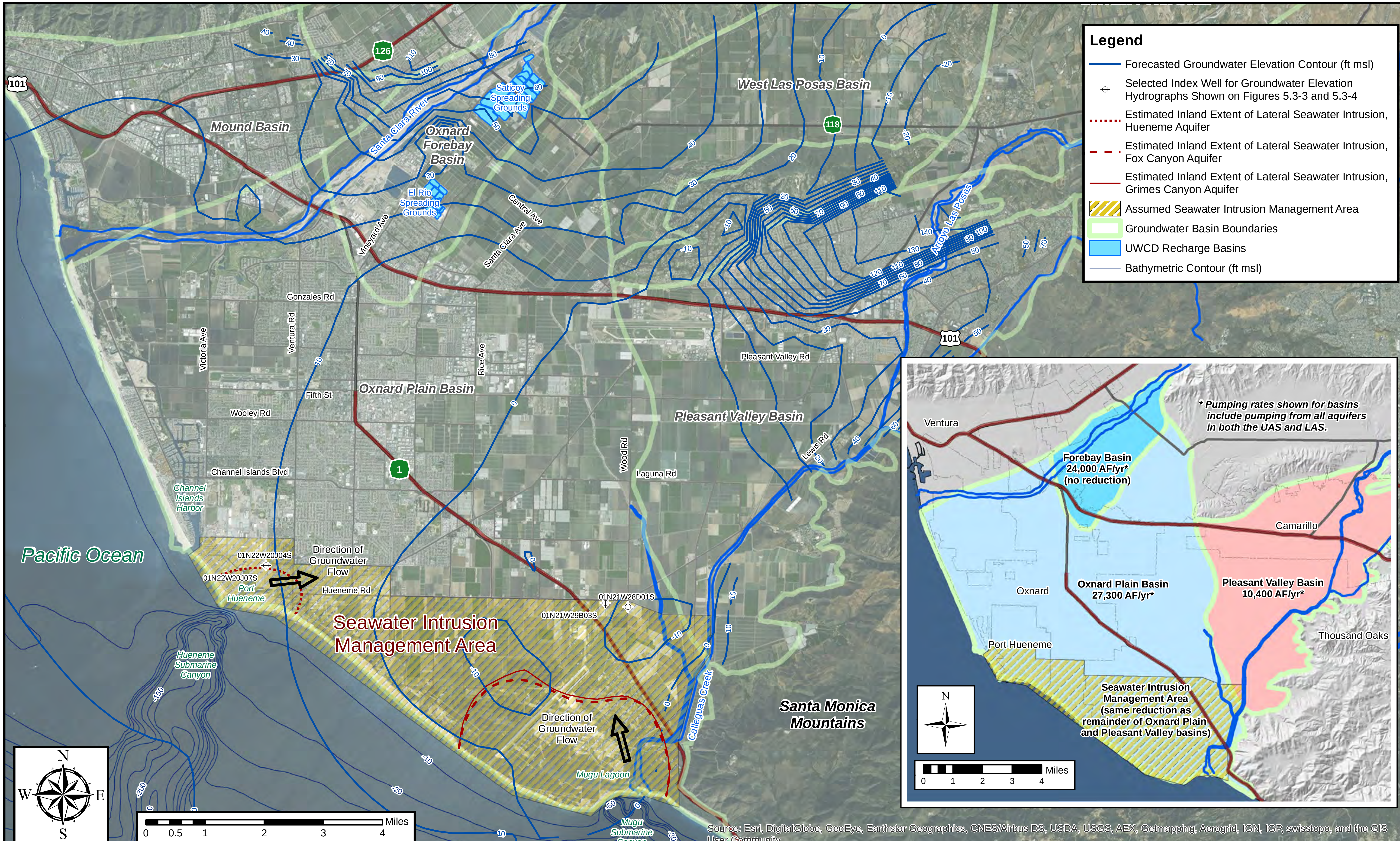

Figure 5.3-8. Simulated Groundwater Elevations in Fox Canyon Aquifer Under Scenario A, Typical Water-Year Conditions.

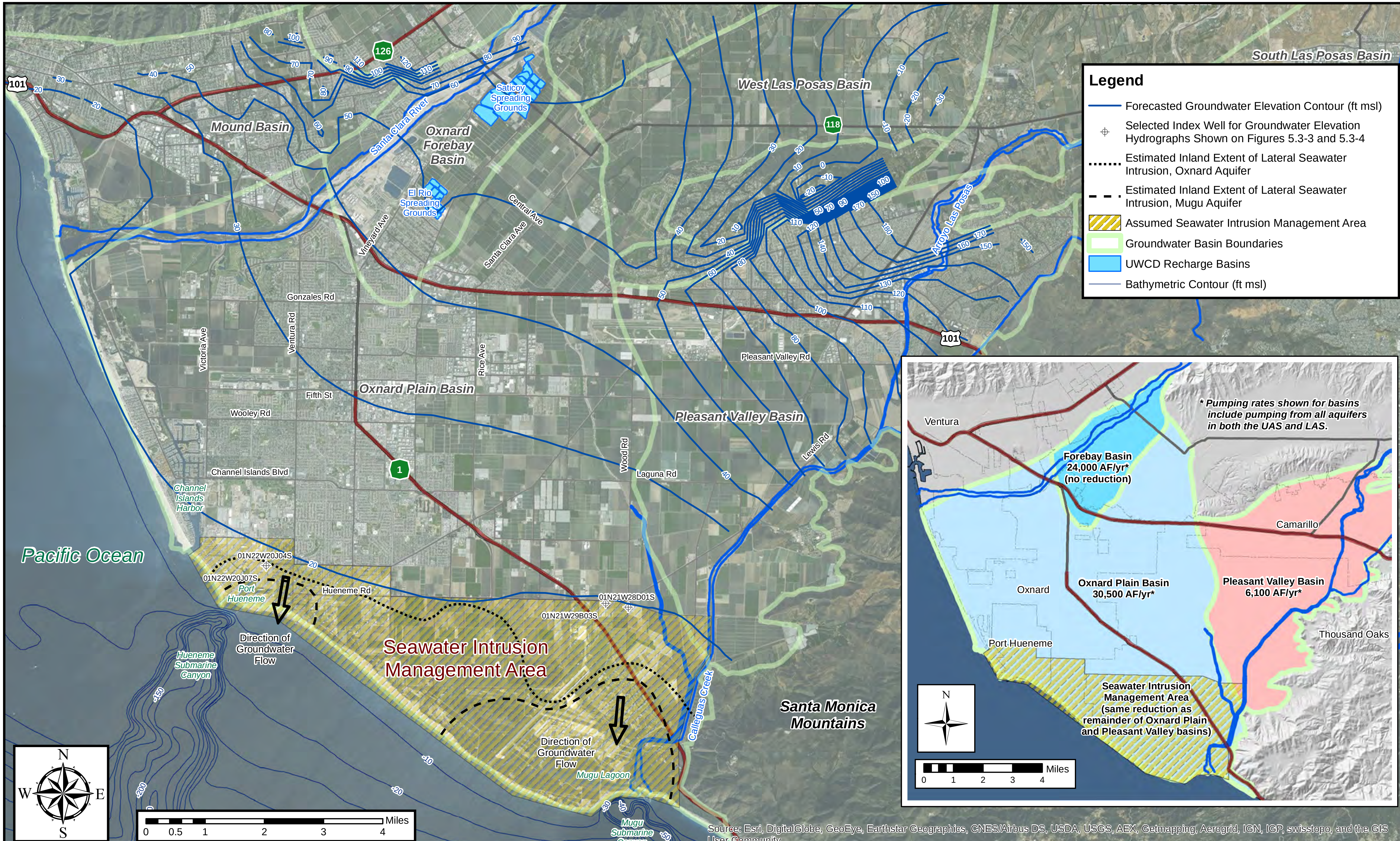

Figure 5.3-9. Simulated Groundwater Elevations in Oxnard Aquifer Under Scenario B, Typical Water-Year Conditions.

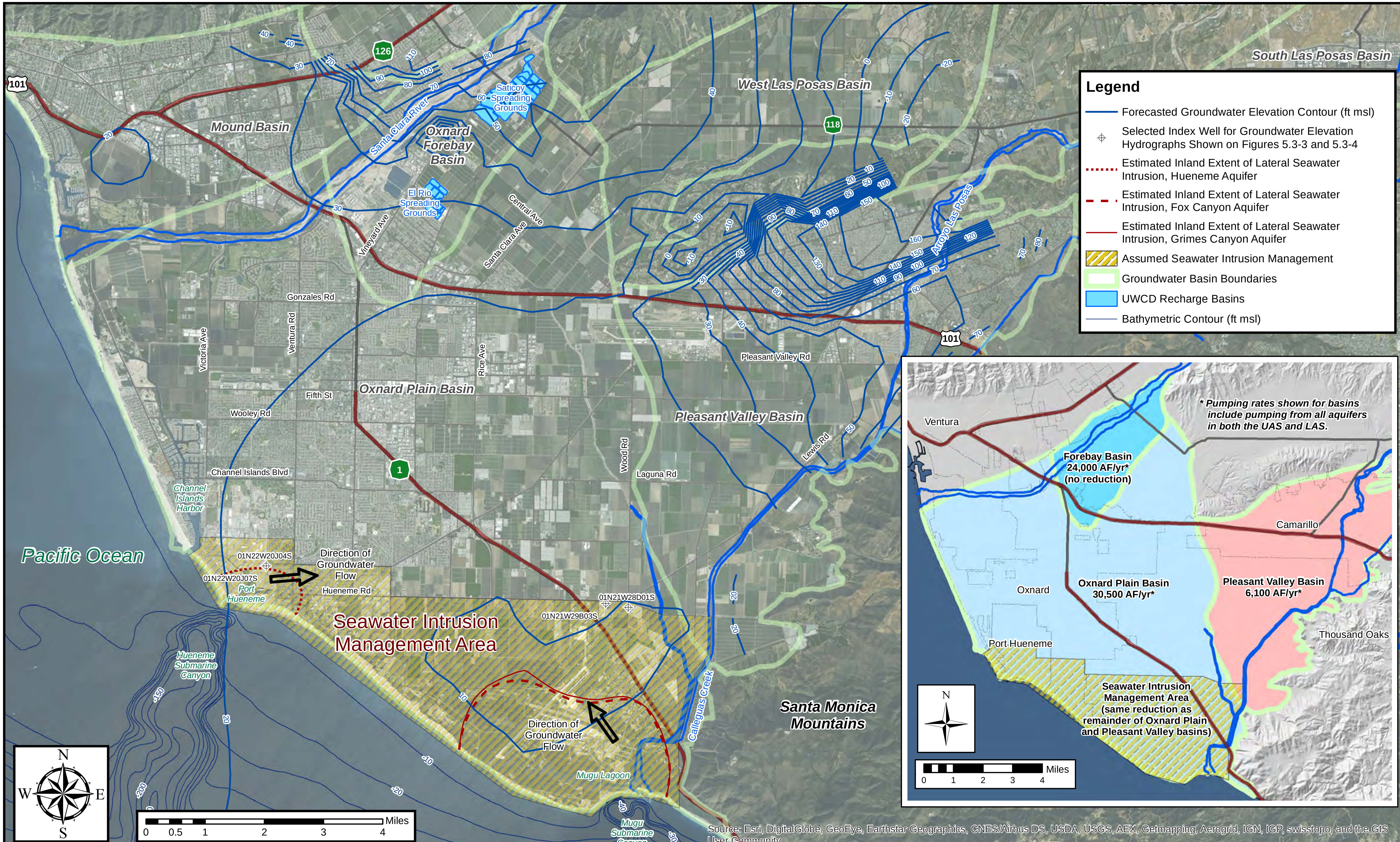

Figure 5.3-10. Simulated Groundwater Elevations in Fox Canyon Aquifer Under Scenario B, Typical Water-Year Conditions.

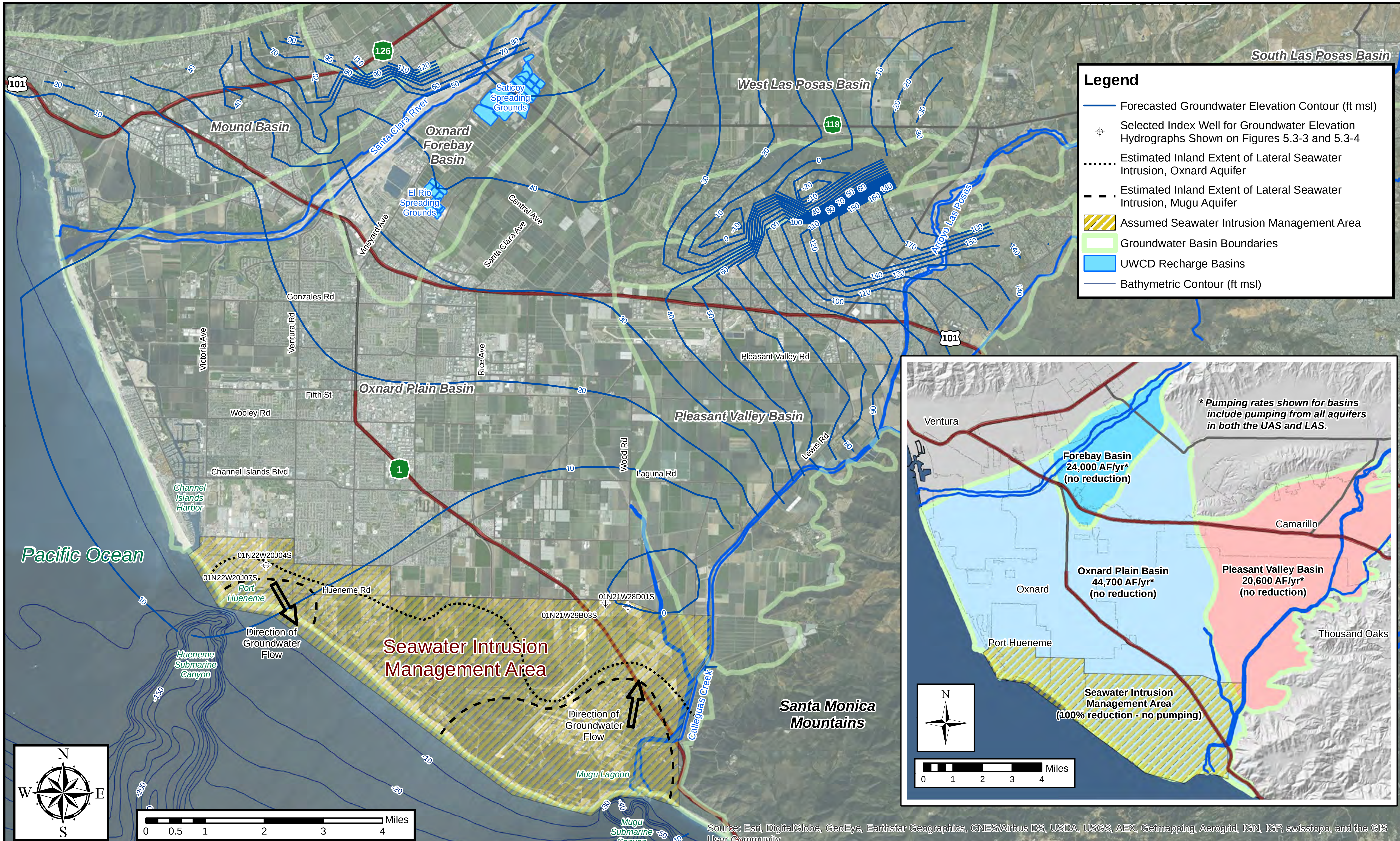

Figure 5.3-11. Simulated Groundwater Elevations in Oxnard Aquifer Under Scenario C, Typical Water-Year Conditions.

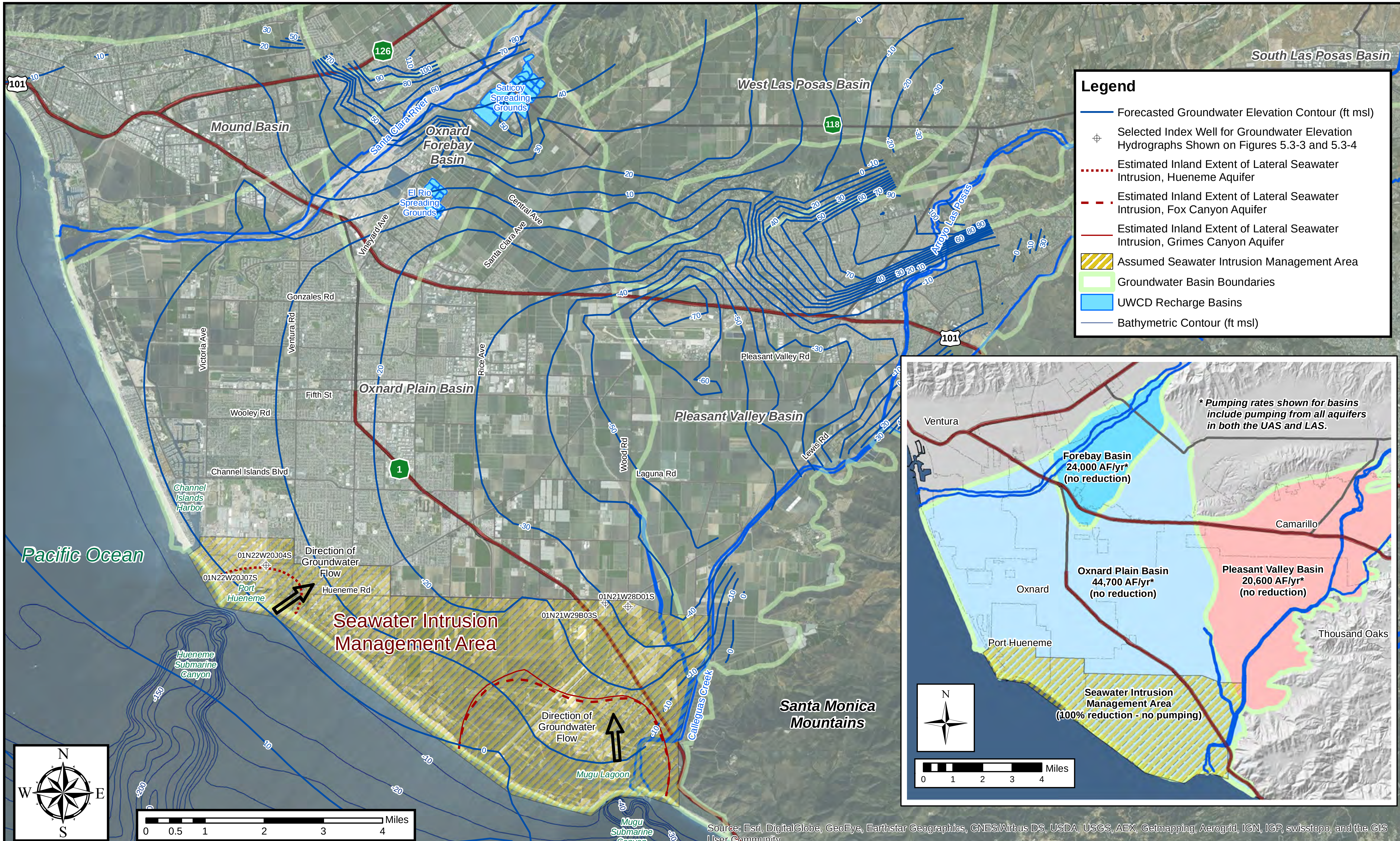

Figure 5.3-12. Simulated Groundwater Elevations in Fox Canyon Aquifer Under Scenario C, Typical Water-Year Conditions.

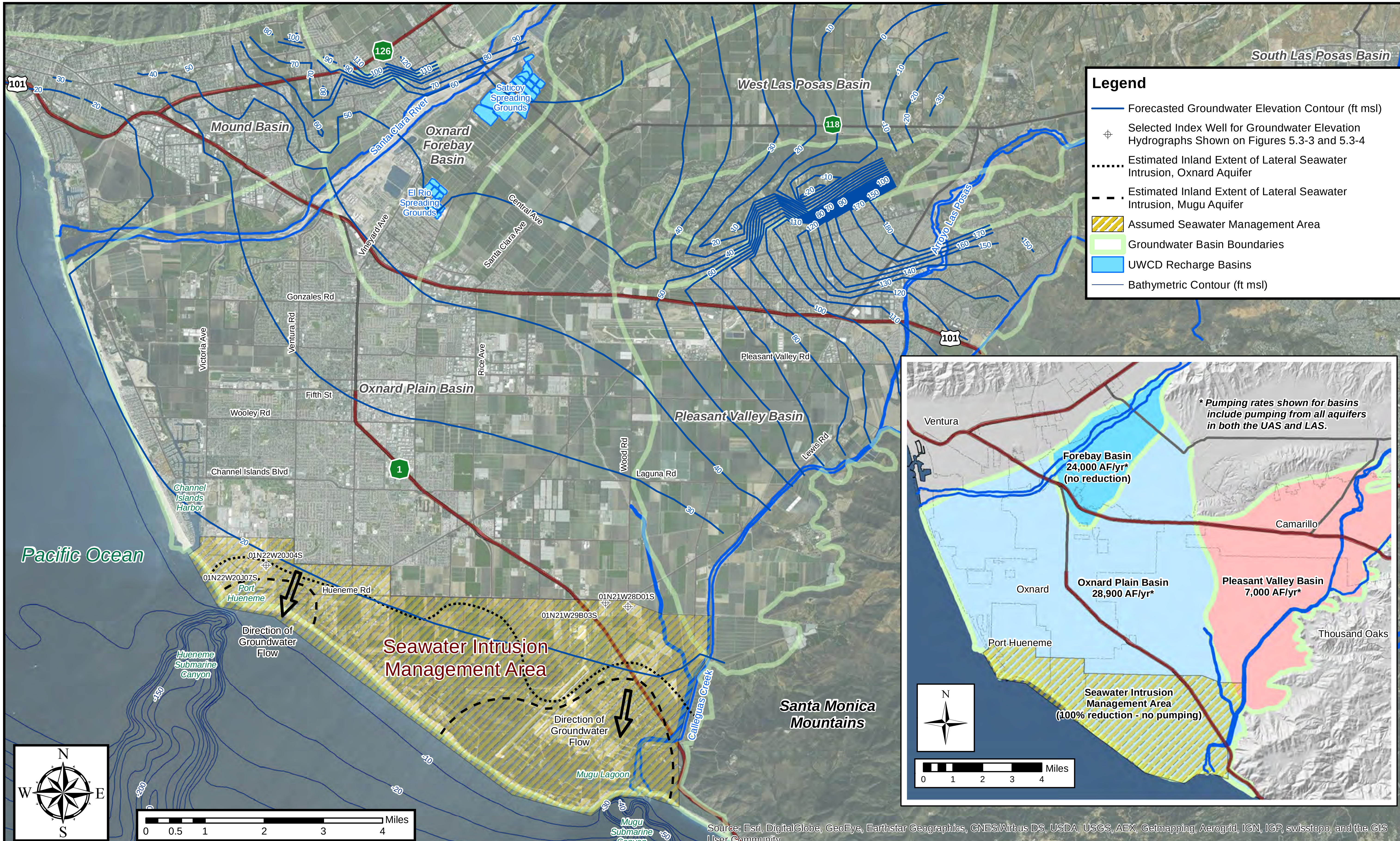

Figure 5.3-13. Simulated Groundwater Elevations in Oxnard Aquifer Under Scenario D, Typical Water-Year Conditions.

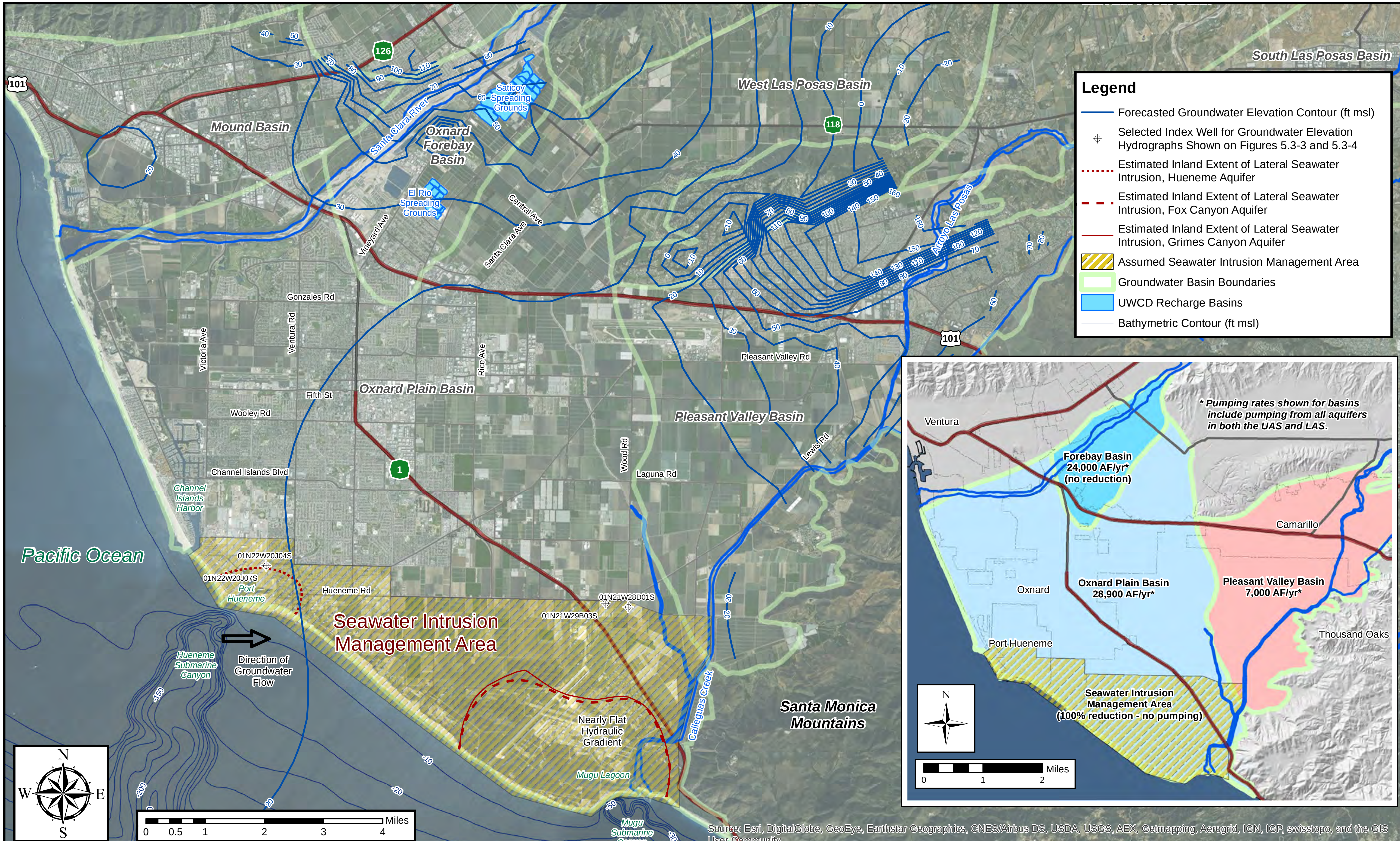

Figure 5.3-14. Simulated Groundwater Elevations in Fox Canyon Aquifer Under Scenario D, Typical Water-Year Conditions.

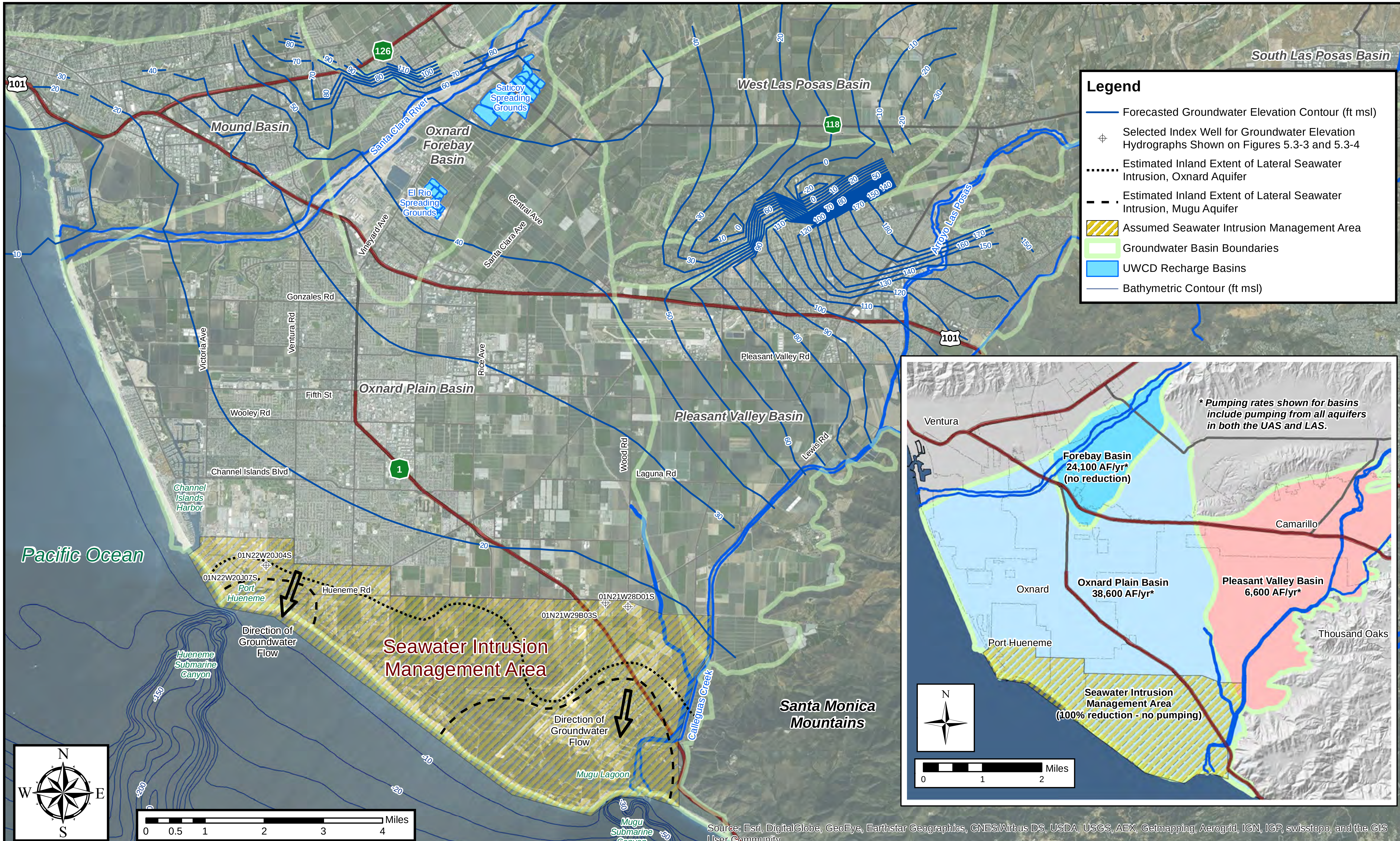

Figure 5.3-15. Simulated Groundwater Elevations in Oxnard Aquifer Under Scenario E, Typical Water-Year Conditions.

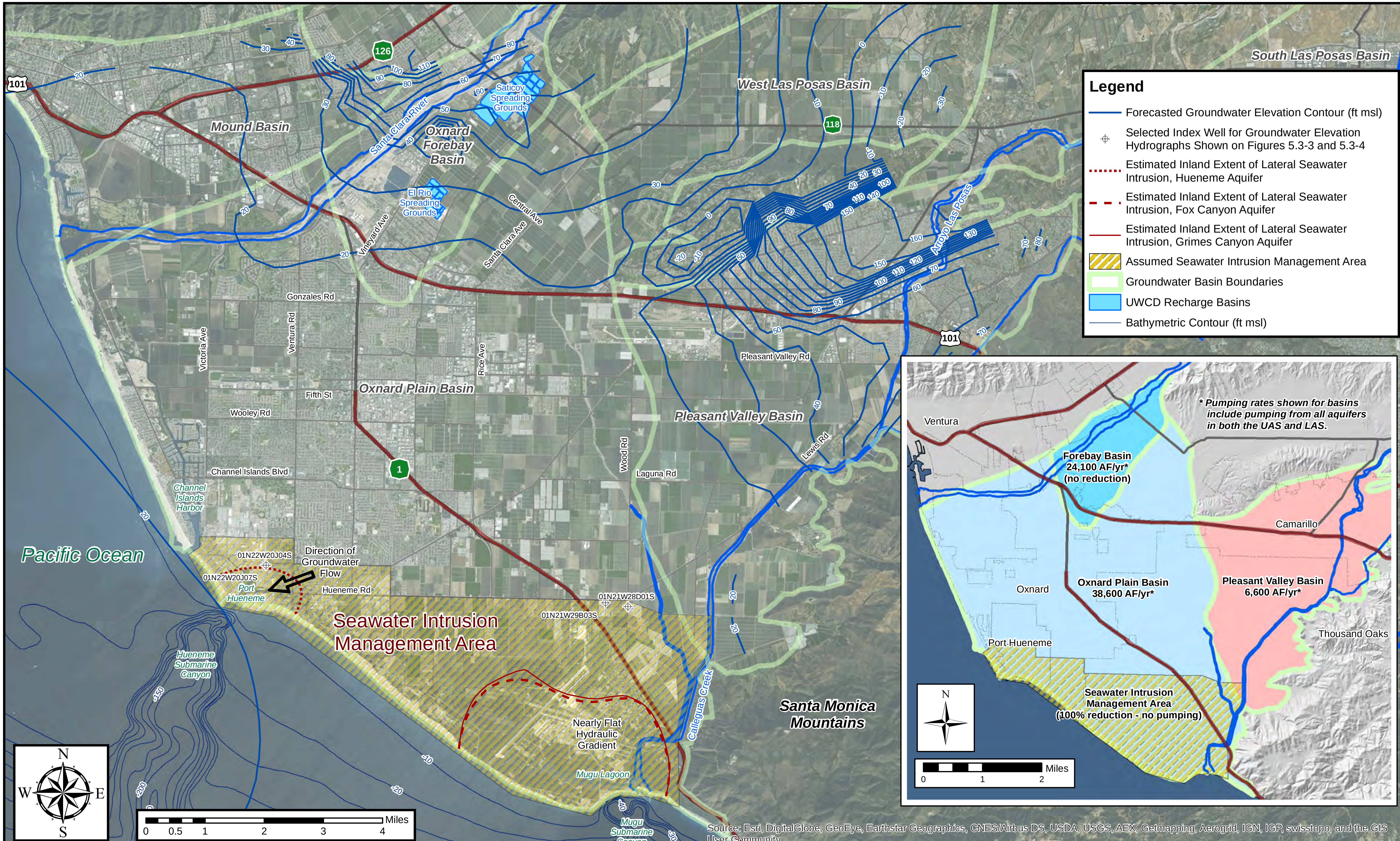

Figure 5.3-16. Simulated Groundwater Elevations in Fox Canyon Aquifer Under Scenario E, Typical Water-Year Conditions.