SALINE INTRUSION UPDATE, OXNARD PLAIN AND PLEASANT VALLEY BASINS

United Water Conservation District
Open-File Report 2016-04
October 2016

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OXNARD PLAIN AND PLEASANT VALLEY BASINS

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

PREPARED BY

GROUNDWATER DEPARTMENT

UNITED WATER CONSERVATION DISTRICT

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UWCD OPEN-FILE REPORT 2016-04

ABSTRACT

The Oxnard Plain basin, located adjacent the Pacific Ocean in southern Ventura County, California, has a long history of groundwater overdraft and saline intrusion. Major investments in infrastructure for groundwater recharge and distribution, State Water Project imports and regulatory programs to manage groundwater extraction have only been partly successful in mitigating groundwater overdraft in the Oxnard Forebay, Oxnard Plain and Pleasant Valley basins. The aquifers of the Upper Aquifer System (UAS) are readily recharged by natural recharge mechanisms and United's artificial recharge activities in the Oxnard Forebay, which rely on surface water from the large watershed of the Santa Clara River. Recent (2012-15) drought conditions have caused greatly diminished flows in the Santa Clara River and other local water bodies, and recharge totals to the groundwater basins over the past four years have been meager. Although healthy groundwater conditions are sometimes achieved in the shallowest confined aquifer of the Oxnard Plain basin following a series of wet years, water levels in many portions of the deeper aquifers of the Oxnard Plain and Pleasant Valley basins remain well below sea level during both wet and dry climatic periods. In fall 2015 broad areas of the Oxnard Plain basin recorded UAS groundwater levels more than 20 feet below sea level. In the Pleasant Valley basin and in the eastern portion of the Oxnard Plain basin, groundwater levels in the aquifers of the Lower Aquifer System (LAS) commonly ranged from 50 to more than 150 feet below sea level. Groundwater levels above sea level were only recorded in recharge areas in the northernmost portions of the basins in fall 2015. Groundwater levels below sea level allow the intrusion of saline water by various mechanisms. The direct lateral intrusion of seawater occurs where aquifers are exposed to the sea in near-shore submarine canyons. Additionally, the compaction of aquitards as a result of groundwater level declines can expel connate brines, and low pressure conditions deep in the aquifer systems can promote the migration of brines along faults and brine upwelling from deeper formations. By these mechanisms, saline intrusion may degrade water quality well inland of the coastal areas where direct lateral seawater intrusion is known to occur.

In the area surrounding Mugu Lagoon, a number of the monitoring wells in the UAS have recorded elevated chloride concentrations since they were installed in 1990. Wells near Port Hueneme show evidence of a new episode of seawater advancing into the basin. Other UAS wells located southeast of Port Hueneme have elevated chloride from past intrusion events, as prevailing groundwater flow directions tend to sweep saline water from the Port Hueneme area down the coast towards Mugu Lagoon during periods having higher water levels. Saline intrusion in the aquifers of the LAS near Port Hueneme appears to impact a limited area to date, but concentrations in one Hueneme aquifer (part of the LAS) well near Hueneme Canyon exceeds 10,000 mg/l. Saline impacts in the LAS are more extensive and severe in the area surrounding Mugu Lagoon, with much of the saline water interpreted to be derived from brines rather than seawater. The network of coastal monitoring wells is somewhat limited in this area, however, and the extent of saline impacts in the various confined aquifers of the Oxnard Plain remains difficult to determine with certainty. In the Pleasant Valley basin a number of deep production wells have chloride concentrations greater than those of similarly-constructed wells on the Oxnard Plain. Water quality samples collected from within the screened portions of LAS production wells in the Pleasant Valley basin show that most chloride enters these wells from the deepest portions of the well.

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1 INTRODUCTION

United Water Conservation District (United, or the District) is a public agency that encompasses about 214,000 acres of southern Ventura County. The District includes the downstream (Ventura County) portion of the valley of the Santa Clara River and much of the Oxnard coastal plain. The District serves as a steward for managing the surface water and groundwater resources within all or part of eight groundwater sub-basins (Figure 1.1). It 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. The developed areas of the District are a mix of agriculture and urban areas, with prime agricultural land supporting high-value crops such as strawberries, avocados, row crops, lemons, and flowers. More than 370,000 people live within the District, including those in the cities of Oxnard, Port Hueneme, Santa Paula, Fillmore and the eastern portions of Ventura.

The District is authorized under the California Water Code to conduct water resource investigations, acquire water rights, build facilities to store and recharge water, construct wells and pipelines for water deliveries, commence actions involving water rights and water use, prevent interference with or diminution of stream/river flows and their associated natural subterranean supply of water, and to acquire and operate recreational facilities (California Water Code, section 74500 et al.).

1.1 HISTORY OF THE DISTRICT

The original founding organization for United Water Conservation District was called the Santa Clara River Protective Association. It was formed in 1925 to protect the runoff of the Santa Clara River from being appropriated and exported outside the watershed. The Santa Clara Water Conservation District (Santa Clara WCD) was formed in 1927 to further the goals of the Association by protecting water rights and conserving the waters of the Santa Clara River and its tributaries. The Santa Clara WCD began a systematic program of groundwater recharge in 1928, primarily through constructing a diversion structure and spreading grounds along the Santa Clara River near the community of Saticoy.

High chloride levels were first detected in groundwater beneath the Oxnard Plain in the vicinity of the Hueneme and Mugu submarine canyons in the early 1930s (CA DWR, 1965). As the area impacted by saline intrusion expanded in the Oxnard Plain basin in the late 1940s, it was clear that the Santa Clara WCD did not have the financial ability to raise money to construct the facilities necessary to combat the problem. With the help of the City of Oxnard, a new district was organized in 1950 under the Water Conservation Act of 1931. The new district was called "United Water Conservation District" for its unification of urban and agricultural concerns. United then constructed a number of water conservation projects, including:

- Santa Felicia Dam (1955) to capture and store winter runoff on Piru Creek to release in controlled amounts during the dry season. The 200-foot high dam originally created storage for 100,000 acre-feet in Lake Piru, but the accumulation of sediment behind the dam has now reduced the reservoir capacity to approximately 82,000 acre-feet. The reservoir is downstream from the State Water Project, enabling the District to receive

State Water Project water by release down middle Piru Creek without the construction of expensive conveyance facilities.

- Spreading grounds at El Rio and a pipeline to convey water diverted from the Santa Clara River to this facility.
- Wells surrounding the El Rio spreading basins to produce water for the Oxnard-Hueneme (O-H) pipeline (1954) that supplies drinking water to the cities of Oxnard and Port Hueneme, several small mutual water districts, and two Navy bases at the coast (at Point Mugu and Port Hueneme). The O-H system supplies groundwater from the Oxnard Forebay basin (the recharge area for the Oxnard Plain), rather than pumping coastal wells that could accelerate seawater intrusion in the populated coastal areas of the Oxnard Plain.
- A pipeline to Pleasant Valley (1958) delivering surface water diverted from the Santa Clara River to offset groundwater pumping for crop irrigation.

United's initial major investments in water supply infrastructure came near the end of an extended dry period which spanned the years 1945-1965. Water levels on the Oxnard Plain, however, remained below sea level in the early 1960s and saline water continued to intrude inland in coastal areas. Conditions improved following some wet winters in the late 1960s, but by the mid-1970s a new significant episode of seawater intrusion was degrading water quality in the Oxnard Plain basin. The State Water Resources Control Board was alarmed by the chronic overdraft of the coastal basins in Ventura County, threatened adjudication, and urged that local agencies take necessary actions to prevent further irreparable harm to the basins (SWRCB, 1979).

The State's threat of adjudication was taken seriously. The necessity to control groundwater extraction was recognized, and the formation of the Fox Canyon Groundwater Management Agency (FCGMA) was authorized by the California legislature in 1982. The FCGMA formed in 1983, conducted studies to determine the safe yield of its basins and initiated programs to reduce pumping. United partnered with the County of Ventura to construct the Pumping Trough Pipeline (completed in 1986) to convey water diverted from the Santa Clara River to agricultural pumpers on the Oxnard Plain, thus reducing groundwater pumping in a critically-overdrafted area. With support from the State Water Resources Control Board, the California Department of Water Resources, and the County of Ventura, and after a lengthy but successful effort to secure a significant loan from the U.S. Bureau of Reclamation, construction of the Freeman Diversion project was initiated in 1988 and completed in 1991. The Freeman Diversion replaced the temporary earthen diversion dikes maintained by United in the Santa Clara River near Saticoy with a permanent concrete structure. This new diversion structure included a fish ladder and allowed for the diversion of storm flows throughout the winter and spring, whereas the earlier earthen diversion dikes were eroded away by high flows in the river early in winter or spring and could not be reconstructed until flow subsided. Another significant benefit of the Freeman Diversion was stabilization of the elevation of the riverbed after years of channel downcutting caused by gravel mining in the floodplain of the river, allowing diversion from a fixed elevation and the distribution of water by gravity flow to United's recharge facilities and pipelines.

Following completion of the Freeman Diversion, United constructed additional facilities to expand and optimize recharge operations in the Oxnard Forebay. These newer facilities include:

- Noble recharge basins (1995), converted from existing gravel mining pits, located near the Saticoy Spreading Grounds.

- Saticoy Well Field (2004), allowing for the extraction of mounded groundwater near the Saticoy Spreading Grounds.

- Ferro and Rose basins, purchased in 2010; the ability to convey surface water to the Rose basin was established in fall 2015, but there are not yet facilities in place to deliver water to the Ferro basin.

1.2 GOALS OF THE DISTRICT

The District's activities and goals are guided by its mission statement,

"United Water Conservation District shall manage, protect, conserve, and enhance the water resources of the Santa Clara River, its tributaries and associated aquifers, in the most cost-effective and environmentally balanced manner." In order to accomplish this mission, United follows these guiding principles:

- Construct, operate, and maintain facilities needed now and in the future to put local and imported water resources to optimum beneficial use.

- Deliver safe and reliable drinking water that meets current and future health standards to cities and urban areas.

- Provide an adequate and economical water supply to support a viable and productive agricultural sector.

- Fight overdraft and seawater intrusion and enhance the water quality of the aquifers through the use of District programs.

- Monitor water conditions to detect and guard against problems and to report those conditions to the public.

- Seek opportunities to develop cooperative programs with other agencies in order to maximize use of District resources and promote mutually beneficial projects.

- Develop, construct, and operate high-quality public recreational facilities that are financially self-supporting.

- Balance District operations with environmental needs to maximize use of the region's water resources.

- Conduct District affairs in a business-like manner that promotes safe investment policy, sound financial audits and the utmost in professional and financial integrity.

United's Board of Directors also uses Resolutions of the Board to set or clarify district policies on various subjects. In March 2014, United's Board of Directors adopted Resolution 2014-01, recognizing the existence of drought conditions within the District and setting priorities for the distribution of surface water diverted from the Santa Clara River. The following order of priorities was adopted for the use of surface water diverted at the Freeman Diversion:

- Dilute nitrate in groundwater surrounding the O-H wells at the El Rio Spreading Grounds so that delivered water meets or exceeds drinking water standards.

- Delivery of the minimum contractual allotment of 12.22% of the diverted water to the Pleasant Valley pipeline.

- Distribute water to the Saticoy and El Rio Spreading Grounds to recharge the Oxnard Forebay, which increases hydrostatic pressure in the aquifers of the surrounding coastal basins to fight seawater intrusion.
- Deliver surface water to the Pumping Trough Pipeline.
- Deliver any remaining available water to the Pleasant Valley pipeline.

The District's mission statement and Board Resolution 2014-01 reflect United's commitment to promoting the sustainability of the basins and aquifers throughout the District for both urban and agricultural users, with consideration of environmental water needs as well.

2 HYDROGEOLOGY

Thick deposits of sedimentary deposits exist within the boundaries of the District. The ancestral Santa Clara River deposited vast quantities of alluvial fill in structural depressions, forming the upper sections of this basin fill. Precipitation within the 1,626-square mile watershed of the Santa Clara River generates significant stream flow in wet and average years; this flow serves as a major source of recharge to the groundwater basins that underlie the floodplain of the river. Unconfined shallow aquifer conditions generally exist beneath the channel of the Santa Clara River in the valley of the Santa Clara River and to within about five miles from the coast on the Oxnard coastal plain (the Oxnard Forebay basin), allowing opportunities for natural and artificial recharge along the lower reaches of this large river system.

2.1 GEOLOGIC SETTING

The District is within the Transverse Ranges geomorphic province of California, in which the mountain ranges and basins are oriented east-west rather than the northeast-southwest trend common to many mountain ranges in California. Major structural features of this area reflect a tectonic regime dominated by compression. Active thrust faults border the basins of the Santa Clara River valley, causing rapid uplift of the adjacent mountains, and the formation of deep basins within regional synclinal features located between the areas of uplift. The basins are filled with thick accumulations of Tertiary and Quaternary sediments that were deposited in both marine and terrestrial settings. The groundwater basins underlying the Oxnard Plain (Figure 1.1) are filled with sediments deposited on a wide delta complex that formed at the terminus of the Santa Clara River. The eastern portion of the Oxnard coastal plain is commonly known as the Pleasant Valley basin, where younger sediment is derived largely from the Calleguas Creek watershed. These sediments tend to be relatively fine-grained as the Calleguas Creek watershed is smaller and less mountainous than the Santa Clara River watershed to the north. The Pleasant Valley basin is bounded on the east by the Santa Monica Mountains. The Mound basin bounds the Oxnard Plain basin to the north, and is characterized by its deep synclinal structure and thick shallow clay deposits.

2.2 AQUIFERS

Most of the coastal groundwater basins within United's district boundaries have a shallow perched aquifer, and the production aquifers of the basins can be classified as being part of either the regional Upper Aquifer System or the Lower Aquifer System (Mukae and Turner, 1975). The UAS consists of the Oxnard and Mugu aquifers. The LAS consists of the Hueneme, Fox Canyon and Grimes Canyon aquifers. The aquifers consist of gravel and sand deposited along the ancestral Santa Clara River, alluvial fans along the flanks of the mountains, a coastal plain/delta complex at the terminus of the Santa Clara River, and marine deposits from transgressional seas. The aquifers are recharged by the natural infiltration of stream flow (primarily from the Santa Clara River), artificial recharge of diverted stream flow, mountain-front recharge along the exterior boundaries of the basins, direct infiltration of precipitation on the valley floors of the basins and on bedrock outcrops in adjacent mountain fronts, the percolation of reclaimed water from septic systems and sanitary sewers, and irrigation return flow in agricultural areas.

Figure 2.2.1 is a schematic of the UAS and LAS showing their subsurface sequence. The figure also shows general depths in feet. However, United's more recent work with an extensive collection of geophysical logs suggest that some of the aquifers are actually deeper than originally mapped and indicated on the schematic. Also note that many of the clay layers (aquitards) shown in the UAS are inter-fingering and in some places are discontinuous.

2.2.1 PERCHED/SEMI-PERCHED

On the Oxnard Plain, the uppermost silt and clay deposits that confine the Oxnard aquifer are overlain by silt and sand layers of the "Semi-perched aquifer," which generally contains poor-quality water. This zone extends from the surface to depths as great as about 100 ft. The confining clay that underlies the Semi-perched aquifer and confines the deeper Oxnard aquifer is sometimes referred to as the "clay cap" and these fine-grained deposits with low hydraulic conductivity generally protect the underlying production aquifers from contamination occurring as a result of activities on land surface.

Deep percolation of rainfall and irrigation return flows are the major components of recharge to the Semi-perched aquifer. Although difficult to quantify, there is likely some vertical movement of water between the shallow perched water and the underlying confined aquifer units. This limited and variable connection with the underlying Oxnard aquifer resulted in the favored term of Semi-perched aquifer for this perched water. Subsurface drainage systems are also common in many agricultural areas, which drain shallow groundwater that would otherwise waterlog plant roots. These "tile drains" are commonly spaced every 100 feet and flow to sumps at collection points where water is pumped out to open ditches. Groundwater elevations in the Semi-perched aquifer are effectively regulated by these engineered drainage systems, and little water level variability is observed in this shallow aquifer. Depth to water is commonly less than about 10 feet. There is some surface water/groundwater exchange between the semi-perched aquifer and surface water bodies such as the Santa Clara River, but much of the discharge from this shallow aquifer is to the ocean. It is very uncommon for the Semi-perched aquifer to be used for water supply on the Oxnard Plain.

2.2.2 UPPER AQUIFER SYSTEM

The Upper Aquifer System consists of the Oxnard and Mugu aquifers. These aquifers are characterized by relatively young alluvium (Oxnard aquifer) of Holocene age and older alluvium (Mugu aquifer) of late Pleistocene age. Both these aquifers are relatively flat-lying, and the Oxnard aquifer rests unconformably on the Mugu aquifer. A clay layer commonly occurs between the two aquifers, but in some areas there is no aquitard separating these two aquifer units. Some researchers apply the Oxnard and Mugu aquifer nomenclature to time-equivalent alluvial deposits in the Santa Clara River valley, but these deposits are more commonly termed Recent Alluvium and Older Alluvium, respectively, in the upstream groundwater basins of the Santa Clara River Valley.

2.2.2.1 OXNARD AQUIFER

The Oxnard aquifer generally consists of river, floodplain, alluvial fan, beach and lagoonal deposits (Turner, 1975). The Oxnard aquifer is present throughout the Oxnard Forebay and the Oxnard Plain, and characterized primarily by coarse-grained (high-energy) river deposits. Historically, the Oxnard aquifer was the primary aquifer used for groundwater supply on the Oxnard coastal plain. This highly-permeable assemblage of sand and gravel is generally found at depths ranging from approximately 80 to 300 feet below land surface, and is commonly between 100 and 240 feet thick. The Oxnard aquifer has suffered more water quality impacts from both direct lateral seawater intrusion and the downward migration of poor-quality (nitrate, TDS, etc.) near-surface groundwater than the deeper aquifers of the Oxnard Plain.

2.2.2.2 MUGU AQUIFER

The Mugu aquifer generally consists of river, floodplain, alluvial fan, terrace, marine terrace, lagoonal and beach deposits. The Mugu aquifer rests unconformably on the LAS. Coarse-grained basal conglomerates occur in many areas (Turner, 1975, Hanson et al, 2003). The Mugu aquifer generally occurs at depths of about 255 to 500 feet below land surface, but depths greater than 400 feet are relatively uncommon.

2.2.3 LOWER AQUIFER SYSTEM

The Lower Aquifer System consists of the Hueneme, Fox Canyon, and Grimes Canyon aquifers (Figure 2.2.1). These aquifers occur within the Saugus, San Pedro, and Santa Barbara Formations of Pliocene to Pleistocene age (Mukae and Turner, 1975).

In the groundwater basins underlying the Oxnard coastal plain, the aquifers of the LAS may be isolated from each other vertically by low-permeability units and horizontally by regional fault systems. The LAS is folded and tilted in many areas, and has been eroded along its upper contact with the UAS. In many areas an aquitard exists between the Mugu and Hueneme aquifers, which constrains vertical flow between the UAS and the LAS.

2.2.3.1 HUENEME AQUIFER

The Hueneme aquifer underlies much of the Oxnard coastal plain, but is generally absent south of Hueneme Road where this unit was uplifted and subsequently eroded (Turner, 1975). The Hueneme aquifer generally consists of interbedded terrestrial fluvial sediments, and marine clays and sands. Thickness of the Hueneme aquifer varies greatly on the Oxnard Plain, and is greater than 1,000 feet thick in some locations. The Hueneme aquifer generally contains more interbeds of silt and clay than the underlying Fox Canyon aquifer.

2.2.3.2 FOX CANYON AQUIFER

The Fox Canyon aquifer underlies the Las Posas, Pleasant Valley, Oxnard Forebay and Oxnard Plain basins. The Fox Canyon aquifer materials generally consist of shallow marine regressive sands and some clays. The Fox Canyon aquifer is the lower unit in the San Pedro Formation, and reaches thicknesses as great as 500 feet. Fine-grained sands are common, and the main unit of the Fox Canyon aquifer has a fairly consistent signature on resistivity logs. Some researchers also delineate a distinct basal unit of the Fox Canyon aquifer based on e-log signatures and lithology.

2.2.3.3 GRIMES CANYON AQUIFER

The deepest fresh water-bearing unit commonly mapped in the greater Oxnard Plain area is Grimes Canyon aquifer, which consists of permeable units of limited areal extent within the Lower Pleistocene Santa Barbara Formation (CA DWR, 1954; Turner, 1975). The Grimes Canyon aquifer generally consists of shallow marine regressive sands. In the northern Oxnard Plain, the Santa Barbara Formation is dominated by fine-grained deposits, and the Grimes Canyon aquifer is not mapped in this area (Turner, 1975).

2.3 GROUNDWATER BASINS

The eight groundwater basins that wholly or partially underlie United's district boundaries are the Piru, Fillmore, Santa Paula, Mound, Oxnard Forebay, Oxnard Plain, Pleasant Valley and West Las Posas basins (Figure 1.1). These basins are all connected as part of the regional Santa Clara-Calleguas hydrologic system. The Piru, Fillmore, and Santa Paula basins are bounded by the Oak Ridge fault to the south and the San Cayetano fault system to the north. These upstream basins within the valley of the Santa Clara River and are not discussed further in this report. The Oak Ridge fault defines the boundary between the Oxnard Forebay and Oxnard Plain basins to the south and the Santa Paula and Mound basins to the north.

2.3.1 OXNARD FOREBAY BASIN

The Oxnard Forebay is the main source of recharge to the Oxnard Plain basin. Recharge to the Oxnard Forebay benefits other coastal basins (Mound, West Las Posas, Pleasant Valley) but a majority of the water recharged to the Forebay flows downgradient to the confined aquifers of the Oxnard Plain. The shallow sediments of the basin are dominated by coarse alluvial deposits of the ancestral Santa Clara River. The absence of low-permeability confining layers between surface recharge sources and the underlying aquifers in the Forebay allow rapid groundwater recharge in the Forebay. 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, and lesser amounts of underflow from the Santa Paula basin and mountain-front recharge from South Mountain. In the area of the Forebay between United's El Rio and Saticoy spreading grounds, the LAS has been uplifted and truncated along its contact with the UAS. In this area recharge from surface sources may enter both the UAS and the underlying LAS, 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. A limited data set of carbon-14 and tritium age dates exist for samples from monitoring wells in the Oxnard Forebay. Samples collected near the Saticoy Spreading Grounds date water as younger than 50 years, but deep LAS monitoring wells near El Rio interpret groundwater age as greater than 13,000 years (Izbicki, 1996a).

2.3.2 OXNARD PLAIN BASIN

The Oxnard Forebay is hydraulically connected with the aquifers of the Oxnard Plain basin, which is overlain by an extensive confining clay layer. Thus, the primary recharge to the Oxnard Plain basin is from lateral groundwater flow from the Forebay rather than deep percolation of water from surface sources. Natural and artificial recharge to the Forebay serves to raise groundwater elevations in this up-gradient area of the groundwater flow system for the Oxnard Plain. 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 water levels in the Forebay are beneficial, as they maintain offshore pressure 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. 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, resulting in some degree of vertical water movement through low-permeability units that occur between most of the major aquifers. When LAS water levels are substantially lower than UAS water levels (creating a downward gradient), there is substantial leakage of UAS water 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 heads in the Oxnard aquifer are lowered (either regionally by drought conditions or locally by pumping wells). The movement of poor quality water from the semi-perched aquifer to the Oxnard aquifer has been documented in some locations, with abandoned or improperly constructed wells being a notable pathway for this downward flow (Izbicki, 1992; Stamos et al, 1992; Predmore, 1993). Conversely, during rare periods of artesian conditions, upward vertical gradients may exist between the Semi-perched aquifer and deeper confined aquifers.

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

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

Groundwater age dating shows that groundwater ages are greater in the LAS than in the UAS. A number of long-screen production wells were sampled for Tritium activity in 2007 (Burton et al, 2011). Most of the UAS wells sampled were in the northern portion of the Oxnard Plain, and water from these wells was characterized as modern. The wells selected for sampling on the southern Oxnard Plan were mostly LAS wells, and water from these wells was interpreted to be of pre-modern age. Groundwater age in a deep LAS monitoring well near the coast on the northwestern Oxnard Plain is estimated to be more than 23,000 years old (Izbicki, 1996a).

2.3.3 PLEASANT VALLEY BASIN

The Pleasant Valley basin 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. 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 feet thick. In Pleasant Valley much of the UAS is fine grained and not extensively pumped for water supply (Turner, 1975; Hanson et al, 2003). UAS deposits in the Pleasant Valley basin are comprised of sediments sourcing from the Calleguas Creek watershed, a smaller and less mountainous drainage than that of the Santa Clara River which deposited UAS deposits on the Oxnard Plain. Some coarse-grained deposits do exist, but these beds 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 feet. 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 in the Pleasant Valley basin. 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. 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 et al., 1976). These underlying marine deposits and volcanic rocks may both contain high-chloride water.

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 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). Additional sampling from some LAS production wells classified water as pre-modern, with groundwater age estimated to range from 11,000 to 16,000 years (Burton et al, 2011). Groundwater age increases with depth, and water within deeper aquifers has longer contact times with aquifer material, allowing greater geochemical reaction with these materials than water in overlying aquifers.

Over the past two decades water levels in two wells in northern Pleasant Valley have recovered more than 250 feet. The re-establishment of surface flow in Arroyo Las Posas 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 in the northern Pleasant Valley basin is poor. The City of Camarillo has proposed construction of a large-scale desalter to treat and utilize this water which tends to be more mineralized than the older water native to the basin. The groundwater mound in the northern Pleasant Valley basin has subsided by about 100 feet in the recent dry years as flow in Arroyo Las Posas has diminished.

2.3.4 MOUND BASIN

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

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

The limited number of wells in the Mound basin, especially in the northern half of the basin, complicates efforts to ascertain the primary sources of recharge to the basin. There likely is some component of recharge from precipitation falling on aquifer units that outcrop in the hills along the northern margin of the Mound basin, but no wells exist to provide evidence of this occurrence. There is general agreement that the basin benefits from recharge in the Oxnard Forebay and Oxnard Plain basins to the south, especially during periods of high water level on the Oxnard Plain (GTC, 1972; Fugro, 1996; UWCD 2012). The amount of recharge from the Santa Paula basin to the east is also uncertain, but high heads in some wells in the eastern Mound basin suggests some degree of connection and recharge. Mann (1959) suggested that there is little underflow from the Santa Paula basin to the Mound basin, although more recent studies suggest the volume of groundwater underflow may be significant (Fugro, 1996; UWCD, 2012).

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

2.3.5 CONNECTIVITY AMONG GROUNDWATER BASINS

The concept of hydrologic interconnection between the subbasins within the boundaries of United Water Conservation District is embraced by major regulatory and research organizations (e.g., CA State Water Resources Control Board [and predecessors such as CA Division of Water Rights and Division of Water Resources], CA Department of Water Resources, U.S. Geological Survey, Fox Canyon Groundwater Management Agency, Ventura County Watershed Protection District,) active in the area (UWCD, 2014). The following section identifies and summarizes some of the more significant historical studies.

Early water resource studies in the Santa Clara River valley and the Oxnard Plain dating to the 1920s recognized a large degree of connectivity among the groundwater basins in southern Ventura County (California Division of Water Rights, 1928). The recognition that a serious problem of overdraft and seawater intrusion already existed in coastal areas motivated the reorganization of the Santa Clara Water Conservation District (SCWCD) into the United Water Conservation District in 1950, and all assets of the SCWCD were transferred to the new agency. United had a much greater bonding capacity than its predecessor agency, as urban areas became part of United’s tax base. United promptly put this new bonding capacity to use when voters approved the construction of Santa Felicia dam on Piru Creek, with the understanding that “the entire Coastal Plain is dependent upon the Santa Clara River system for its water supply.” United also recognized that the groundwater basins within the district boundaries operated as components of a large hydrologic system, and that the water-bearing materials of the “alluvial formation not only underlies the entire Santa Clara Valley but also extends beneath the Coastal Plain from Saticoy to Ventura and Point Mugu” (Hinds, 1953). United hired the esteemed groundwater geologist John F. Mann to further investigate the groundwater basins of the District. Dr. Mann’s (1959) report estimated potential groundwater yields from the various basins, delineated specific aquifer units, and reported on water quality problems specific to some aquifers and locations. Mann’s report also detailed the occurrence of groundwater underflow between the various groundwater basins within the District (earlier reports had commonly focused on rising water and gains in surface water flow around basin boundaries, and less on subsurface flow at these constrictions in the regional groundwater flow system).

Following an extended period of population growth and several dry years in the mid-1970s, the California Department of Water Resources published Bulletin 118-80, *Ground water basins in California*. This publication introduced the “Ventura Central Basin” and reasoned “the four valleys identified in Bulletin 118 (1975) as the Santa Clara River Valley, Pleasant Valley, Arroyo Santa Rosa Valley and Las Posas Valley are contiguous and hydrologically continuous” and stated that “ground water moves into the Santa Clara River Valley from the other three valleys, particularly into the Oxnard Plain.” This change in naming convention sourced from the State’s recognition that the local groundwater basins are more appropriately considered subbasins of a larger regional system. Bulletin 118-80 also identified the Ventura Central Basin as a basin “subject to critical conditions of overdraft” (defined as: “a basin is subject to critical conditions of overdraft when continuation of present water management practices would result in significant adverse overdraft-related environmental, social, or economic impacts”).

In the late 1980s, with financial support from United, Calleguas MWD, and the Fox Canyon GMA, the U.S. Geological Survey initiated a major investigation of the regional alluvial-aquifer systems of the Santa Clara River and Calleguas Creek watersheds. The study of the hydrogeology of the Santa Clara-Calleguas Basin was completed as part of the Southern California Regional Aquifer-System Analysis Program. The regional groundwater system in southern Ventura County was selected as a representative southern California basin for study, with cultural practices and geohydrologic processes common to other basins or groups of basins. Publications from the RASA study noted that “the onshore part of the Santa Clara-Calleguas alluvial basin is about 32 mi long and includes about 310 mi^2” and that “the Santa Clara-Calleguas Basin is a regional ground-water basin that can be divided into 12 onshore subbasins” (Hanson et al, 2003).

Following the authorization of the Sustainable Groundwater Management Act (SGMA) in 2015, DWR revisited their terminology for the Ventura Central basin. The concept that groundwater basins are connected to and influenced by neighboring basins is central to the SGMA legislation. With this concept now generally accepted, the severity of overdraft conditions in the various subbasins of a large system are now classified individually. The Oxnard Plain and Pleasant Valley basins are designated as high priority basins subject to critical overdraft.

3 OVERDRAFT AND SALINE INTRUSION

In general terms, overdraft is considered to exist when groundwater extraction by wells exceeds the long-term recharge rates for a basin. This results in falling groundwater elevations which may cause additional negative impacts such as saline intrusion and land subsidence. Seawater intrusion is a threat in coastal areas where production aquifers may be in direct contact with seawater. A landward gradient can be created when pumping in excess of recharge causes water levels to fall below sea level, allowing seawater to flow laterally into the aquifers. The southern Oxnard Plain is particularly vulnerable to lateral seawater intrusion due to the existence of two deep submarine canyons near the shore at Port Hueneme and Mugu Lagoon. Saline intrusion may also occur away from the coast due to upwelling of brines or the compaction of marine clays when water levels remain depressed for extended periods. There is a long history of overdraft and saline intrusion on the Oxnard Plain.

3.1 HISTORY OF OVERDRAFT

Historic Ventura County precipitation records indicate that the region has experienced several extended drought periods over the past century. The period 1923-1934 was relatively dry, experiencing only two years with rainfall totals greater than average. Although relatively few water level records exist for water wells on the southern Oxnard Plain during at this time, a number of records show water levels below sea level in the early 1930s. The period 1935-1944 was relatively wet, but the summer of 1945 marked the start of another extended dry period. By the early 1950s a number of wells on the southern Oxnard Plain again recorded water levels below sea level. Water levels recovered somewhat in the late 1950s, but depleted basin conditions persisted in the early 1960s before the onset of wetter conditions in the late 1960s. Wide areas of the Oxnard Plain had water levels below sea level again in the mid-1970s and late 1980s, before an extended wet period beginning in 1991 allowed substantial recovery of the aquifers of the UAS. The aquifers of the UAS and LAS are now again substantially depleted following persistent drought conditions beginning in the year 2012. Each of the above drought periods witnessed water levels below sea level near the coast, resulting in episodes of lateral seawater intrusion from the near-shore Hueneme and Mugu submarine canyons.

High chloride levels were first detected in groundwater beneath the Oxnard Plain in the vicinity of the Hueneme and Mugu submarine canyons in the early 1930s (CA DWR, 1965) and became a serious concern in the 1950s. Early monitoring programs used only existing production wells and older abandoned wells as monitoring points; sampling of these wells indicated that there was a widespread area of elevated chloride concentrations in the Port Hueneme to Mugu Lagoon areas. In some instances this reliance on old production wells led to misinterpretations regarding the extent of saline intrusion in the aquifers of the UAS, as high chloride concentrations in some of these samples were related to poor quality water leaking from the Semi-perched aquifer (rather than seawater, as presumed). Interpretations of the historical extent of saline intrusion have been previously characterized by both the USGS (Figure 3.1.1) and the FCGMA's 2007 Update to their Groundwater

Management Plan. The current network of nested monitoring wells on the southern Oxnard Plain allows a more reliable determination of conditions in the various aquifers.

3.2 PREVIOUS STUDIES

In October 1965 the California Department of Water Resources published Bulletin 63-1, *Sea-Water Intrusion, Oxnard Plain of Ventura County.* This report detailed the findings of the DWR's Oxnard Plain investigation that was initiated in 1959 and reported on aquifer conditions observed in 1962 and 1963. The investigation included descriptions of the various aquifer units present in the study area, mapped aquifer thickness in plan view and in cross-section, and detailed the installation of several new monitoring wells completed in specific aquifers. The report included the mapping of the potentiometric surface and chloride conditions in specific aquifers. The rate of advance of lateral seawater intrusion in the Oxnard aquifer near Port Hueneme was estimated at 1,000 feet per year. Also notable was the UAS pumping depression in the Hollywood Beach area where Channel Islands Harbor now exists.

Following the publication of CA DWR Bulletin 63-1, the State Legislature appropriated $310,000 for the construction of an experimental extraction barrier located along Pleasant Valley Road northeast of Port Hueneme (CA DWR, 1970). The facility consisted of five 1,100 gpm extraction wells spaced over one-half mile just west of Ventura Road, discharge piping, multiple observation wells and a cathodic protection system. United personnel operated the barrier between February and September 1967 and again in the winter and spring of 1968. Pumping from the extraction wells was sufficient to modify hydraulic gradients in the vicinity of the demonstration project, although transmissivity of the Oxnard aquifer was greater than expected compared to values obtained elsewhere in the Oxnard Plain basin. The cathodic protection system failed after eight months of operation, leading to the obvious recommendation that noncorrosive materials be used in saline environments. The project did however demonstrate the feasibility of extraction barriers as a means to mitigate seawater intrusion.

Southern California generally experienced drought in the years 1970 through 1977, at a time when population and commerce was growing rapidly. United's replenishment efforts and delivery systems such as the Oxnard-Hueneme pipeline proved insufficient to match water demand, and saline intrusion continued on the Oxnard coastal plain. In March 1979 the State Water Resources Control Board (State Board) published a Staff Report titled *Oxnard Plain Groundwater Study* summarizing much of the earlier DWR work in the area. The report describes existing water projects and imports to the greater Oxnard Plain, and lists a number of potential future projects contemplated by various agencies. The State Board noted the lack of a coordinated effort to resolve the ongoing seawater intrusion problem and suggested the basin might require an adjudication of water rights. The preference for local control was recognized, and the Fox Canyon Groundwater Management Agency was formed by State Assembly Bill No. 2995 in 1982. The agency is charged with preserving the groundwater resources within its jurisdiction, with the pressing need to control extractions from the Oxnard and Mugu aquifers and mitigate saline intrusion on the Oxnard Plain.

In 1989, as previously noted, the USGS initiated their Regional Aquifer-System Analysis study and other cooperative studies with United within the Santa Clara-Calleguas groundwater basin. Calleguas MWD and the FCGMA also contributed funding for the RASA study. As part of those studies, a series of 14 nested well sites, with two or more wells installed at each site, were drilled and completed at specific depths in the Oxnard Plain basin (Densmore, 1996). It was this research effort that determined that some areas previously thought to be intruded by seawater were not, and that high chloride readings from some older production wells were the result of perched water leaking down failed well casings and contaminating the aquifer (Izbicki, 1992; Izbicki et al, 1995; USGS, 1996). During periods of low water levels in the Oxnard aquifer there exists a downward hydraulic gradient from the semi-perched zone to the Oxnard aquifer, and significant leakage is thought to occur.

The USGS also used detailed chemical analyses and interpretive methods to identify various processes that result in elevated chloride in the production aquifers of the UAS and the LAS. These methods allow differentiation between chloride from seawater, deep brines, and poor quality water from the semi-perched zone. Based on the interpretation of water samples from both the new network of monitoring wells and existing production wells, along with some of the geophysical methods detailed below, the USGS developed new interpretations of the extent of saline impacts in the various aquifers near the coast. Another significant product of the USGS work was the construction of a groundwater flow model that simulated heads in UAS and LAS wells throughout the Ventura County portion of the Santa Clara-Calleguas basin (Hanson et al, 2003). Various water resource scenarios were modeled by the USGS, and later by United, using both the original model and later updated versions.

United has routinely monitored the network of coastal monitoring wells since the completion of the RASA studies, and has periodically published the results of this monitoring. United's *2003 Coastal Saline Intrusion Report* (2004) detailed chloride concentrations and groundwater elevations on the southern Oxnard Plain. In 2007 United reported on the *Mugu Seawater/Saline Water Intrusion Monitoring Program,* which was largely funded through an AB 303 grant administered by CA DWR. This project included the installation of a new nested monitoring well in the area north of Mugu Lagoon, aquifer characterization, water quality sampling and the characterization of saline waters observed in the network of USGS coastal monitoring wells, and some groundwater modeling.

United proposed additional studies for the Pleasant Valley basin in 2001 and was awarded grant funding by the CA DWR. United contracted with the USGS to perform flow logging and depth-dependent water quality sampling in a number of deep production wells in the basin. United issued a report on groundwater conditions in the basin, including results from the static and dynamic flow logging performed by the USGS. Modeling results for various future water supply scenarios were included in the report to DWR (UWCD, 2003). The USGS later published three articles in technical journals (Izbicki et al, 2005a, Izbicki et al, 2005b, Newhouse et al, 2005) detailing their observations related to water quality and flow in the deep Pleasant Valley basin wells they sampled.

Geophysical methods have also been used to help delineate the extent of saline groundwater on the southern Oxnard Plain. In 1990 the USGS conducted a large-scale direct current resistivity survey on the southern Oxnard Plain (Zohdy et al, 1993). A total of 94 “Schlumberger” soundings were collected, with resistivity profiles modeled to an effective depth of approximately 500 meters (1,640 feet). Results were calibrated to water quality samples from some of the recently-installed coastal monitoring wells. Geophysical methods such as these allow the mapping of subsurface resistivities at various depths over broad areas, as drilling wells at this many locations would be cost prohibitive.

Also in the early 1990s the USGS conducted down-hole conductivity surveys in several of the new coastal monitoring wells. Results from these surveys indicated that saline intrusion was occurring in individual permeable sand and gravel beds, as opposed to intruding along the entire thickness of the various named aquifers. As intrusion continues, more individual beds are impacted, resulting in increasing chloride levels in long-screen wells. Information gathered in Zohdy et al’s resistivity survey and the down-hole conductivity logging suggest the edges of the recognized lobes of saline water are relatively distinct.

In 2010, with support of a grant from CA DWR, United sponsored a high resolution seismic reflection survey along Hueneme Road, J Street and the Oxnard Industrial Drain on the southern Oxnard Plain (UWCD, 2011). The principal objectives of the study were to delineate depths and structure within the major aquifer units of the UAS and LAS, and to better understand the extent and origin of a large low permeability deposit near the western extent of the survey area.

Also in 2010 United completed a Time Domain Electromagnetic (TDEM) survey on the southern Oxnard Plain, in large part updating the work performed by Zohdy et al (1993) twenty years prior. The TDEM survey covered an area of approximately 30 square miles and consisted of 125 individual soundings (UWCD, 2010). From the field measurements, resistivities associated with saline and brackish waters were estimated in four depth zones. A Protem 47 system was used to estimate resistivities in the upper and lower portions of the UAS (to depths of approximately 500 feet). The more powerful Protem 57 system allowed estimation of resistivities in the upper and lower portions of the LAS (to depths of about 1300 feet). Resistivity values less than 5 ohm-meters were characterized as saline, 5-20 ohm-meters as brackish, and 20-30 ohm-meters as slightly brackish to background. Maps displaying the findings of the TDEM survey are used as base maps in selected figures in the water quality chapter of this report. This 2010 report also reported recent sample results from the network of coastal monitoring wells sampled regularly by United.

In summer 2011 United hired a contractor to conduct borehole surveys in many of the coastal monitoring wells. Conductivity and gamma logging was conducted, and the logs generally showed low resistivities (saline waters) in distinct horizons. More recently, United equipped some Oxnard aquifer piezometers with both pressure transducers and electrical conductivity (EC) loggers. Results of high-frequency monitoring indicate rapid increases in chloride concentration with falling head in some wells. In one well, following suspension of the EC logger near the top of the well screen, recorded EC values rose rapidly from the known calibration value of water being pumped to the surface for sampling. This suggests that even within a 20-foot screened interval, water quality can vary significantly between individual beds.

United's 2010 TDEM survey indicated broad areas of saline water in the vicinity of both Port Hueneme and Mugu Lagoon. Discontinuous areas of low resistivity were also observed at various depths and locations, supporting the concept that saline waters are expelled from fine-grained layers during compaction of sediments. These results are consistent with what was observed by Zohdy et al (1993). United's 2010 TDEM survey results also suggest extensive areas of saline waters near the coastline west of Mugu Lagoon, which differs from Zohdy et al's findings and is inconsistently supported by samples from monitoring wells. There are, however, few wells existing in this area, so confirmation of the water quality in certain deep zones is presently lacking.

3.3 SOURCES OF SALINE WATER

Historic assessments of saline intrusion focused largely on chloride and total dissolved solids (TDS) or electrical conductivity as indicators of water quality degradation. The evaluation of major and minor-ion chemistry, trace element analysis and specific isotope chemistry from samples collected during and since the USGS RASA study has led to the conclusion that chloride degradation in the Oxnard Plain and Pleasant Valley basins is related to four sources and processes (Izbicki, 1991; Izbicki 1992; Izbicki et al, 2005a).

- **Lateral Seawater Intrusion -** the inland movement of seawater (under the influence of a landward hydraulic gradient).
- **Cross Contamination** - the introduction of poor quality water into fresh water aquifer zones via existing wellbores that were improperly constructed, improperly destroyed, or have been corroded by poor quality water in the Semi-perched aquifer.
- **Compaction of Salt-Laden Marine Clays** - the dewatering of marine clays, interbedded within the sand and gravel rich aquifers, yields high concentrations of chloride enriched water.
- **Lateral Movement of Brines from Tertiary formations** - the lateral movement of saline water from older geologic formations that have been uplifted by faulting to positions adjacent to younger freshwater-bearing formations.

Lateral intrusion of seawater is most common near the Hueneme and Mugu submarine canyons where seawater enters confined production aquifers in response to landward hydraulic gradients. Near-shore submarine canyons can shorten the flow path of seawater into onshore coastal aquifers, enhancing the potential for seawater intrusion (Hanson et al., 2009).

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

Clay beds are common both between and within the aquifers of the Oxnard Plain, and saline connate waters may be expelled from these clays as they compact in response to prolonged periods of low pressure within the surrounding aquifer units. Low pressure in the aquifers is commonly caused by groundwater extraction by wells. Saline water (also referred to here as brine) can also originate from older geologic formations, which may be displaced by faulting to a position adjacent fresh water aquifers, or may move upwards from greater depths, along fault traces in response to low pressures in production aquifers (Izbicki et al, 2005a). Lateral movement occurs across a buried fault face near Pt. Mugu where Tertiary rocks are in contact with the younger aquifers.

4 RECENT BASIN CONDITIONS

This section details recent water level and water quality conditions on the Oxnard Plain and in the Pleasant Valley basin. Following four years of below-average rainfall, both natural and artificial recharge totals are far below normal, water levels have fallen, and saline intrusion continues in coastal areas. The distribution of pumping in the basins remains similar to that in prior years.

4.1 RECHARGE AND DISCHARGE

Southern California experienced a wetter-than-average winter in 2011, but from that time through fall 2015 California experienced drought conditions. State Water Project imports, which constitute an important component of the water supply for the City of Oxnard and other coastal communities on the Oxnard Plain, have been less available than in preceding years. Conservation programs and mandates have been successful in reducing some water demand among both urban and agricultural water users in southern Ventura County, but the area's population and industry remain heavily reliant on local groundwater resources.

Drought conditions have resulted in diminished runoff from the watersheds of the Santa Clara River and Calleguas Creek. Both winter stormflow and summer baseflow in these water bodies provide recharge to the Oxnard Forebay basin and the northern Pleasant Valley basin.

4.1.1 ARTIFICIAL RECHARGE

United's current water resource management strategies are largely reliant on runoff from the watershed of the Santa Clara River to be effective. Water is commonly released from Lake Piru in the late summer or early fall, providing direct recharge to the Piru, Fillmore and Santa Paula basins, with additional flow diverted at the Freeman Diversion for use in the groundwater basins of the coastal plain.

The Freeman Diversion is located in the Santa Paula basin, approximately one mile upstream of the northeast margin of the Oxnard Forebay basin. This permanent diversion structure is located nearly eleven miles upstream of the mouth of the Santa Clara River. Water diverted from the river is distributed either to recharge basins in the Oxnard Forebay basin, or directly via pipeline to growers in the Pleasant Valley basin and on the east-central Oxnard Plain basin. The direct delivery of surface water to growers in overdrafted portions of these basins allows them to irrigate with surface water "in lieu" of pumping groundwater. United's last significant conservation release from Lake Piru was in fall 2012. Since that time a continuous release of 7 cfs has been maintained for fish habitat in lower Piru Creek, but water from minor release rates such as this percolates in the upstream portion of the Piru basin.

Diversion totals at Freeman Diversion are lower during drought periods due to the lack of winter storm flows, diminished base flows in the river, flow diversion by upstream diverters, and the lack of fall conservation releases from Lake Piru. Diversion totals for 2015 were the lowest since construction of the Freeman Diversion was completed in 1991, totaling only 2,600 acre-feet. United has a water right to divert up to 144,000 acre-feet per year, and diversions averaged nearly 71,000 acre-feet per year for the period 1991-2014.

The majority of this water diverted in 2015 was routed to the El Rio spreading grounds, where high nitrate concentrations in many of the UAS wells of the O-H well field remain a concern and a challenge for United's operations staff. Approximately 1,300 AF of diverted surface water were recharged at El Rio, and some 1,200 AF were recharged at the Saticoy spreading grounds. No water was distributed to the Piru spreading grounds, the Noble basins, or the Rose basin.

4.1.2 WATER DELIVERIES

Elevated nitrate concentrations in the O-H wells screened in the UAS at United's El Rio facility remained a problem throughout the 2015 calendar year, and District policy requires that health and safety concerns are mitigated before diverted Santa Clara River water is distributed to agricultural users. Therefore, United had to pump the O-H LAS wells in the Oxnard Forebay basin to blend with the high-nitrate water produced by the UAS wells. In 2015 the UAS and LAS O-H wells pumped 10,900 AF for delivery to municipal users in coastal area of the Oxnard Plain basin (Cities of Oxnard and Port Hueneme, and the Naval Base Ventura County).

United delivered no surface water delivery to the Pleasant Valley County Water District in 2015, and no surface water was delivered to the Pumping Trough Pipeline. Both these water delivery systems continued to operate however, relying more heavily than usual on LAS production wells to satisfy irrigation demands.

4.1.3 GROUNDWATER EXTRACTION

Owners and operators of production wells within the boundaries of UWCD are required to report well use to the district. Reporting frequency is semi-annual, for the first and second half of the calendar year. During 2015, reported groundwater extractions totaled 19,400 AF from the Oxnard Forebay, 59,100 AF from the Oxnard Plain, and 18,500 AF from the portion of the Pleasant Valley basin within United's district boundaries. An additional 5,700 AF of pumping was reported to the FCGMA from the northern and eastern portion of the Pleasant Valley basin that fall outside of United's district boundaries.

Reported groundwater production from the UAS and wells screened across both the UAS and LAS in 2015 is shown on Figure 4.1.1. Production occurs from the UAS throughout the Forebay, the northwestern Oxnard Plain and the eastern Oxnard Plain. Few UAS wells are active near the southern portion of the Oxnard Plain basin, due to water quality problems. UAS pumping by the City of Oxnard is consolidated in two primary well fields, so few active wells are shown for the area underlying the City. UAS extraction from the Pleasant Valley basin is relatively minor, and located near the far eastern boundaries of the District.

Reported 2015 groundwater production from the LAS is displayed on Figure 4.1.2. LAS pumping from the Forebay is relatively minor, and concentrated in the area south of United's Saticoy spreading grounds. On the northwestern Oxnard Plain the majority of the groundwater extraction from the LAS is located north of the Santa Clara River. The City of Ventura's Golf Course wells are located here, which export water to the Mound basin. Pumping from the LAS is common in the eastern portion of the Oxnard Plain basin, and in the western Pleasant Valley basin.

The distribution of groundwater pumping by locality and aquifers has not changed significantly in the last few years. There has, however, been increased production from UAS wells within the service area of the PTP. The PTP has struggled to meet demand during the recent drought as surface water has been unavailable, and some growers on the system have relied more heavily on their own wells for crop irrigation.

While the water districts and cities of southern Ventura County have invested in a number of physical projects to import water from the State Water Project, move pumping away from coastal areas vulnerable to saline intrusion, convey water to areas of need and increase the yield of the basins, measures to reduce pumping from the basins has been managed by the Fox Canyon Groundwater Management Agency. Following an allocation base period in the late 1980s, the FCGMA required a series of 5% pumping reductions, approximately every five years, to reduce pumping demands within their area of jurisdiction. Agricultural water users had the option of demonstrating efficient irrigation practices, thereby avoiding the specified pumping reductions mandated for the municipal pumpers. The original goal of a 25% pumping reduction from baseline allocation was achieved in 2012, but this reduction was largely limited to municipal pumpers, as many agricultural users demonstrated irrigation efficiency. Despite the implementation of these various measures to reduce pumping from the coastal basins, chronic overdraft conditions persist in the aquifers of both the UAS and the LAS (FCGMA, 2015).

In April 2014, Emergency Ordinance E was adopted by the FCGMA Board. This ordinance was crafted in response to the severely depleted conditions in the coastal basins, following the lack of substantial rainfall since spring 2011. "Temporary Extraction Allocations" were applied within the FCGMA under this ordinance, resulting in additional pumping restrictions to area wells. Additionally, in February 2015 the County of Ventura passed a well ordinance prohibiting the construction of new wells in the overdrafted basins of Ventura County, including the basins within the jurisdiction of the FCGMA (http://vcpublicworks.org/pwa/groundwater-resources). Replacement wells can still be installed, as the ordinance was intended to limit the expansion of groundwater use rather than to limit existing use. The County has indicated that this ordinance will remain in effect until Groundwater Sustainability Agencies are formed under SGMA within the various medium and high-priority basins.

4.1.4 GROUNDWATER DISCHARGE

Following rare, multiple-year periods of above-average precipitation, artesian conditions have been documented in the western Oxnard Plain and in the area surrounding Port Hueneme. Under these conditions a seaward groundwater gradient is maintained, and there is likely groundwater discharge from the confined aquifers to the Pacific Ocean at Hueneme Canyon. Water level conditions in 2015, detailed in the following section of this report, show water levels in much of the Oxnard Plain and Pleasant Valley basins below sea level. Under groundwater conditions such as these, there is no groundwater discharge from the confined aquifers to the ocean in Hueneme or Mugu Canyons.

Groundwater elevations in the Semi-perched aquifer, however, remain above sea level. Groundwater in this shallow aquifer system is routed to surface water channels and flows to the sea via an extensive network of subsurface "tile drains," lift pumps and ditches. Natural groundwater discharge from the Semi-perched aquifer also contributes water to unlined streams and channels, coastal wetlands and estuaries, and direct seepage at the beach/ocean interface.

4.2 GROUNDWATER ELEVATIONS

The history and occurrence of saline intrusion in the coastal basins of southern Ventura County is closely associated with groundwater elevations in the basins. Under pre-development conditions there was natural groundwater flow from inland recharge areas well above sea level to the offshore extensions of the major aquifer units. There are historical accounts of groundwater discharge to the near-shore Hueneme and Mugu submarine canyons, and pervasive artesian conditions in the confined aquifers of the Oxnard Plain (Freeman, 1968). Following the widespread development of irrigated agriculture and population growth on the Oxnard Plain, groundwater extraction exceeded recharge to the basin in many years. When water levels in the onshore confined aquifers fall below sea level a landward gradient is established, allowing seawater to laterally intrude into the fresh water aquifers and migrate toward areas with the lowest hydraulic heads (areas of pumping). Landward gradients were first observed in the late 1930s, but were soon reversed by a wet climatic period. By 1945 groundwater elevations began to decline again, and by 1949 certain near-shore water levels were as much as 30 feet below sea level (CA DWR, 1970). Historical water level hydrographs from selected wells in the coastal basins of the District are illustrated in Figures 4.2.1 through 4.2.4, where depressed water levels associated with the drought periods of the early 1960s, mid 1970s, late 1980s and recent years are apparent in many wells.

UAS water levels in the Forebay fluctuate by as much as 120 feet, with groundwater elevations in the southern portion dropping below sea level during periods of drought and recovering during wet periods (Figure 4.2.1). High water levels in the Forebay provide both recharge and hydrostatic pressure to the confined aquifers of the Oxnard Plain and other surrounding basins.

As seen on Figure 4.2.2, the range of recorded groundwater elevations from UAS wells on the Oxnard Plain diminishes with distance from the Forebay. The records from wells 02N22W31A01S and 01N22W02A02S show extended periods when groundwater elevations were below sea level, corresponding with drought periods in the early 1960s, mid 1970s, late 1980s and in recent years. Well 01N22W20J08S, located near Port Hueneme and the Hueneme submarine canyon, has the least variability among the wells shown. This is not only related to the well's distance from the Forebay (where most basin recharge occurs) and from active supply wells, but also its proximity to Hueneme Canyon. When water levels in this well fall below sea level, the ocean serves as a nearby constant-head source of recharge.

Figure 4.2.3 shows available water level records for selected LAS wells on the Oxnard Plain. Most of the water levels shown are below sea level, some by more than 100 feet. Superimposed on the longer record, an annual water level fluctuation of about 30 feet is apparent in some of the wells, caused by seasonal changes in both recharge and pumping rates related to agricultural use on the Oxnard coastal plain.

Water level records from three Pleasant Valley wells are shown in Figure 4.2.4. Wells 01N21W03C01S and 01N21W15J04S in the central portion of the basin show water levels below sea level for the entire period of record dating to the mid-1960s. In the northern portion of the basin, well 02N20W19L05S shows water level recovery of approximately 250 feet between 1993 and 2011, before declining about 100 feet in recent years. The water level recovery in this well is related to increased recharge from surface flows in Arroyo Las Posas.

Water level records from the network of coastal monitoring wells installed as part of the RASA study are included in Appendix A, Figure A-1. Measurements from individual wells are plotted with others from the same well site. Significant vertical gradients are apparent a number of the well locations, with lower groundwater elevations common to the deeper wells.

4.2.1 UAS GROUNDWATER ELEVATIONS, SPRING AND FALL 2015

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

Groundwater elevation contours for the UAS in spring 2015 are shown for the Forebay and Oxnard Plain in Figure 4.2.5. These conditions are far from typical, with water levels in much of the Forebay and virtually all of the Oxnard Plain below sea level. In the northern portion of the Forebay, water levels were above sea level and gradients were steeper than usual (and groundwater flow direction is interpreted to be more southerly than usual). The -10 foot contour is drawn within about a mile of the coast across the entire Oxnard Plain coastline, indicating landward gradients at all locations. The potentiometric surface in the interior portions of the basin is nearly flat, with a few minor pumping depressions indicated. In Appendix A, Figure A-2 shows UAS contours from spring 2012, with more typical groundwater flow from the Forebay to distal portions of the Oxnard Plain. Between spring 2012 and spring 2015 the zero elevation contour moved about ten miles inland, from near Mugu Lagoon to the northern portion of the Forebay. In 2015 the lowest groundwater elevations were recorded in the middle of the basin, and not at the southern margin as is typical.

By fall 2015, UAS groundwater elevations were lower than in the spring, with the -20 foot contour drawn near the coast all along the margin of the basin (Figure 4.2.6). The hydraulic gradient in the interior of the basin was still nearly flat, and the lowest Oxnard aquifer water levels were recorded in the Forebay near United's El Rio spreading grounds where the O-H well field is in operation. Steep groundwater gradients exist between this location and the northern extent of the Forebay, where heads as high as 56 feet were recorded.

In many areas of the Forebay and Oxnard Plain, groundwater elevations in the Mugu aquifer are similar to or a few feet lower than those in the Oxnard aquifer. On the southern Oxnard Plain, and most notably in the area surrounding Mugu Lagoon, water levels in the Mugu aquifer may be as much as 30 feet lower than in the Oxnard aquifer. Groundwater elevation hydrographs for all coastal monitoring wells are included in the Appendix A, where the separation between the UAS piezometers is shown for individual well locations. Mugu aquifer heads in some wells south of Hueneme Road are nearly as deep as LAS heads. United contours Oxnard aquifer heads (to represent the UAS) by convention, despite the lower Mugu aquifer heads at some well sites. Water levels from wells screened in both the UAS and LAS are mapped with UAS wells for contouring. Likewise, if water levels are available for more than one LAS well at the same location, the intermediate or highest level is selected for contouring.

4.2.2 LAS GROUNDWATER ELEVATIONS, SPRING AND FALL 2015

Figure 4.2.7 displays groundwater elevations from Lower Aquifer System wells in the Oxnard Forebay, Oxnard Plain and Pleasant Valley basin from spring 2015. LAS water levels were below sea level for the entire Oxnard Plain, most of the Forebay, and much of the Pleasant Valley basin. The highest water levels were recorded in the northern Forebay and the northern Pleasant Valley basins, which are recognized areas of recharge. Although LAS water levels are lower than in preceding years, the overall pattern of the contours remains similar. A persistent broad pumping depression is centered on the Oxnard Plain/Pleasant Valley basin boundary, where several wells recorded spring 2015 water levels at least 110 feet below sea level. This pumping depression extends to the coast near the Mugu submarine canyon, where the spring 2015 water level in well CM1A-565 was measured at 58 feet below sea level.

Figure 4.2.8 displays contours of groundwater elevations recorded in LAS wells in fall 2015. Water levels in the Forebay fell about 10 feet since the spring, but the main pumping depression shifted eastward into the Pleasant Valley basin. An area of more than three square miles had groundwater elevations deeper than 150 feet below sea level, located between the Bailey fault near Round Mountain and the Pleasant Valley basin boundary to the west. The broader pumping trough with groundwater elevations deeper than 100 feet below sea level is centered beneath the Oxnard Plain/Pleasant Valley basin boundary, extending from the Camarillo Hills to near Mugu Lagoon. The water level at the coast near Mugu Lagoon was measured at 98 feet below sea level. LAS piezometers surrounding Port Hueneme recorded water levels ranging from -19 to -40 feet below sea level in fall 2015.

Figures 4.2.7 and 4.2.8 show steep groundwater gradients in the northeast Oxnard Plain near the West Las Posas basin boundary. Along the northern portion of the West Las Posas basin boundary, the production wells used for water level monitoring tend to be screened in the Hueneme aquifer. To the south in the area west of the Camarillo Hills, the Hueneme aquifer is more fine-grained and interbedded, and most wells are completed in deeper beds of the Fox Canyon aquifer where heads are lower. There are steep LAS gradients in this area as the character of the Hueneme aquifer changes, but the apparent gradient displayed in the contouring is also influenced by the shift to deeper well completions to the south. The deep LAS monitoring wells at the El Rio spreading grounds record water levels similar to the Fox Canyon wells near the Camarillo hills, so contouring water levels from the deeper LAS wells in the Forebay would extend the eastern Oxnard Plain/Pleasant Valley pumping depression into the Forebay. United’s modeling of groundwater flow in the coastal basins shows the LAS aquifers of the Oxnard Plain do receive significant recharge from the Forebay, but much of the groundwater leaves the Forebay as flow in the UAS. Across the Oxnard Plain there is significant downward groundwater flow from the UAS to the LAS, especially in areas where large vertical gradients exist and aquitards between the aquifers are thin or discontinuous.

4.3 GROUNDWATER QUALITY

The principal water quality concern for the Oxnard Plain basin since the late 1940s has been saline intrusion. Elevated chloride concentrations are a concern for both irrigation and potable uses. The maximum recommended chloride concentration in drinking water is 250 milligrams per liter (mg/l), and the upper advisory limit is 500 mg/l (California Department of Health Services, 2000). The production of food crops common to the Oxnard Plain is generally not feasible when chloride in irrigation water approaches the lower drinking water limit, and certain sensitive crops are impaired by chloride concentrations as low as 100 mg/l.

About 70 coastal monitoring wells on the Oxnard Plain have been sampled regularly by United staff since being installed by the USGS in the early 1990s. These monitoring wells have relatively short screened intervals (commonly 20 or 40 feet) positioned within the major units of the Upper Aquifer System, including the Oxnard and Mugu aquifers, and the Lower Aquifer System, including Hueneme, Fox Canyon and Grimes Canyon aquifers. These monitoring wells allow sampling of water from a discrete zone in the target aquifer. Production wells, in contrast, commonly have long screened intervals that may span multiple aquifers, and samples from these wells represent a blend of waters from various depths. The following section deals primarily with water quality samples collected in fall 2015, with some discussion of trends in specific wells.

4.3.1 CHLORIDE CONCENTRATIONS

This section provides a description of chloride concentrations within each mapped aquifer across the coastal areas of the Oxnard Plain basin, where lateral seawater intrusion is a concern. Figures 4.3.1 through 4.3.6 present chloride results from fall 2015 sampling for each monitoring well. On the figures, wells are labeled by their common name and the depth of the bottom of the well screen (e.g. CM5-220 is screened from 200 to 220 feet below land surface). Wells GP2, CM7, SWIFT and SW penetrate only the UAS, while all other well sites have wells completed in both the UAS and the LAS. Figures 4.3.2 through 4.3.6 use results from United's 2010 geophysical survey as a base image. The density and distribution of available monitoring wells is fairly poor for the large area of the southern Oxnard Plain, but the TDEM findings of high salinity are substantiated in a number of wells. In other areas there is poor agreement between sampled chloride concentrations and areas of impact modeled by the TDEM geophysical methods. Without additional monitoring well installations it is difficult to ascertain whether high salinity exists in beds not screened by the short screened intervals of the monitoring wells, or if the geophysical survey results are inaccurate. The maps include an interpreted line suggesting the current inland extent of saline intrusion based on measured concentrations from monitoring wells, United's 2010 geophysical survey, and other prior studies detailing the extent of the intrusion front. Saline impacts associated with the compaction of sediments or brine migration have a more random distribution, however, and are not necessarily represented by a frontal boundary.

United samples monitoring wells along the coastal portion of the Oxnard Plain for general minerals, metals and select trace elements. Wells with stable chemistry that are not impacted by saline intrusion are sampled annually, while wells in impacted areas or areas of variable water quality are sampled as often as four times per year. General mineral analyses are performed for some wells only on alternating years, with an abbreviated list of analytes run on other years. Special sampling events for specific metals and trace elements are conducted infrequently. Groundwater quality results from 2014 and 2015 (general mineral) samples are tabulated in Appendix B, Tables B-1 and B-2.

Time series graphs for individual monitoring wells, displaying recorded chloride concentrations and EC over time, show water quality trends for wells grouped by aquifer (Appendix B, Figures B-1 through B-7). Many of the coastal wells were installed near the end of a significant drought period (1989-1991), when high chloride levels were recorded in a number of the coastal monitoring wells. The period 1993 through 2005 was among the wettest on record in Ventura County, and chloride concentrations in some coastal wells near Port Hueneme decreased during this period. Other wells, in the area surrounding Mugu Lagoon, have shown continuous increases in chloride concentration since they were installed.

4.3.1.1 SEMI-PERCHED AQUIFER

The shallow groundwater of the Semi-perched aquifer is rarely used for supply purposes, and relatively little water quality data exists for this zone. Water quality of the Semi-perched zone can vary dramatically with time and location, ranging from fresh to saline. United's fall 2015 sampling event documented chloride concentrations in Semi-perched wells ranging from 77 mg/l to 13,000 mg/l (Figure 4.3.1). Near Port Hueneme, groundwater of this unit is consistently saline, with chloride concentration recorded at 13,000 mg/l in well A2-70. Chloride concentrations are much lower east of Port Hueneme, with well SW recording 398 mg/l chloride, and fresh water observed in the SWIFT well (77 mg/l chloride). Farther inland between Port Hueneme and Point Mugu, chloride concentrations are variable in the SCE well, with higher chloride concentrations observed during dry periods (Figure B-1). Elevated chloride of 1,950 mg/l was recorded in well SCE-38 in fall 2015.

4.3.1.2 UPPER AQUIFER SYSTEM, NORTHWEST OXNARD PLAIN AND MOUND BASIN

Widespread degradation by chloride has not been documented in the UAS wells located north of Channel Islands Harbor. Well CM3-145 is located near the coast in the northwest portion of the Oxnard Plain, and has consistently had chloride concentrations well under 100 mg/l (Figure B-2). Farther north in the Mound basin, well MP-240 is located near the north jetty of Ventura Harbor, and installed by a cooperative agreement between United and the City of Ventura to monitor for seawater intrusion. Chloride levels from this coastal well have been stable since monitoring began, measuring 120 mg/l in 2015.

4.3.1.3 OXNARD AQUIFER

There are two distinct areas of known saline intrusion in the Oxnard aquifer, generally occurring near and southeast of Port Hueneme and in the area surrounding Mugu Lagoon (Figure 4.3.2). Near Port Hueneme, chloride concentrations have been increasing since 2013 in the area west of the harbor, with 1,080 mg/l recorded in well A2-170 in fall 2015 (Figure B-3). Concentrations in well A1-195 located to the east of the harbor have remained stable, and were measured at 159 mg/l in 2015.

Southeast of Port Hueneme, an area of elevated chloride is observed and includes the locations of coastal wells CM4 and CM7, and the more inland wells SW and SWIFT. The highest fall 2015 chloride concentrations are found near the coast, with 5,520 mg/l recorded in well CM4-275 and 1,890 mg/l in well CM7-190. Well CM7-110 has had nearly a ten-fold increase in chloride, rising from 2,470 mg/l in 2013 to a peak of 22,500 mg/l in March 2015 (Figure B-3). Since 2014, chloride samples from this well have been more concentrated than seawater (~19,000 mg/l). It is interesting to note that nearby coastal well clusters CM4 and CM7 both have two wells screened in the Oxnard aquifer. Each of these four wells have significantly different chloride concentration in 2015, and the lesser chloride is recorded in the shallower well at CM4 and the deeper well at CM7. To the southeast of well CM7, the coastal well CM5 records relatively low and fairly stable chloride. The more inland wells SW and SWIFT display long-term trends discussed later in this report; these Oxnard aquifer wells recorded 2015 chloride concentrations of 462 and 1,100 mg/l, respectively.

Located on the coast south of Mugu Lagoon and near the Mugu submarine canyon, well CM1A-220 has historically had chloride levels approaching that of seawater, recorded at 16,700 mg/l in fall 2015. Northwest of that location, water quality in well CM6-200 remains moderately degraded, measuring

2,060 mg/l chloride in 2015. At the DP and Q2 well sites, Oxnard aquifer chloride was measured at 374 and 402 mg/l, respectively, in fall 2015.

Farther inland and north of Mugu Lagoon, the Oxnard aquifer samples from the GP and SCE well sites do not show chloride degradation.

4.3.1.4 MUGU AQUIFER

Chloride impacts are less widespread in the Mugu aquifer than in the Oxnard aquifer. Well CM2-280, located west of Port Hueneme and on the coast near the Hueneme submarine canyon, recorded a slight increase in chloride in recent years (Figure B-4). Wells A1-320 and A2-320, also located near the port, record chloride concentrations common to unimpaired areas of the Mugu aquifer.

The Mugu aquifer wells located north and northwest of Mugu Lagoon record high chloride values that have increased fairly consistently since the wells were installed. Fall 2015 chloride concentrations in wells CM6-300, Q2-285 and Q2-370 ranged from 2,590 to 2,900 mg/l (Figure 4.3.3). These elevated chloride concentrations are believed to be associated with brines and not direct lateral seawater intrusion, as discussed in Section 4.3.4 below.

The remaining piezometers completed in the Mugu aquifer and located in both the coastal and more inland areas between Port Hueneme and Point Mugu consistently have low chloride concentrations ranging from about 30 to 40 mg/l.

4.3.1.5 LOWER AQUIFER SYSTEM, NORTHWEST OXNARD PLAIN AND MOUND BASIN

Chloride data from LAS wells located in the northwestern Oxnard Plain (well CM3) and the Mound basin (well MP) are plotted on (Figure B-2). Sampling of these nested monitoring wells does not indicate saline intrusion in the LAS. Artesian conditions have existed intermittently in wells CM3 and MP since 1995. Seaward hydraulic gradients are thought to be common in the LAS at these locations, and the threat of seawater intrusion does not appear likely under such conditions.

4.3.1.6 HUENEME AQUIFER

Relatively few coastal monitoring wells are completed in the Hueneme aquifer, and all of those are located in the area surrounding Port Hueneme. Wells A1-680 and CM4-760, located east of the port, do not indicate any recent or historic chloride impacts (Figure B-5). Three of the four Hueneme aquifer wells located west of the port, however, have recorded elevated chloride concentrations (Figure 4.3.4). The highest chloride concentrations are recorded in well CM2-760, generally measured at greater than 10,000 mg/l since fall 2003. An increase in chloride has also been observed since 2014 in well CM2-520, recently reaching 365 mg/l. Chloride concentrations in this well reached 2,800 mg/l in 1993, but this peak concentration was followed by a long period of decreasing chloride lasting until 2014. The A2 well cluster is located north of the CM2 site, and chloride impacts have not been observed in well A2-560. Chloride concentrations have however increased in well A2-740 since 2004, reaching a high of 208 mg/l in fall 2015.

No Hueneme aquifer wells exist in the area surrounding Mugu Lagoon, as the sediments that make up the Hueneme aquifer are interpreted to have been uplifted and eroded in this vicinity.

4.3.1.7 FOX CANYON AQUIFER

The sampling of existing monitoring wells screened in the Fox Canyon aquifer near Port Hueneme and nearby coastal areas to the east has not detected evidence of saline water intrusion (Figure 4.3.5 and Figure B-6).

The Fox Canyon aquifer wells surrounding Mugu Lagoon, however, document continued water quality degradation. Well Q2-640 is located north of Mugu Lagoon, samples show steady degradation since the well was constructed, and the fall 2015 sample contained 5,140 mg/l chloride. Northwest of Mugu Lagoon, chloride concentrations in well CM6-400 have had an increasing trend since 1999, measuring 1,430 mg/l, in a recent sampling event. Well CM6-550 has shown a decreasing trend in chloride concentrations since a significant peak in 2004, most recently measuring 205 mg/l chloride. The Fox Canyon aquifer wells of the DP cluster, located north of CM6 well cluster, have differing trends. DP-580 has recorded an increasing chloride trend, rising from 460 to 1,790 mg/l throughout the period of record, while DP-450 has had a more stable chloride trend (average concentration of approximately 1,000 mg/l) since 2007.

Further inland, a slightly elevated chloride concentration of 99 mg/l was recorded in fall 2015, which is consistent with the ten-year record for well GP1-740. Well GP1-460 does not show chloride impacts, nor does well SCE-414 located farther to the north.

4.3.1.8 GRIMES CANYON AQUIFER

There are no Grimes Canyon aquifer monitoring wells at Port Hueneme, and wells CM4-1395 and CM5-1200, located near the coast to the southeast of the port do not show evidence of saline intrusion (Figure 4.3.6).

Grimes Canyon wells surrounding Mugu Lagoon do show significant chloride impacts (Figure B-7). At the coast near the Mugu submarine canyon, well CM1A-565 has become steadily more saline since its installation in 1989, with 5,820 mg/l chloride recorded in fall 2015. North and northwest of Mugu Lagoon, deterioration of water quality is documented at the Q2 and DP well locations. Chloride concentrations of 14,300 and 4,050 mg/l were recently observed in wells Q2-840 and Q2-970, respectively. Northwest of that location, chloride was measured at 6,060 mg/l in well DP-720 in fall 2015. The rising chloride concentrations in these deep wells in the Mugu Lagoon area is thought to be associated with brines and not the directed lateral intrusion of seawater, as discussed in Section 4.3.4.

4.3.2 MAJOR ION CHEMISTRY

Various studies have evaluated age and provenance of coastal groundwaters using major-ion chemistry and small changes in minor ion and trace-element concentrations (Izbicki, 1991, Izbicki et al, 2003 and Land et al, 2004). Although no new isotopic analyses were performed for this report, some interpretations based on recent major-ion chemistry and trace element analysis from prior sampling events are presented here.

A number of researchers have documented the chemical characteristics of saline waters in marine sedimentary depositional environments. If the original pore water is assumed to be seawater trapped at the time of deposition, a number of geochemical changes can take place over time. Membrane processes, bacterial sulfate reduction, cation exchange, and other processes are often important elements in the evolution of brines in sedimentary depositional environments (Drever, 1988). Chemical changes such as those that occur during saline intrusion and sulfate reduction are often revealed by evaluating changes in the relative abundance of major ions in solution. Major ion analysis is helpful in determining certain chemical conditions and progressions, but not the source of brines causing changes in water quality.

Numerous methods have been developed for the graphical display and comparison of major ion composition of water samples. One popular technique was advanced by Piper (1944). This method employs a trilinear diagram to effectively characterize a large number of samples in a single figure. Piper plots show the relative contribution of major cations and anions as a percentage of the total ion content of the water. In the standard triangular Piper diagram, major cations are plotted in a smaller triangle in the lower left. Within this smaller triangle, samples for which calcium is the dominant cation plot in the lower left. Samples dominated by sodium and potassium plot in the lower right, and samples dominated by magnesium plot at the top of the triangle. Major anions are shown in the smaller triangle to the right. Samples dominated by chloride plot in the lower right, bicarbonate in the lower left, and sulfate at the top. Points from the cation and anion triangles are projected to the central diamond and display the general chemical class of each water sample.

Another common technique to graphically display general water chemistry is the Stiff diagram (Stiff, 1951). This method shows the concentrations in milliequivalents per liter (meq/l) of the major ions as a proportional polygon, with dominant cations plotted on the left and anions on the right. The greater the concentration of the various ions, the larger the area of the respective limbs of the diagram.

4.3.2.1 PIPER DIAGRAM

Piper diagrams with samples differentiated by aquifer system (semi-perched, UAS, and LAS) are presented on Figure 4.3.7. Samples delineated by aquifer system and chloride concentration (above or below 100 mg/l) are presented in Figures 4.3.8 and 4.3.9. Previous analyses of major ion data from coastal wells on the Oxnard Plain demonstrated that groundwater of the UAS and LAS have distinct chemical compositions (Izbicki, 1991). For example, groundwater in the LAS tends to be enriched in bicarbonate and depleted in sulfate in comparison with UAS (Figure 4.3.7).

For all of the 2015 monitoring well samples, calcium, or sodium plus potassium are the dominant cations, illustrated in the lower left triangle of the Piper diagram. The greatest concentration of samples, and notably the UAS samples not impacted by high salinity, show calcium as the dominant cation (Figures 4.3.8 and 4.3.9). From this cluster of points, most other samples trend toward a greater sodium prevalence. This is common to groundwater of other coastal sedimentary basins in California (Izbicki et al, 2003 and Land et al, 2004).

The distributions of dominant anions are shown in the lower right triangle of the Piper diagrams. Most samples with high chloride concentration plot in the lower right, indicating chloride is the dominant anion. In these samples, the relative concentration of sulfate is small, but the measured sulfate concentration can be elevated (e.g., wells CM1A-220, CM4-275, CM7-110 and CM2-760). Among samples not impacted by high chloride, sulfate and bicarbonate are the dominant anions (carbonate is rarely observed in groundwater in coastal Ventura County). Bicarbonate is strongly represented in some LAS samples not impaired by high chloride concentrations (Figure 4.3.9).

Elevated sulfate (above 500 mg/l) is found mainly in UAS wells, while the generally reducing conditions in the LAS results in the consumption of sulfate and the generation of hydrogen sulfide. Sulfate reduction in the LAS in the Pleasant Valley basin has been attributed to the oxidation of organic carbon from aquifer materials or from organic carbon dissolved in the groundwater. Sources of sulfate include the oxidation of reduced sulfur in sulfide minerals from sedimentary deposits and sulfur in marine evaporate deposits (Izbicki et al, 2005a).

The Piper diagrams shown in Figures 4.3.10 and 4.3.11 present water quality data from 1989 to 2015 for select UAS and LAS wells with both low and elevated salinity. The samples with high salinity plot along the upper right edge of the central diamond diagram (Figure 4.3.10), as calcium chloride to sodium chloride waters. In both UAS and LAS plots, two wells are presented as examples of high chloride to illustrate the range in major ion chemistry observed in groundwater impacted by high salinity. The shift in plotting position along the right edge of the central triangle diagram is the result of exchange of sodium for calcium and magnesium on clay minerals within aquifer deposits as chloride concentrations increase (Izbicki 1991).

For UAS wells not affected by salinity, samples plot in the middle of the central diamond of the Piper diagram (Figure 4.3.10). Groundwater in the UAS receives the majority of recharge, which mixes with existing groundwater. UAS samples trend towards mixing in addition to some base exchange (Figure 4.3.11) (Hanson et al, 2009). The groundwater in the deeper aquifers of the LAS are older waters and are removed from significant amounts of recent recharge from local runoff and imported water (Hanson et al. 2009).

For LAS wells with low chloride concentrations, three examples are presented (A2-940, CM4-746 and CM4-1395) due to the range in major ion chemistry observed in the deeper aquifer wells (Figure 4.3.12). Samples not affected by salinity plot in the middle of the central diamond shaped figure, and range from calcium sulfate waters to sodium bicarbonate waters. Sodium and bicarbonate are the dominant ions in CM4-760, likely a result of significant sulfate reduction and cation exchange. These lower aquifers exhibit a trend towards cation exchange, calcite precipitation, sulfate reduction and gypsum dissolution (Figure 4.3.11) (Hanson et al, 2009).

4.3.2.2 STIFF DIAGRAM

Stiff diagrams use proportional polygons to show the relative concentrations of major cations and anions in milliequivalents per liter (meq/l). In Appendix B, Figures B-8 and B-9 present Stiff diagrams for the same selected UAS and LAS wells used as examples for the Piper diagrams in the preceding section. Recent samples from these wells are used to illustrate the general shapes of Stiff diagrams for coastal wells that have high or low salinity. A complete list of Stiff diagrams for the fall 2015 monitoring well samples are shown by aquifer designation in Appendix B, Figures B-10 through B-15.

In general, wells that are not affected by high salinity have Stiff diagrams of similar appearance and characterized by narrow diagrams (e.g., wells CM3-145, A2-940, CM4-760 and CM4-1395). A Stiff diagram for seawater has a shape characterized by a top and bottom bulge (more prominent on top) and converging middle, denoting sodium and chloride as the dominant ions, along with high concentrations of magnesium and sulfate. Samples from coastal monitoring wells on the Oxnard Plain having elevated salinity have varied Stiff diagram shapes. Some have shapes similar to these for seawater (wells CM1A-220 and CM2-760). Other high-chloride wells have Stiff diagrams characterized by the top right (chloride) extended more than the top left, indicating relatively lower sodium and potassium levels, with the left-middle extended in some samples having more calcium (wells Q2-285 and DP-720, Figures B-8 and B-9). The Stiff diagrams aid in recognizing typical geochemistry associated with saline intrusion processes. One geochemical change readily apparent on the Stiff diagrams is the rapid exchange of sodium for calcium and magnesium on clay minerals, as the prominent sodium (plus potassium) limb common to seawater is soon diminished with flow through the local aquifers.

Although the Piper and Stiff graphical interpretations of water quality may not provide all the information required to classify the source of high salinity in coastal wells, these graphical methods do allow a preliminary characterization of what chemical processes may be taking place and help guide further geochemical investigation.

4.3.3 MINOR IONS AND TRACE ELEMENTS

A number of researchers have used specific trace elements to assist in evaluations of sources of saline intrusion in coastal California aquifers. The USGS has long been active in the advancement of these techniques. Piper and Garrett (1953) identified the minor ions iodide and bromide as useful indicators in identifying the source of brines, along with the trace elements boron and barium. This research was largely related to the identification of sources of chloride in production wells in coastal Los Angeles and Orange Counties.

In water affected by saline intrusion, minor ions and trace elements are often present in concentrations much lower than chloride concentrations. By presenting trace elements as a ratio relative to chloride, and plotting against chloride concentration, small changes in trace element and minor ion concentrations become much more apparent (Izbicki et al, 2003). Chemical concentrations are converted from mass-based units (mg/l or ug/l) to millimoles per liter, allowing direct comparisons between the various chemical ratios. Minor ion and trace elements, including iodide and bromide data, presented in this section are from coastal monitoring wells sampled by United staff in winter 2007 (UWCD, 2007). Because these ions are useful in identifying samples impacted by brines of various origins, and no more recent data set is available, data from the 2007 sampling event is presented again in this report.

Iodine concentrations in groundwater have been used to assist interpretations of groundwater age within a regional aquifer system. In solution, this element is generally represented as iodide. Iodide is reactive in groundwater systems, and water flowing through rocks of marine origin may have iodide concentrations greater than that of seawater (Izbicki et al, 2003). Iodide concentration in seawater is quite low, totaling approximately 0.06 mg/l. Some near-shore marine plants such as kelp concentrate iodine from seawater (Hem, 1985). As a result of this near-shore concentration, marine rocks, and especially sedimentary deposits of coastal origin, may contain elevated iodide. Another mechanism for the concentration of iodide is the reducing conditions common to areas of saline intrusion, which may promote increased mobilization of iodide relative to other locations within the basin (Izbicki, 1991).

Figure 4.3.13(a) displays chloride/iodide molar ratios plotted relative to chloride in millimoles per liter for samples collected in 2007. Three end members are identified in the plots, including seawater, “oilfield brine” and a representative sample of native groundwater not impacted by salinity (Hem, 1985 and Izbicki et al., 2005a). Samples enriched with iodide have a lower chloride/iodide ratio, and plot below the seawater mixing line shown on the figures.

Figure 4.3.13(b) displays chloride/iodide molar ratios for samples from the UAS and wells completed in the Semi-perched aquifer. Wells SCE-130 and MP-240 recorded the lowest chloride/iodide molar ratios of the coastal Ventura County monitoring wells. However, neither of these two wells have high chloride concentrations, and it is unclear why these wells have more iodide enrichment relative to other wells not impaired by high chloride. UAS wells from the Q2 and CM6 well sites have iodide enrichment and high chloride, consistent with prior interpretations of brine influence in the area north of Mugu Lagoon. Well CM7-110, approximately 2.4 miles distance up the coast (northwest) from well CM6, and located east of the Ormond Beach wetlands, also has a brine signature (and since late 2014 has recorded chloride concentrations greater than seawater). The sample from well CM1A-220 is similar to seawater, but it also shows some iodide enrichment. Among the semi-perched wells, A2-70 is saline and plots on the seawater mixing line; wells SCE-38, SW-65 and SWIFT-65 are less saline but do show iodide enrichment.

Samples from LAS wells show a number of wells having high chloride levels that are also enriched with iodide (Figure 4.3.13(c)). Among the 2007 LAS samples with elevated chloride concentrations, the lowest chloride/iodide ratios were measured in the DP wells. These wells are located more than 2.5 miles from the coastline inland from the Mugu submarine canyon. Well CM1A-565 is located at the coastline near the Mugu submarine canyon, but iodide concentrations suggest salinity is related to brines more than seawater. The LAS completions of the Q2 well cluster also displayed iodide enrichment above that of seawater, suggesting that brines of various origins are impacting the wells of the Q2 site. Variable and increasing chloride has been recorded in wells CM6-550 and CM6-400, respectively, and both these wells showed enrichment with respect to iodide in the 2007 data set. The USGS recognized brine impacts in the LAS wells of the DP, Q2 and CM1A sites following their installation and sampling as part of the RASA study. Iodide enrichment is now recognized in the LAS wells of the CM6 cluster, indicating the area impacted by brines in the greater Mugu area is expanding.

Bromide concentrations can also be used to assist determinations of origins and residence times of groundwater in coastal basins. Unlike iodide, bromide is considered to be non-reactive in aquifer environments and behaves much like chloride (Izbicki et al, 2003). Seawater and oilfield brine samples identified as end member water sources have bromide concentrations of about 65 mg/l and 11 mg/l. Bromide has been measured at high concentrations in some brines and has been observed to gradually increase as groundwater flows through certain coastal California aquifers (Hem, 1985 and Izbicki et al, 2003).

Figure 4.3.14(a) displays the 2007 chloride/bromide molar ratios for all the coastal monitoring wells, plotted relative to chloride in millimoles per liter. The molar ratios of chloride/bromide are less variable than the chloride/iodide ratios for the same set of samples. The chloride/bromide molar ratio of seawater is approximately 640, and samples plotting below this line indicate higher bromide concentrations relative to seawater (Land et al, 2004). Significant enrichment of bromide has been documented in oilfield brines, allowing an evaluation of impacts from these waters on fresh aquifers in coastal California (Piper and Garrett, 1953).

Results from the winter 2007 sampling of the coastal Ventura County monitoring wells reveal bromide enrichment in several wells. Samples from UAS and Semi-perched wells are shown in Figure 4.3.14(b). The lowest chloride/bromide ratio was observed in well MP-240. This well is located just north of Ventura Harbor, in the Mound groundwater basin. The aquifers of this coastal area have likely experienced less groundwater flushing than those in the southern Oxnard Plain. Well CM7-190 showed minor bromide enrichment, but other UAS wells did not.

A few LAS wells had some bromide enrichment, most notably the deeper wells of the DP cluster (Figure 4.3.14(c)). The higher bromide in well DP-720 could be sourcing from brines from deeper formations in the basin. Conditions in the LAS DP wells are believed to be strongly reducing, and all sulfate in these zones has been converted to other sulfur compounds. This may result in other chemical changes that have not been thoroughly evaluated at this time. The samples from wells CM3-1490 and MP-1070 also show bromide enrichment, but these wells have low chloride concentrations.

The UAS and LAS wells impaired by high salinity in 2007 remain impaired in 2015. While chloride concentrations in the individual wells may have changed, the process associated with the degradation (seawater vs. brine) likely has not changed.

4.3.4 CHLORIDE CONDITIONS IN THE PLEASANT VALLEY BASIN

While high chloride concentrations are generally found only in wells in the coastal area of the southern Oxnard Plain, elevated chloride levels are present in wells distributed throughout the Pleasant Valley basin, and most notably in the southeastern portion of the basin near the Bailey Fault. Figure 4.3.15 shows the maximum chloride concentration from available 2015 samples, with results delineated by aquifer system. Few 2015 samples from the Pleasant Valley basin had a chloride concentration less than 100 mg/l. Two of the Pleasant Valley UAS wells with very high chloride also have high nitrate concentrations, suggesting impacts from shallow semi-perched groundwater. Most of the LAS wells had chloride concentrations over 100 mg/l; the four that did not are located near the western boundary of the basin. Over the past decade groundwater recharge from Arroyo Las Posas in the northern portion of the basin has been recognized as an additional source of salts in the basin (Bachman, 2012).

Pleasant Valley wells yielding high-chloride water may have been drilled too deep and directly penetrate formations having high-chloride water, or brines may have invaded deep freshwater aquifers from surrounding and underlying deposits as a result of pumping stresses (Izbicki et al., 2005b). These potential brine migration pathways are illustrated in Figure 4.3.16. As water levels within the Lower Aquifer System decline as a result of groundwater extraction by wells, especially during dry periods, a greater percentage of water produced from the well may be from deeper zones with poor water quality, including water yielded by underlying deposits. Chloride concentrations in water from deep wells in the Pleasant Valley basin tend to increase during dry periods when groundwater pumping increases. Conversely, chloride concentrations generally decrease during wetter periods when more surface water supplies are available as irrigation water and groundwater extractions decrease. As on the Oxnard Plain, poor-quality near-surface waters such as irrigation return flow can potentially contribute high chloride concentrations to deep wells if wells are either improperly constructed or corroded. Samples collected from the discharge point of a long-screen production well are representative of the composite chemistry of water from all producing zones within the screened interval. While elevated chloride is observed in a number of wells in the Pleasant Valley basin, the collection of typical wellhead samples does not indicate which zones may be contributing high-chloride water at depth. The USGS has developed flow-profiling and discrete-depth sampling techniques to determine zones within the screened interval of a well that yield water to the well (Izbicki, 1999). Measurements of the velocity of water flow within the screened zones of a well determines what zones are producing water and the amount of water from each zone. The water quality samples collected from the various production zones allows the use of a mass-balance equation to determine the water quality associated with each zone yielding water to the well. In the Pleasant Valley basin, deeper formations tend to produce water with higher chloride concentrations. Because the deeper parts of the long-screen production wells commonly contribute high-chloride water representing only a small part of the total yield of the well, the chloride concentration of the overall discharge from the well is less than in the deeper zones. Changes in chloride concentrations are controlled by site-specific geology, well construction or changes in well hydraulics through time (Izbicki et al, 2005b). Figure 4.3.17 shows how well yield can be relatively low from deeper portions of a well where chloride concentrations are elevated. In well PVCWD #2, the most northerly PVCWD production well, composite chloride concentrations have ranged from 150 mg/l to 221 mg/l since 1984. During the 2002 USGS sampling event, a wide range of chloride concentrations (170 to 502 mg/l) were observed in samples collected from distinct depth intervals in PVCWD #2, with 190 mg/l chloride measured at the surface. The contribution of water to the well decreased with depth, and the deeper zones that produced chloride levels over 500 mg/l contributed less than one percent to the total flow. Prior sampling of the same well allowed the determination that the water level and amount of pumping influenced the contribution of water from the distinct LAS aquifers, affecting the composite water quality produced by the well. When water levels decline, yield increases from deeper zones, and poor quality water from the Grimes Canyon aquifer can enter the well (Izbicki et al, 2005b).

Deep nested monitoring well PV1 was installed in the Pleasant Valley basin by the USGS in 1990 as part of the RASA study. The well is located adjacent United's Pleasant Valley reservoir just east of the Camarillo Airport. The individual piezometers are completed to depths of 190, 380, 436, 860 and 998 feet; the three shallower wells each have 20 feet of screen and the deeper wells each have 60 feet of screen. Graphs for each well (except for PV1-436, screened in an aquitard) showing chloride concentrations and EC versus time are shown on Figure 4.3.18. Time series graphs were also created to show chloride concentrations and groundwater elevation (Figure 4.3.19). Water levels in all of the piezometers show recovery from 1990 through 2011, but only the shallowest well recorded groundwater elevations above sea level over the period of record. This well, PV1-190, is screened in the Oxnard aquifer and has fairly stable chloride concentrations above 100 mg/l, measuring 125 mg/l in fall 2015. Well PV1-380, screened in the Mugu aquifer, has stable chloride concentrations below 100 mg/l. LAS wells PV1-860 and PV1-998 are screened in the main and basal unit of the Fox Canyon aquifer, respectively (although the USGS interprets PV1-998 to be in the deeper Grimes Canyon aquifer). Chloride concentrations in well PV1-860 decreased from 130 mg/l to 74 mg/l as groundwater levels rose over the period 1996 through winter 2012. Since 2012, chloride concentrations have increased to 94 mg/l, coinciding with a period of declining groundwater levels. In well PV-998, chloride concentrations decreased from 130 mg/l to 98 mg/l while the groundwater level rose from 1990 through winter 2012. Since 2012, chloride concentrations increased to 141 mg/l, coinciding with a recorded water level decline of more than 110 feet in the well.

Wells belonging to Pleasant Valley County Water District (PVCWD) are well-distributed throughout the central and southern portion of the Pleasant Valley groundwater basin. The PVCWD wells were constructed in 1979 and 1980 with long screened intervals within the aquifers of the LAS. These wells have been sampled fairly consistently since they were constructed. Three of the PVCWD wells (wells 3, 7 and 11) are located on the Oxnard Plain just west of the Pleasant Valley basin, and are not discussed in this section.

In 2015 the PVCWD wells recorded chloride concentrations ranging from 103 mg/l to 224 mg/l. Chloride concentrations are generally lower in the western portion of the basin. Near the southwestern boundary of the basin, the 2015 chloride levels observed in samples from PVCWD wells #9 and #10 were measured at 103 mg/l and 107 mg/l, respectively. Time series graphs for these wells, displaying chloride and EC concentrations versus time, and well locations are shown on Figure 4.3.20. Time series graphs were also created with chloride concentrations and groundwater elevation versus time (Figure 4.3.21).

Water quality records from three selected private wells are shown in Figure 4.3.18. Private well #3, is located west of PVCWD #6 and is screened in the Fox Canyon aquifer. Samples collected from this well show chloride concentrations ranging from 52 mg/l to 82 mg/l since 1996, with levels remaining above 70 mg/l since 2010. Available samples collected from Private well #1, located in the east-central portion of the basin, show poor water quality. Chloride concentrations in this well did, however, decrease to 211 mg/l in 2015, from a peak of 277 mg/l in 2009.

PVCWD wells #1, #4, #5 and #8 are screened in both the LAS and the deeper portions of the UAS. In well PVCWD #1, the most eastwardly PVCWD well, chloride measured 224 mg/l in 2015. Chloride concentrations in this well increased from 1984 to 2011 (peaking at 300 mg/l) and have since decreased somewhat. Chloride concentrations in PVCWD #4 are elevated above 100 mg/l since 1985, with the exception of 2002 with 98 mg/l. Chloride concentrations in well PVCWD #5 have fluctuated over time, but have been elevated above 100 mg/l since 2012, which may be related to depressed water levels. In well PVCWD #8, chloride concentrations increased steadily from 150 mg/l to 232 mg/l during 1997 to 2011, however, they have now decreased slightly to 187 mg/l. During the 2002 USGS study, samples collected from distinct depth intervals in wells PVCWD #4 and #8 revealed the distribution of high chloride water with depth, resulting from poor water quality in the Grimes Canyon aquifer. The sampling also showed a large percentage of water of poor quality was yielded from the UAS, contributing to the high chloride levels observed in these two wells (Izbicki et al, 2005b).

Wells PVCWD #6, #9 and #10 are screened in the Fox Canyon and Hueneme aquifers. Chloride concentrations in samples collected from well PVCWD #6 are commonly over 100 mg/l, with 140 mg/l recorded in 2015. Wells PVCWD #9 and #10, show similar chloride concentrations in 2015 with 103 mg/l and 107 mg/l. During the 2002 USGS study, lower chloride concentrations were attributed in part to these wells not being screened in the UAS or in the Grimes Canyon aquifer (Izbicki et al, 2005b).

5 DISCUSSION

This section provides discussion on overdraft conditions, locations where saline water is observed, and how saline water may migrate with the groundwater flow on the Oxnard coastal plain.

5.1 OVERDRAFT CONDITIONS

Historically, problems with saline intrusion on the Oxnard Plain were constrained 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 some groundwater users valued the lower TDS concentrations common to some of the deeper aquifers of the Oxnard Plain. In fall 1975 UAS water levels in the entire southeastern quadrant of the Oxnard Plain were below sea level, with the sea level contour extending from Port Hueneme northeast as far as 5th Street and Rice Road (SWRCB, 1979). In the LAS the sea level contour extended from north of Port Hueneme to the Camarillo Hills, so the southeastern Oxnard Plain and all of the Pleasant Valley basin was below sea level. In contrast to recent conditions, the deepest LAS pumping depression at that time was in the northeastern portion of the Pleasant Valley basin, at approximately 120 feet below sea level (SWRCB, 1979). These depleted basin conditions led the State Board to threaten the adjudication of water rights under Water Code Section 2100. Local pumpers expressed a preference for local control of the overdraft problem, and the Fox Canyon Groundwater Management Agency was authorized by Legislative act in 1982. The act became effective in January 1983, and the initial goals of the agency were to bring the aquifers of the UAS into balance by the year 2000, and the LAS by the year 2010 (FCGMA, 2007). Major investments were made for infrastructure to enhance recharge and convey water to areas with the greatest pumping depressions, and for the importation of water from the State Water Project. In addition, significant regulatory programs were enacted to reduce groundwater pumping. These investments and programs were largely successful in eliminating overdraft in the UAS under wet and average climatic conditions, while the LAS remains in a condition of chronic overdraft. Following the onset of drought conditions in 2012, many areas in the coastal basins are now at or near their record low water levels.

SGMA presents new mandates and timelines to achieve sustainability in California's heavily utilized groundwater basins. In January 2015 the board of the FCGMA accepted the authority to be the Groundwater Sustainability Agency for the basins within its jurisdiction. A team of consultants has been retained to study the basins and present a plan for achieving sustainable operating conditions by the year 2040, as required in the SGMA legislation. As noted in this report, groundwater levels in the basins underlying the Oxnard coastal plain are below sea level, exacerbating saline intrusion. The recent drought, on top of the long-term overdraft conditions common the coastal basins, makes the path to sustainability more difficult. The SGMA plans for the basins of the FCGMA, due for completion by the year 2020, will contemplate both pumping reductions and various projects to augment water supplies in order to achieve sustainability.

While the distribution of pumping depressions is different today than when the State Board was threatening adjudication in the late 1970s, UAS groundwater levels in 2015 were generally as low as they were during periods of drought in the 1960s and 1970s (Figures 4.2.1 and 4.2.2). In the LAS, the greatest pumping depression now commonly straddles the boundary of the Pleasant Valley and Oxnard Plain basins, east of the City of Oxnard and south of the City of Camarillo. Available LAS water level records indicate that groundwater levels in only the northernmost portions of the Oxnard Forebay and Pleasant Valley basins remained above sea level in fall 2015, while groundwater levels throughout the entire Oxnard Plain basin were below sea level (Figure 4.2.8). The greatest water level depression was observed in the southern Pleasant Valley basin, where an area of about three square miles had groundwater elevations more than 150 feet below sea level.

5.2 SALINE INTRUSION

Saline intrusion occurs when water levels fall below sea level (and even before water levels fall below sea level, given the greater density of seawater compared to fresh water). For the aquifers of the UAS in the area near Port Hueneme, saline intrusion is primarily a result of lateral seawater migration, occurring primarily during times of below-average precipitation and recharge. Seawater plumes advance inland from the Hueneme Canyon when landward groundwater gradients exist. Figure 3.1 shows a USGS interpretation of the historical extent of UAS saline intrusion on the southern Oxnard Plain over time, and a similar set of figures is included in the 2007 Update to the FCGMA Groundwater Management Plan. During periods of high water levels in the UAS, the predominant gradient in the area inland of Port Hueneme is to the southeast. This groundwater flow direction serves to flatten the northern extent of the intruded area, and move the chloride plume down the coast towards Mugu Lagoon. As a result of these typical wet- and dry-period gradients not reversing, but rather shifting by roughly 90 degrees from northeast to southeast, saline waters are not readily flushed from the UAS in the Hueneme area during periods of high water levels in the basin. The chloride trends observed in a number of the Oxnard aquifer monitoring wells located east and southeast of Port Hueneme are supportive of this interpretation. Monitoring wells CM4-200, SW-195, CM7-190 and SWIFT-205 show chloride trends consistent with a plume moving past these wells, with chloride peaks significantly delayed from periods of drought when seawater initially entered the groundwater system (Figure B-3). In contrast, well CM7-110 shows significant chloride spikes during periods of low water levels, suggesting the compaction of clays or the vertical movement of saline water is dominant at that particular location.

Closer to Hueneme Canyon, chloride concentrations recently began to increase again in wells A2-170 and CM2-280, indicating a new episode of seawater intrusion. UAS water levels were above sea level here as recently as 2013, but since that time heads have fallen and the new seawater front is only now reaching some of the coastal monitoring wells. Increasing chloride trends are expected in these wells until such a time that a seaward hydraulic gradient is reestablished.

Measured chloride concentrations are also increasing in some of the Hueneme aquifer monitoring wells located just west of the Port of Hueneme. Chloride in well CM2-520 increased from 150 mg/l to over 400 mg/l between June 2014 and December 2015, following a long period of improving water quality dating back to 1993. Deeper in the LAS at this same location, chloride concentrations have been greater than 10,000 mg/l for the past twelve years in well CM2-760. Some 2,200 feet to the north, chloride has been gradually increasing in well A2-740 since 2006. United's interpretation of groundwater flow direction in the LAS in this vicinity is generally easterly, so the A1 monitoring well cluster located northeast of the port and Hueneme Canyon may be poorly positioned to detect this saline intrusion in the LAS as it progresses inland.

In the Mugu area, water level measurements from UAS monitoring wells commonly record water levels below sea level. Well CM1A-220, installed at the coast west of Mugu Canyon in 1989, has never measured water levels above sea level and consistently records chloride concentrations near that of seawater. UAS water levels in the other monitoring wells in the Mugu area (CM6, Q2, DP and GP) rarely measure above sea level. This location on the Oxnard Plain is the most distant from the Forebay, where much of the water that recharges the UAS enters the groundwater flow system. This is also the area of the Oxnard Plain where water levels in the Mugu aquifer are observed to be significantly lower than in the Oxnard aquifer. In this southern portion of the Oxnard Plain the sediments of the LAS were uplifted and eroded prior to the deposition of the Mugu aquifer. The Hueneme aquifer is interpreted to be absent in the Mugu area, and in some locations the Mugu aquifer is thought to be in direct contact with the Fox Canyon aquifer (Turner, 1975, and SWRCB, 1979). Heads are commonly lower in the Fox Canyon aquifer than in the aquifers of the UAS in this vicinity, and these persistent downward vertical gradients and the connection between aquifers likely results in significant vertical flow from the UAS to the LAS. Such a flow regime would explain the deeper water levels in the Mugu aquifer (in an area without significant groundwater pumping). As shown in Appendix B, Figure A-1, water levels in the Mugu aquifer monitoring wells at the CM6, DP and Q2 well sites are more similar to LAS water levels than to water levels in the overlying Oxnard aquifer.

Prolonged periods of depressed water levels promotes the compaction of clay and silt aquitards (USGS, 1999). Silt and clay deposits are common on the southern Oxnard Plain, forming both the major aquitards between the major aquifers, and thin interbeds within the aquifer units (Densmore, 1996). Compaction of these fine-grained sediments can lead to land subsidence and an unrecoverable loss of groundwater storage, and also can be a source of poor quality water (documentation of land subsidence on the Oxnard coastal plain, however, remains sparse). Marine clays and lagoonal deposits commonly have saline water in their pore space, and this water is expelled into surrounding aquifer material when these aquitards are compressed. This is a common source of chloride degradation in the greater Mugu area, as originally interpreted by the USGS and discussed in Section 4.3.4 of this report. Poor water quality is common to nearly all the UAS monitoring wells surrounding Mugu Lagoon, with the Mugu aquifer well DP-330 being the main exception. Strong increasing trends in chloride concentrations are notable in the Mugu aquifer at the CM6 and Q2 well sites. While a number of local studies indicate the compaction of fine-grained sediments can degrade water quality in nearby wells, there appears to be little available data to quantify land subsidence associated with groundwater overdraft on the southern Oxnard Plain.

Water quality degradation also continues in the Fox Canyon aquifer monitoring wells CM6-400 and Q2-640 (Figure 4.3.12). These wells have a consistent increasing chloride trend since the late 1990s, and despite their proximity to Mugu Canyon, have a geochemical signature that suggest brine origin. The Grimes Canyon aquifer monitoring wells in the Mugu area all have strongly increasing chloride trends, and brines appear to contribute at least some of this chloride. Strong downward gradients exist in this vicinity, complicating interpretations (in the deeper wells) as to whether brine origin is deeper or shallower than the various well screens.

Well CM1A-565 is located on the coast near the mouth of the Mugu Canyon. Despite this location, water level records from this well show significant seasonal variability, more common to LAS wells in the heavily-pumped areas of the Oxnard Plain and Pleasant Valley. If the aquifer penetrated by this monitoring well was exposed to the ocean in the nearby Mugu submarine canyon, a more muted water level signature would be expected because the ocean would serve as a nearby constant-head (recharge) boundary. A geologic section in the USGS RASA report depicts a shallowing of Tertiary marine sediments in the Mugu area, and uplift along the offshore trace of the Sycamore Canyon Fault that helps isolate the LAS aquifers from contact with seawater (Hanson et al, 2003). While it is difficult to resolve the offshore geology in the Mugu area, uplift along the Sycamore Canyon Fault remains a plausible explanation for the water levels observed in well CM1A-565 and the brine signatures interpreted in other nearby monitoring wells. Seawater is thought to be entering the Fox Canyon aquifer in the Mugu area, but the seawater likely travels laterally through aquifers of the UAS before moving deeper into the aquifers of the LAS. Offshore faulting has likely slowed seawater intrusion in the Mugu area, but the area of chloride impact continues to expand as compaction of clays continues to expel brine, brine migrates along fault traces and from deeper formations, and seawater continues to move inland in response to low pressures in production aquifers that span the coastal basins. In December 2015 the water level in well CM1A-565 was measured at 100 feet below sea level.

5.3 MIGRATION AND MONITORING OF SALINE WATER

United continues to sample and monitor water levels in about 70 monitoring wells in coastal areas of the Oxnard Plain basin. These wells are located at only 15 distinct locations, as many of the wells are co-located as nested wells in a single borehole. 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. The construction of monitoring wells is expensive, however, and it can be difficult to secure permission to install wells in the highly-developed coastal areas of southern Ventura County. Both the USGS and United have used geophysical methods in an attempt to document zones of elevated salinity where well data are not available. Results from these investigations suggest the occurrence of areas of low resistance (generally correlated with high salinity) are indeed highly variable in the subsurface, as has been confirmed by both the sampling of nested monitoring wells and wireline (downhole) resistivity surveys in individual wells. The TDEM surveys on the southern Oxnard Plain have also identified areas of low resistivity at various depths in the subsurface where confirmation by sampling is not yet possible. As displayed in Figures 4.3.1 through 4.3.6, recent water quality samples confirm poor quality in some of the mapped areas, but other areas have non-saline groundwater despite TDEM interpretation to the contrary. Figure 4.3.2 serves as a good example, as the large lobe of low resistivity surrounding the SCE well cluster is not consistent with the fresh water samples drawn from that well. A mile to the southwest, impaired water quality at the SWIFT well is correctly identified by the TDEM survey. In areas such as this, distant from the canyons, saline water in the Oxnard aquifer is likely related to the downward leakage of poor quality water from the semi-perched zone, or from the compaction of clay interbeds. The wire line surveys show that impacts are sometime constrained to individual beds, and in some cases the bed screened by a monitoring well may not be the one most degraded by chloride. There is no doubt that areas of the southern Oxnard Plain are degraded by chloride at various depths, but uncertainty remains regarding the true extent of this degradation and where additional wells will next be impacted.

Significant vertical groundwater gradients are now documented to exist in many of the coastal and inland areas of the greater Oxnard Plain. United's recent work creating stratigraphic sections and correlating aquifers across the Oxnard Plain and Pleasant Valley basins suggests a number of points of aquifer mergence. These areas of direct connection between aquifers have been recognized by others (e.g. Turner, 1975, and SWRCB, 1979) but some investigators in Ventura County characterize more vertical isolation between named aquifer units than may actually exist. United's current efforts to calibrate a 13-layer groundwater flow model for the coastal basins of the greater Oxnard Plain requires significant groundwater flux from the UAS to the LAS in order to calibrate a number of the LAS wells on the Oxnard coastal plain. Groundwater flow between aquifers has long been recognized on the Oxnard coastal plain (CA DWR, 1971, Hanson et al, 2003). This has significant implications for the control of saline intrusion in the basin, as a large difference in heads between the UAS and LAS makes the control of saline plumes a problem in three dimensions, not just two as it is commonly conceptualized.

In the Pleasant Valley basin, questions also remain regarding the origin and distribution of poor-quality groundwater. Available records suggest high chloride is derived primarily from deep in the groundwater basin, with the upwelling of brines from deeper sedimentary rocks occurring in response to chronic low pressure in the aquifers of the LAS. Poor quality water may also be present in the shallow groundwater system, and may move downward in some locations and impact deeper wells. Recharge to the northern portion of the basin has increased over the past twenty years, but few wells remain in the northern portion of the basin to monitor water level and water quality changes associated with this recharge from Arroyo Las Posas. Gradual long-term water level recovery has been observed in a number of the PVCWD wells, but it is unclear if this recovery is more related to recharge in the northern part of the basin or increased surface water imports by PVCWD. This recovery ceased in late 2012 during the current drought, and the northern recharge mound near Arroyo Las Posas has declined by more than 100 feet.

6 CONCLUSIONS

Some 60 years after the initial investment in some major water supply and groundwater recharge projects to combat saline intrusion on the Oxnard Plain, saline intrusion persists in the coastal areas of the southern Oxnard Plain and in the Pleasant Valley basin. In wet and normal years, existing groundwater recharge facilities and surface water delivery pipelines generally distribute enough water to maintain groundwater levels above sea level in the Upper Aquifer System. However, much of the existing water infrastructure is reliant on flow in the Santa Clara River to be effective. During periods of drought the recharge facilities and surface water distribution pipelines are largely idle for lack of surface water, and groundwater extraction reduces groundwater storage in the basins. Following the recent four years of drought conditions, water levels are below sea level in the UAS in all but the most northerly portions of the coastal basins, and a new episode of seawater intrusion is currently degrading water quality in the coastal areas of the southern Oxnard Plain. When water levels in the UAS are eventually restored, much of the seawater that entered the UAS aquifers via Hueneme Canyon will be swept down the coast to the southeast by the prevailing groundwater gradients. Recent samples from UAS wells near Hueneme Canyon show increasing chloride concentrations. The Oxnard aquifer monitoring well near Mugu Canyon consistently records chloride concentrations near that of seawater.

In recent decades there has been increased groundwater production from the aquifers of the LAS, and water levels are now as much as 180 feet below sea level in these deeper aquifer units. Chloride concentrations are rising steadily in many of the LAS monitoring wells surrounding Mugu Lagoon. The inland extent of saline intrusion near Hueneme Canyon appears to be more limited than in the area surrounding Mugu Lagoon, but the locations of the existing monitoring wells may be poorly positioned to document intrusion moving east from Port Hueneme. Chloride concentrations exceeding 10,000 mg/l we recently measured in well CM2-760 near Hueneme Canyon. Areas with significant groundwater extraction from the LAS do not record water levels above sea level, even in the wettest of years.

Depressed water levels in more inland areas also causes saline intrusion from the compaction of fine-grained marine sediments. Chloride derived from either seawater or brine tends to move deeper in the basin over time, given the persistent downward vertical gradients that exist in the basin. The Pleasant Valley basin, however, appears to have brines that originate at greater depths, and some of the deeper wells in the basin routinely produce water with moderately elevated chloride concentrations, but of sufficient quality for irrigation.

Overdraft conditions have produced all of the water quality problems detailed in this report. Lateral seawater intrusion would not be a problem on the Oxnard Plain if seaward groundwater gradients could be maintained near the coast. The compaction of sediments in coastal and more inland areas can be arrested by maintaining groundwater levels above historic lows. The upwelling and migration of brines in the LAS can be mitigated by higher water levels in those aquifers, as would the downward movement of water from shallower units. It is easy to recognize the fix for the various forms of saline intrusion on the greater Oxnard Plain, but this goal is far from being achieved. As saline intrusion continues it becomes increasingly difficult to restore water quality within the coastal basins, as degraded waters do not necessarily exit the groundwater system with the restoration of groundwater elevations higher than sea level.

Additional measures to reduce groundwater extraction, increase water supply and move water to critical areas are necessary to bring the coastal basins of southern Ventura County into a sustainable condition. Just four years of drought has clearly illustrated that the significant investments in water supply infrastructure made to date by a number of local agencies and entities, and the various existing mandatory and voluntary conservation programs, is not enough to preserve the long-term groundwater quality in the Oxnard Plain and the Pleasant Valley basin.

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FIGURES

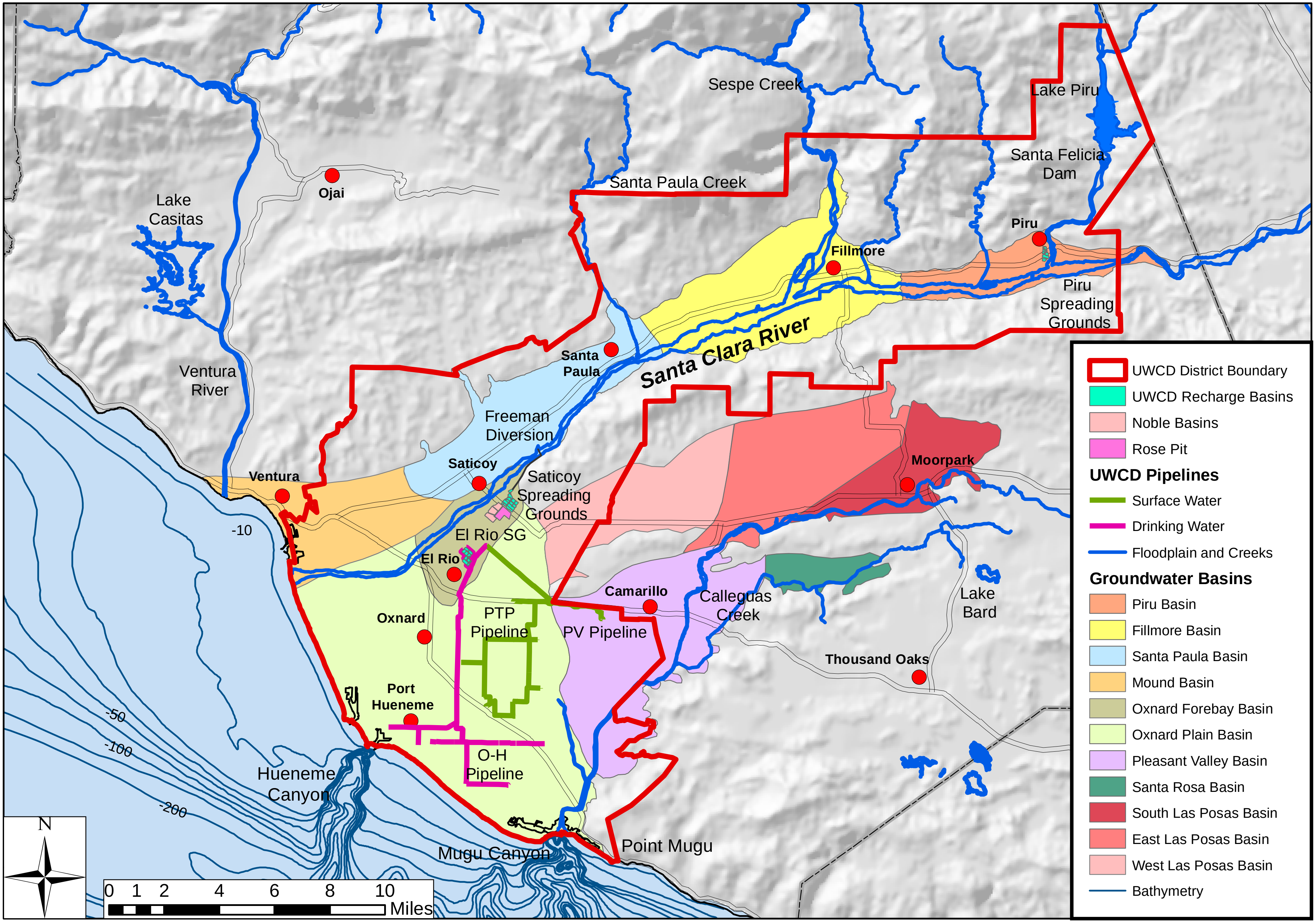


Figure 1.1. Groundwater basins, District boundary, and major recharge and conveyance facilities

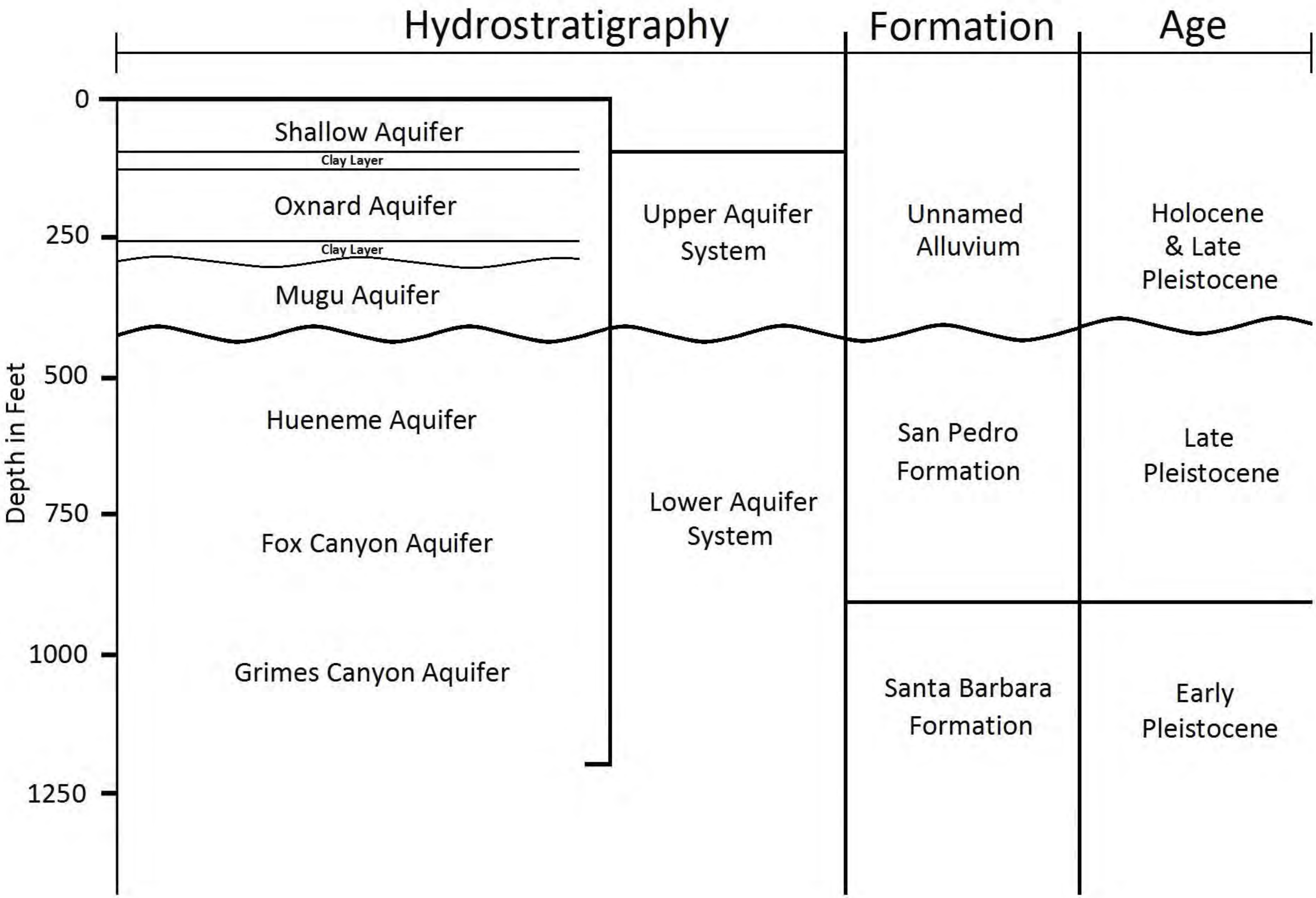


Figure 2.2.1 Schematic of Upper and Lower Aquifer Systems

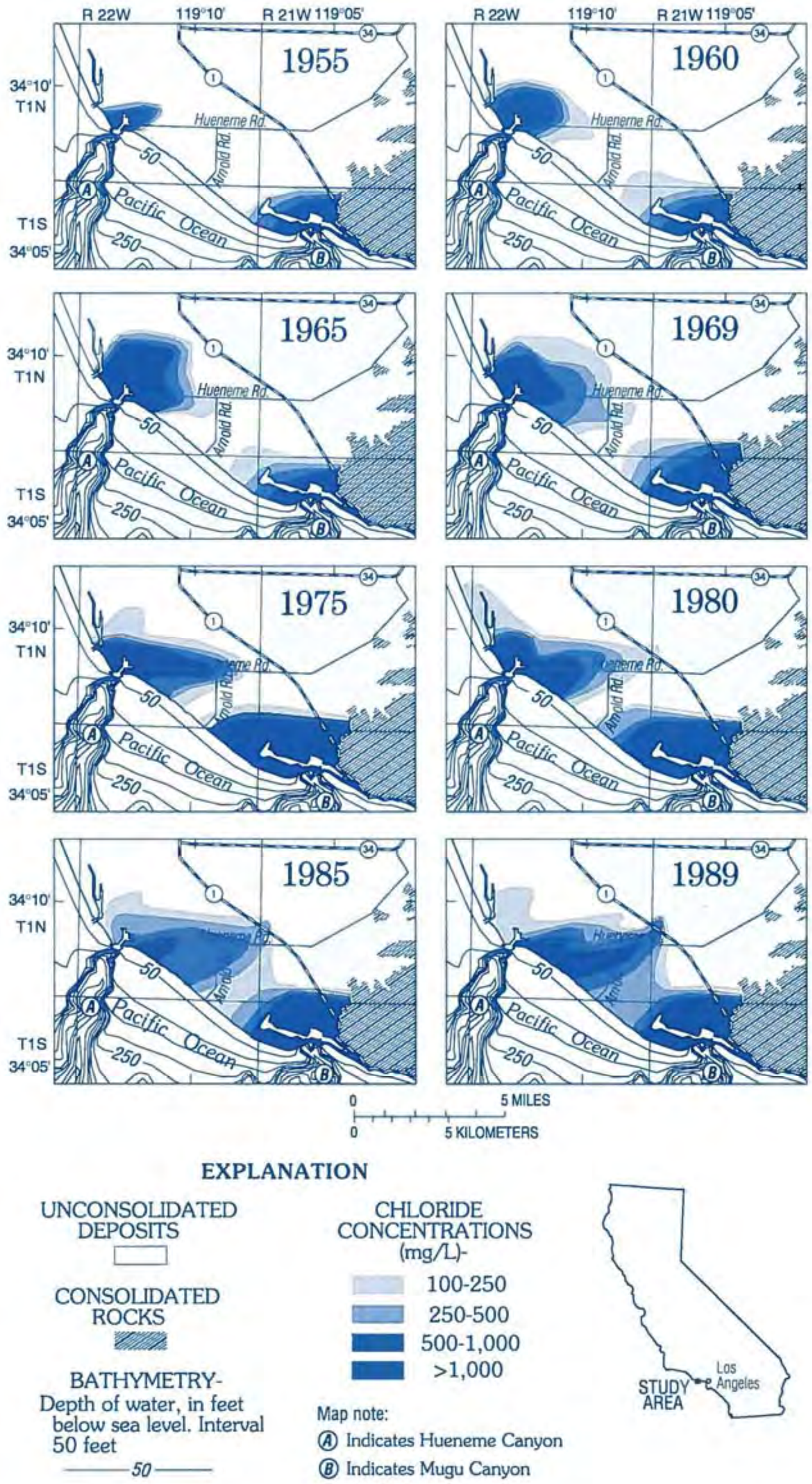


Figure 3.1.1. Chloride concentrations in water from wells in the Upper Aquifer System in the Oxnard Plain, 1955-89 (Data from California Department of Water Resources and County of Ventura Public Works Agency; figure from Izbicki, 1996c).

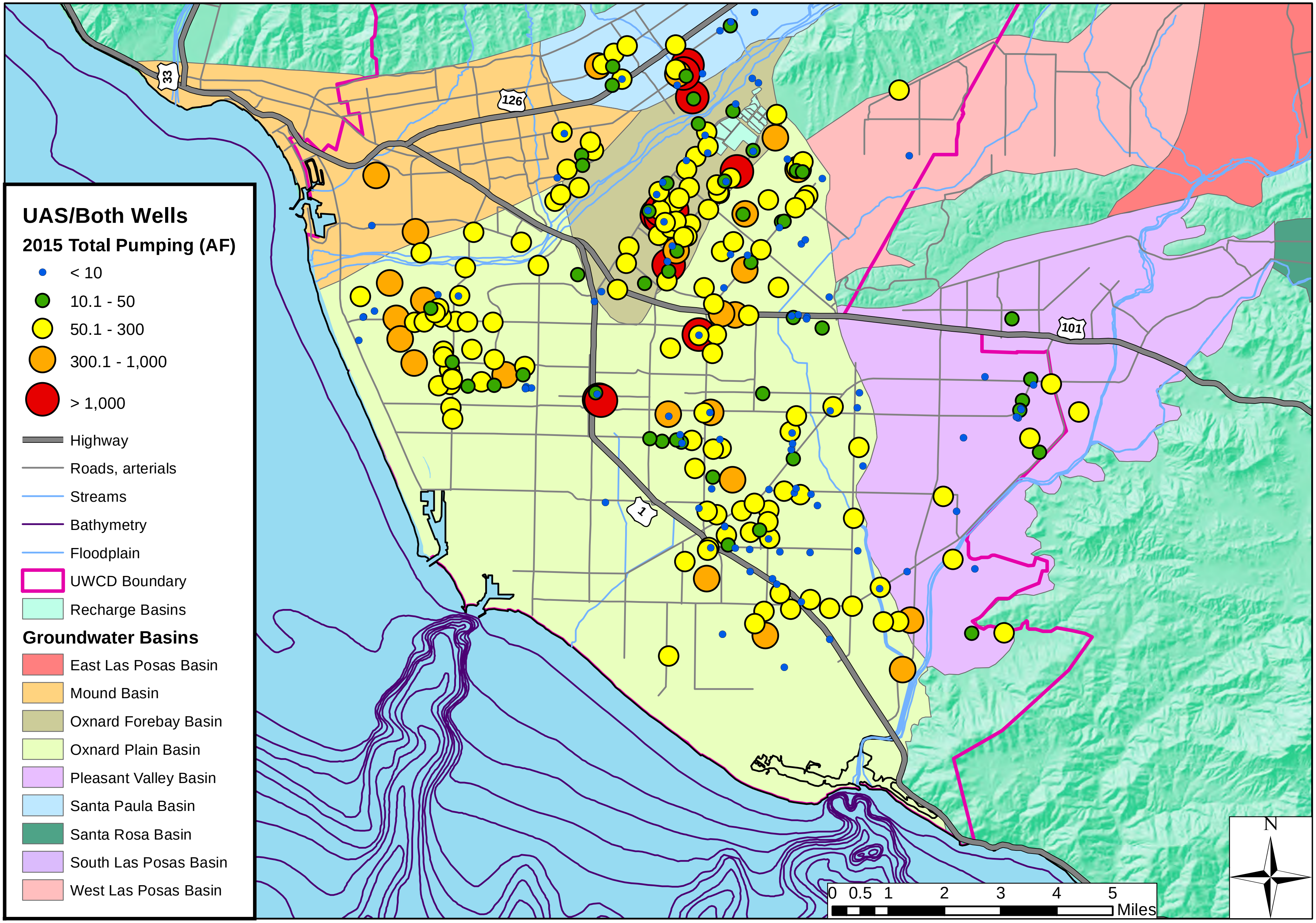


Figure 4.1.1. Reported Upper Aquifer System groundwater extraction from coastal basins, 2015.

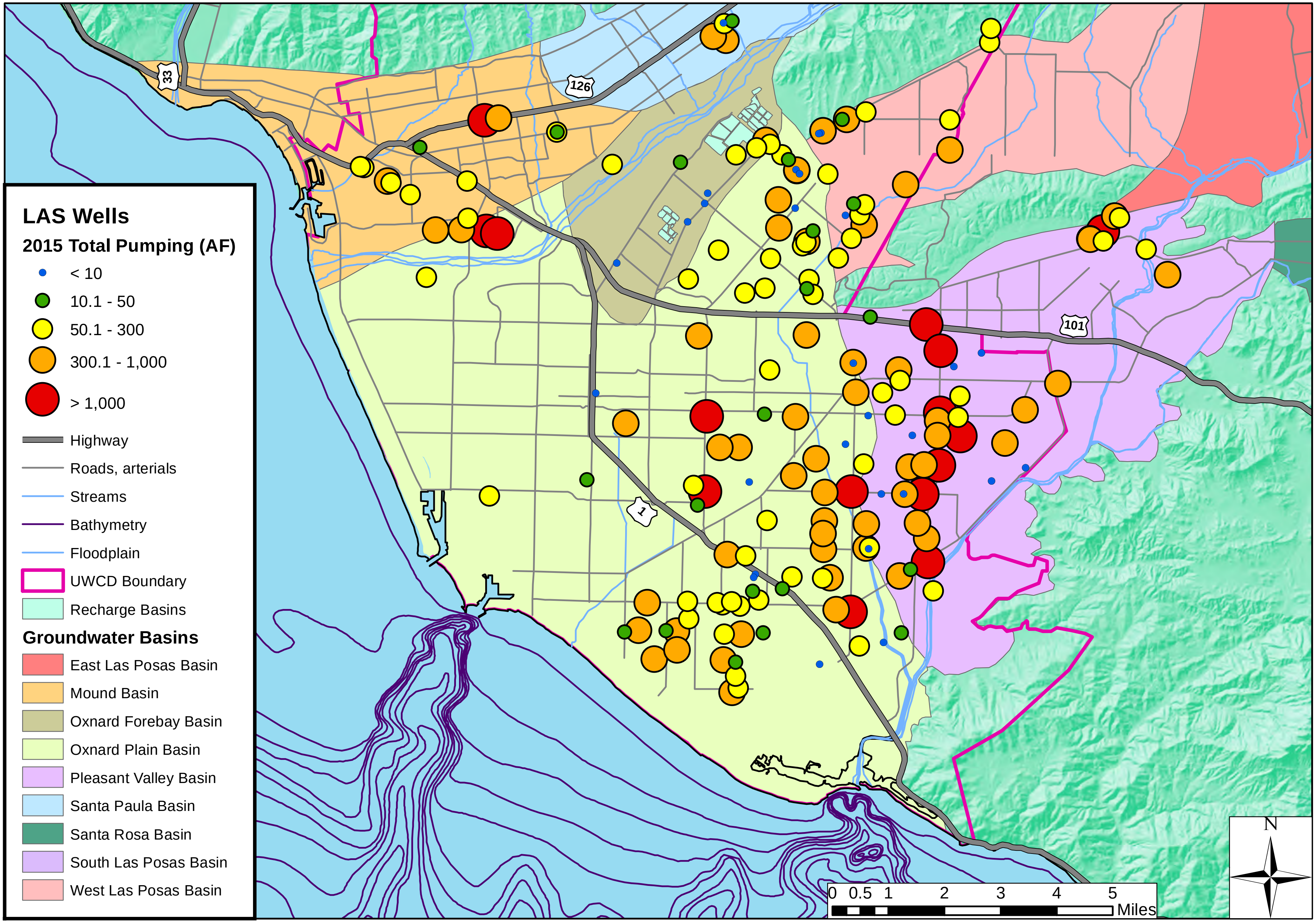


Figure 4.1.2. Reported Lower Aquifer System groundwater extraction from coastal basins, 2015.

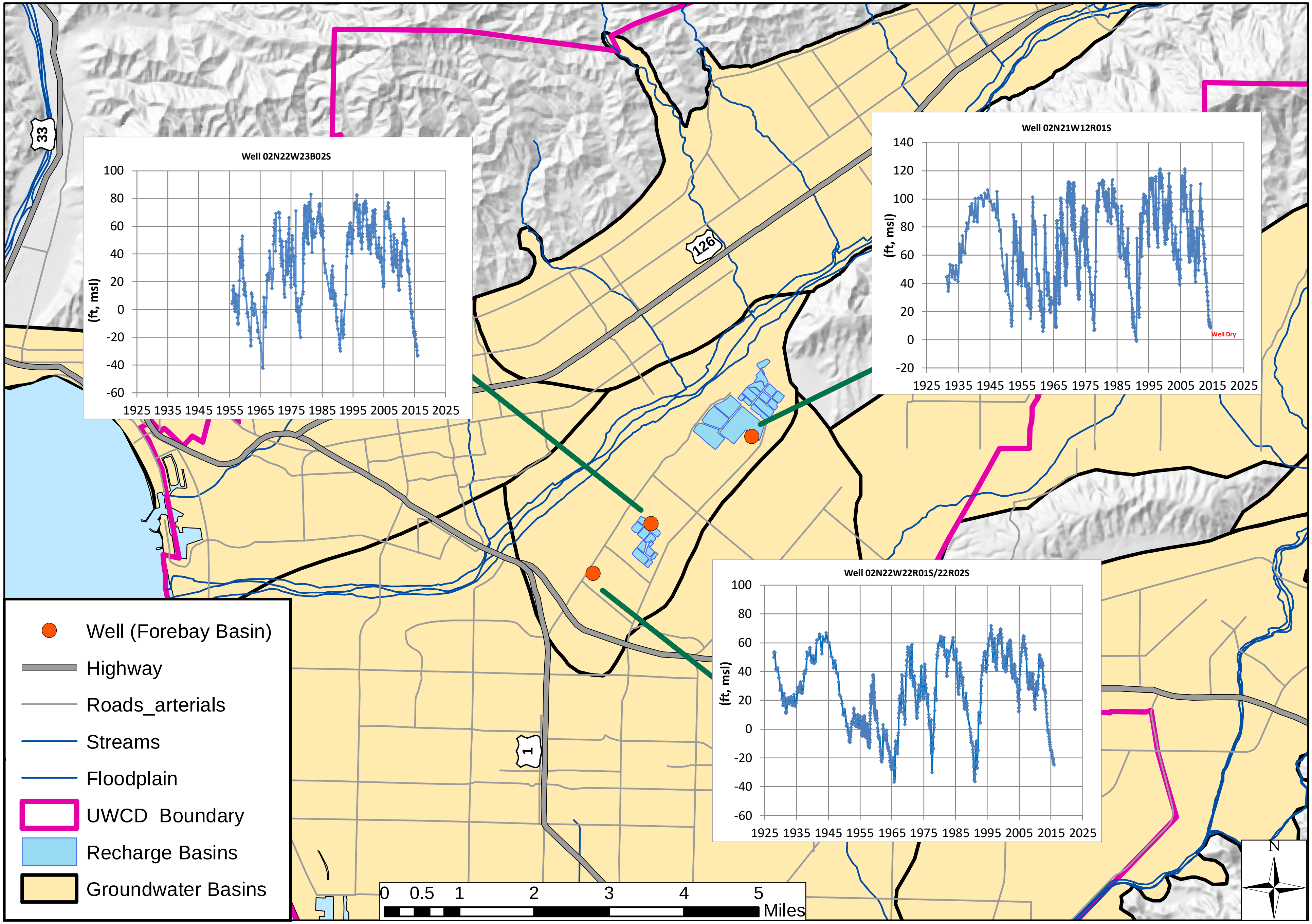


Figure 4.2.1. Groundwater elevation time series, selected Forebay basin wells.

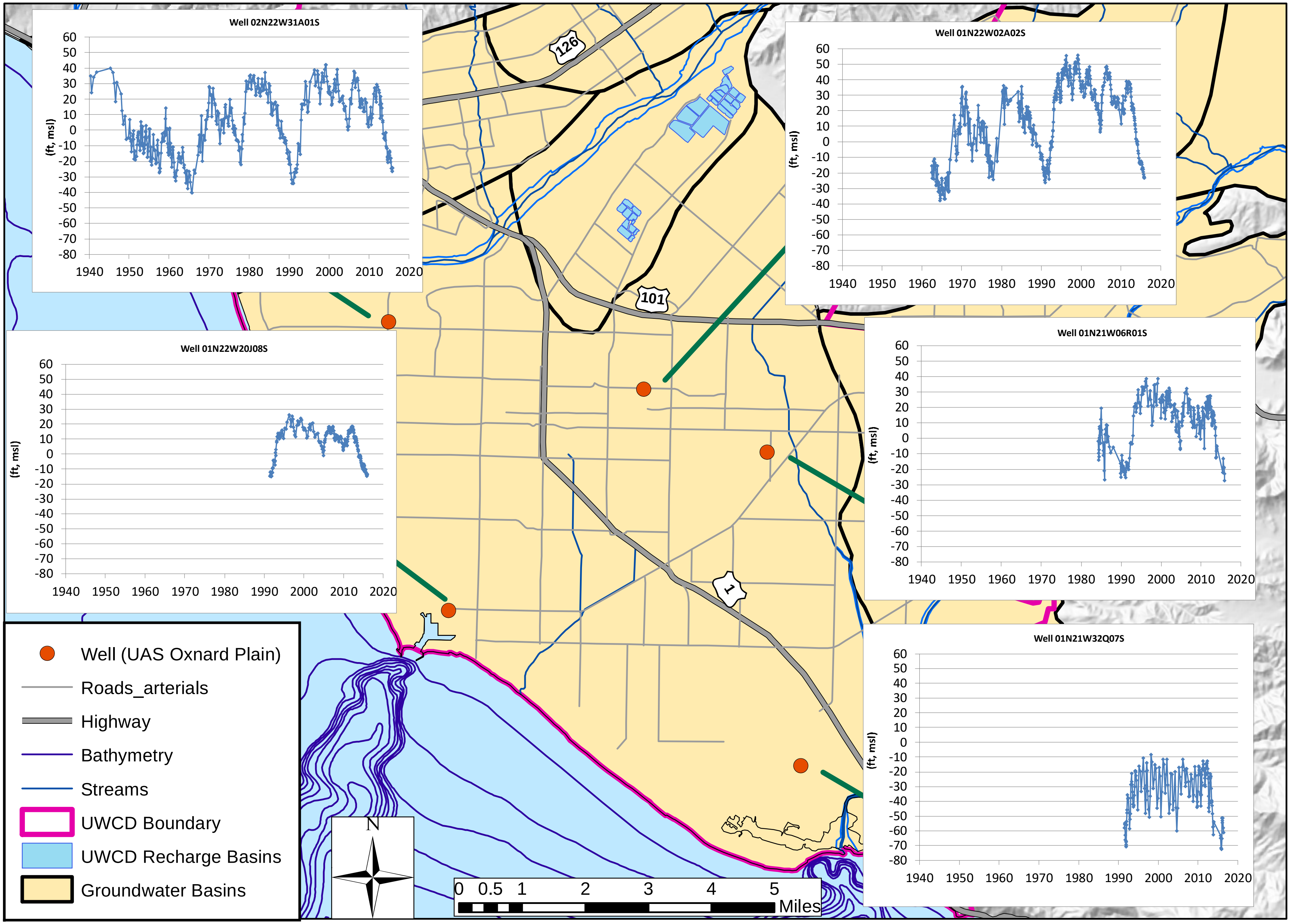


Figure 4.2.2. Groundwater elevation time series, selected Upper Aquifer System wells, Oxnard Plain basin.

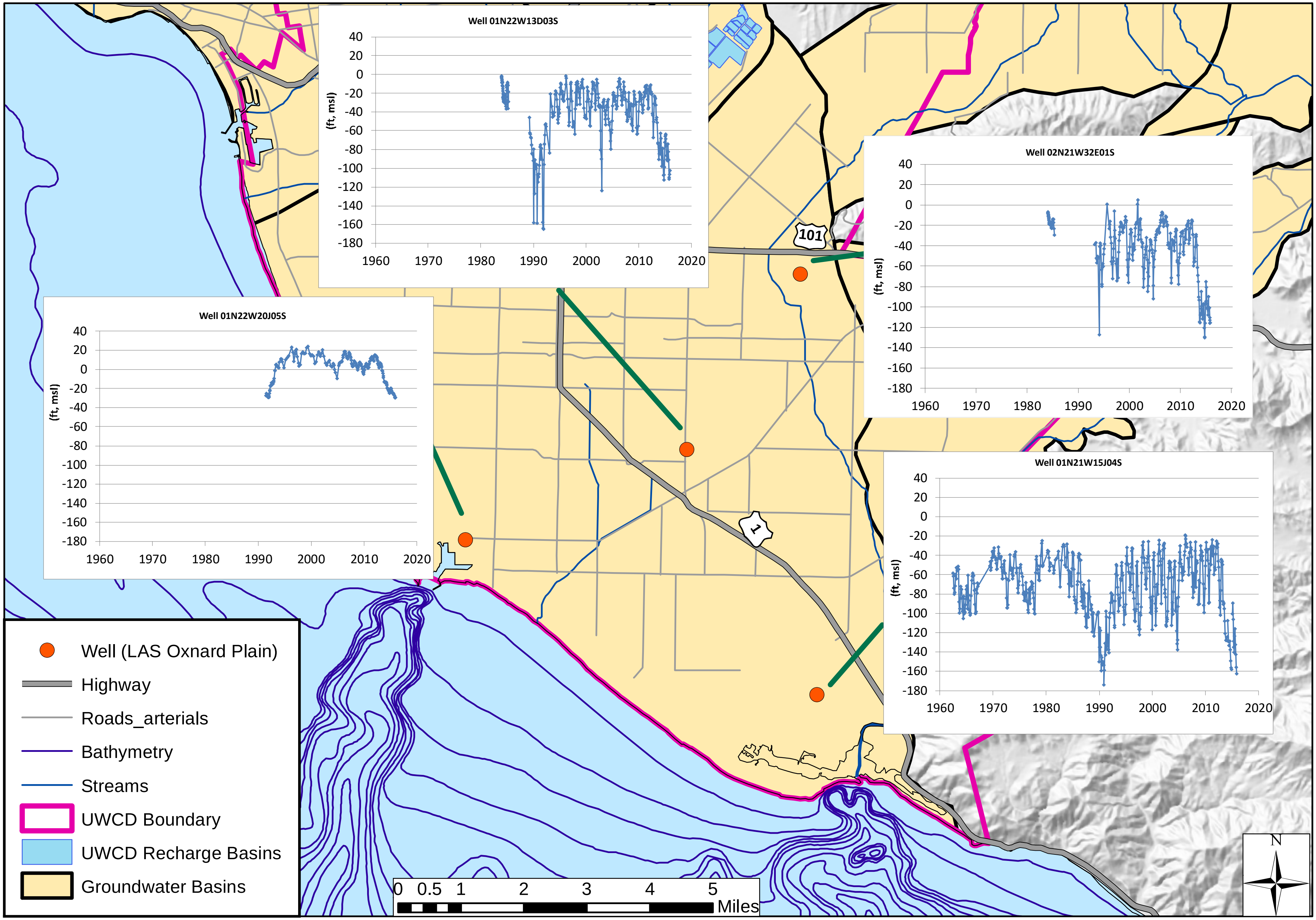


Figure 4.2.3. Groundwater elevation time series, selected Lower Aquifer System wells, Oxnard Plain basin.

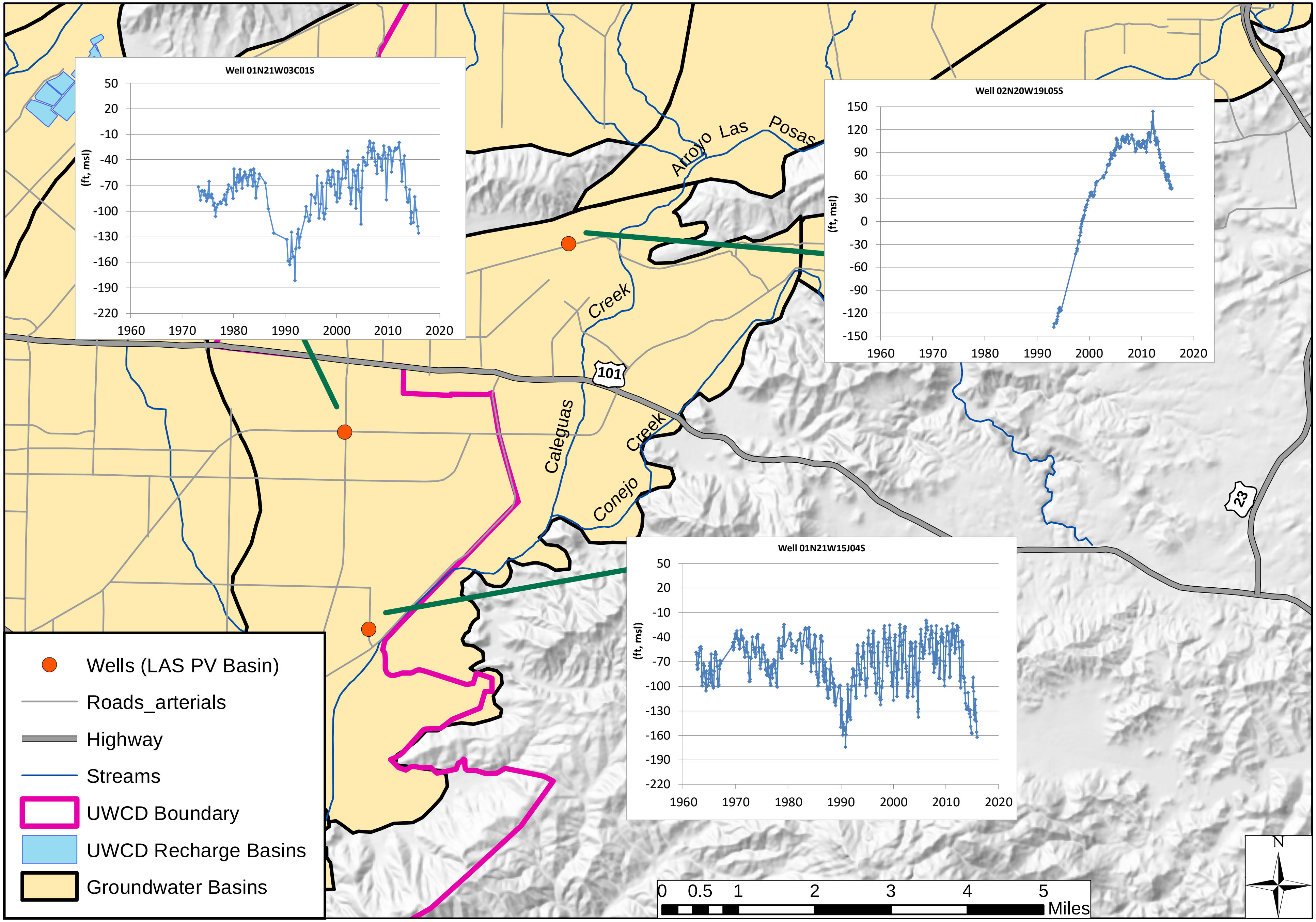


Figure 4.2.4. Groundwater elevation time series, selected Lower Aquifer System wells, Pleasant Valley basin.

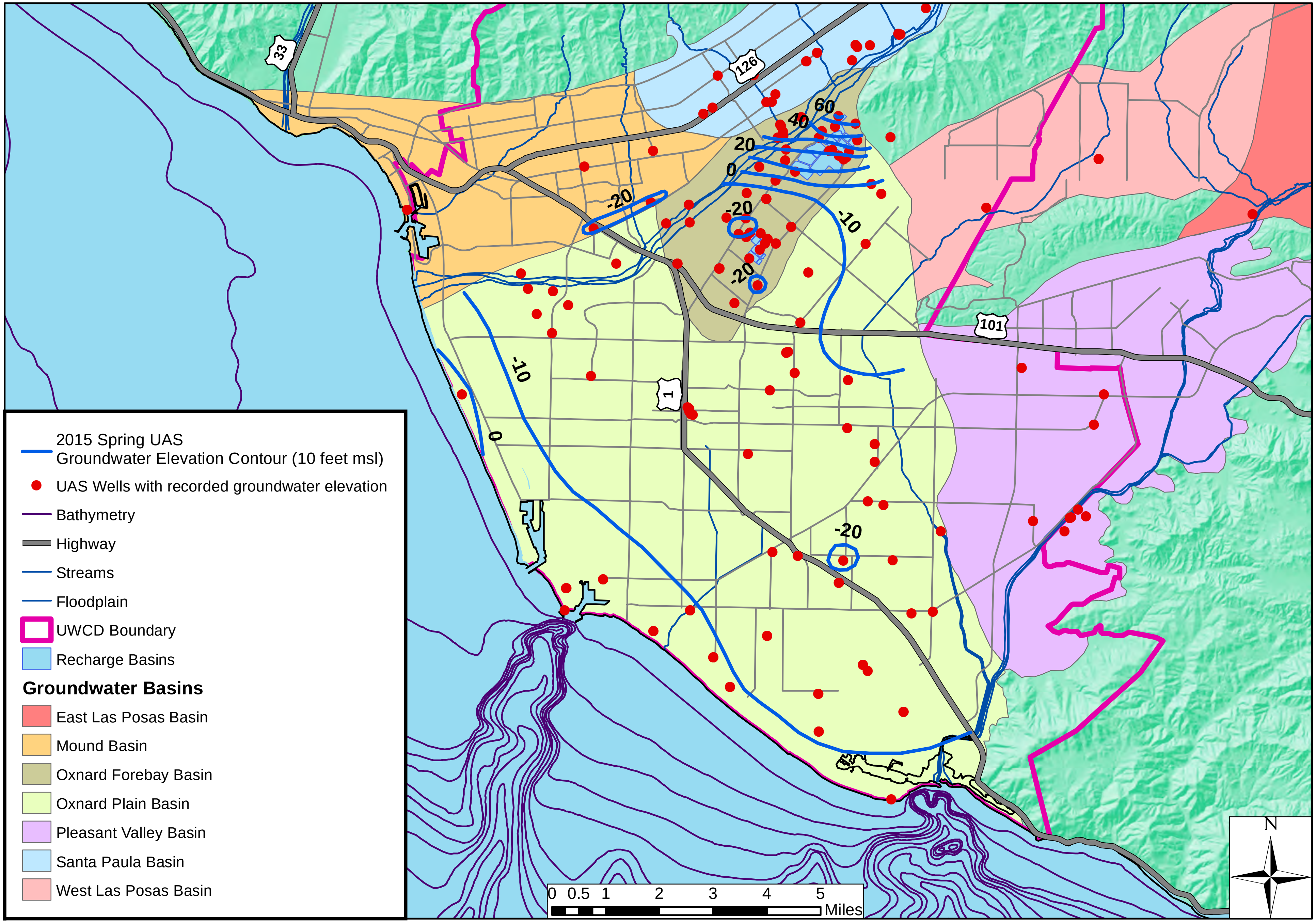


Figure 4.2.5. Spring 2015 groundwater elevations, Upper Aquifer System wells.

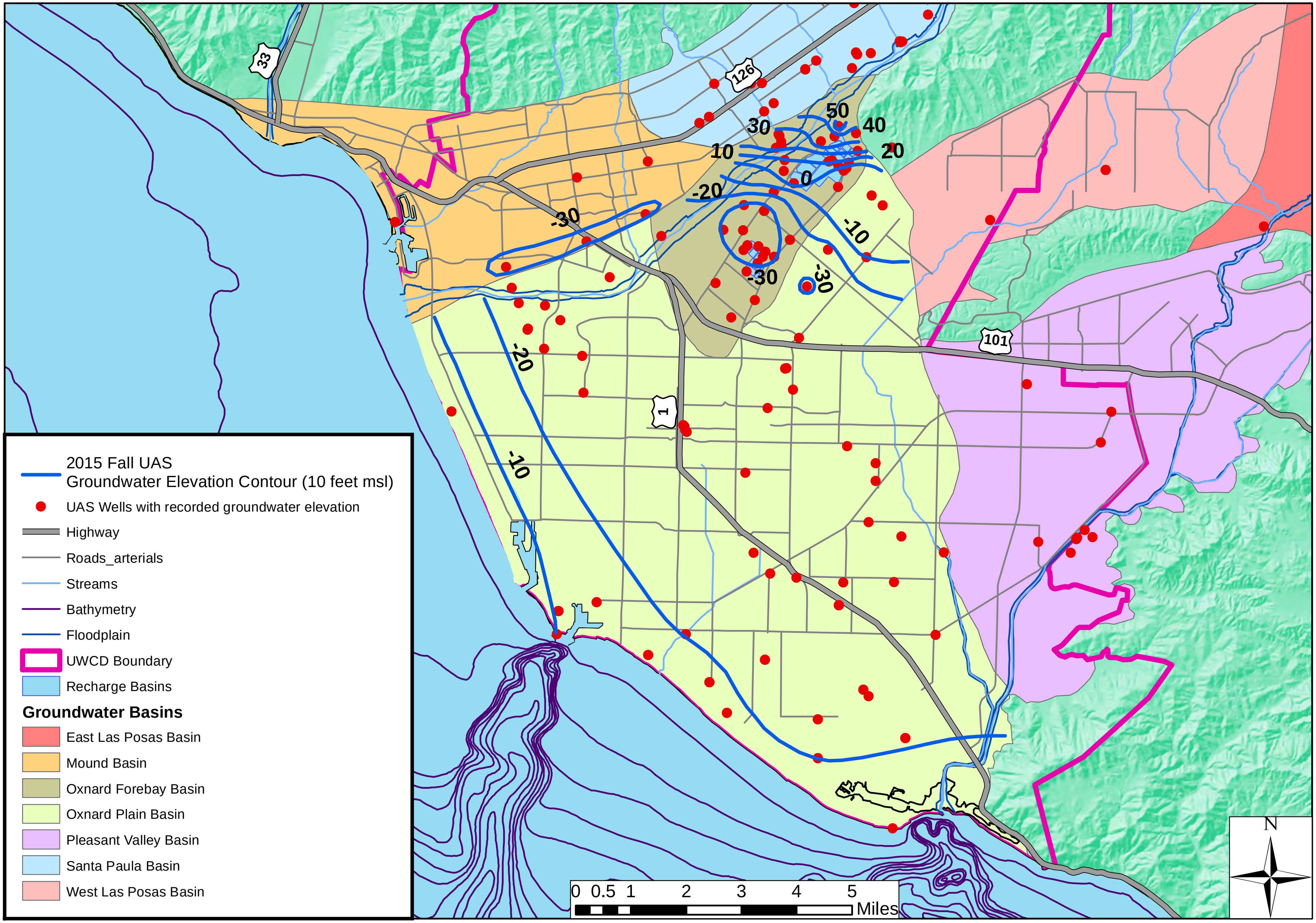


Figure 4.2.6. Fall 2015 groundwater elevations, Upper Aquifer System wells.

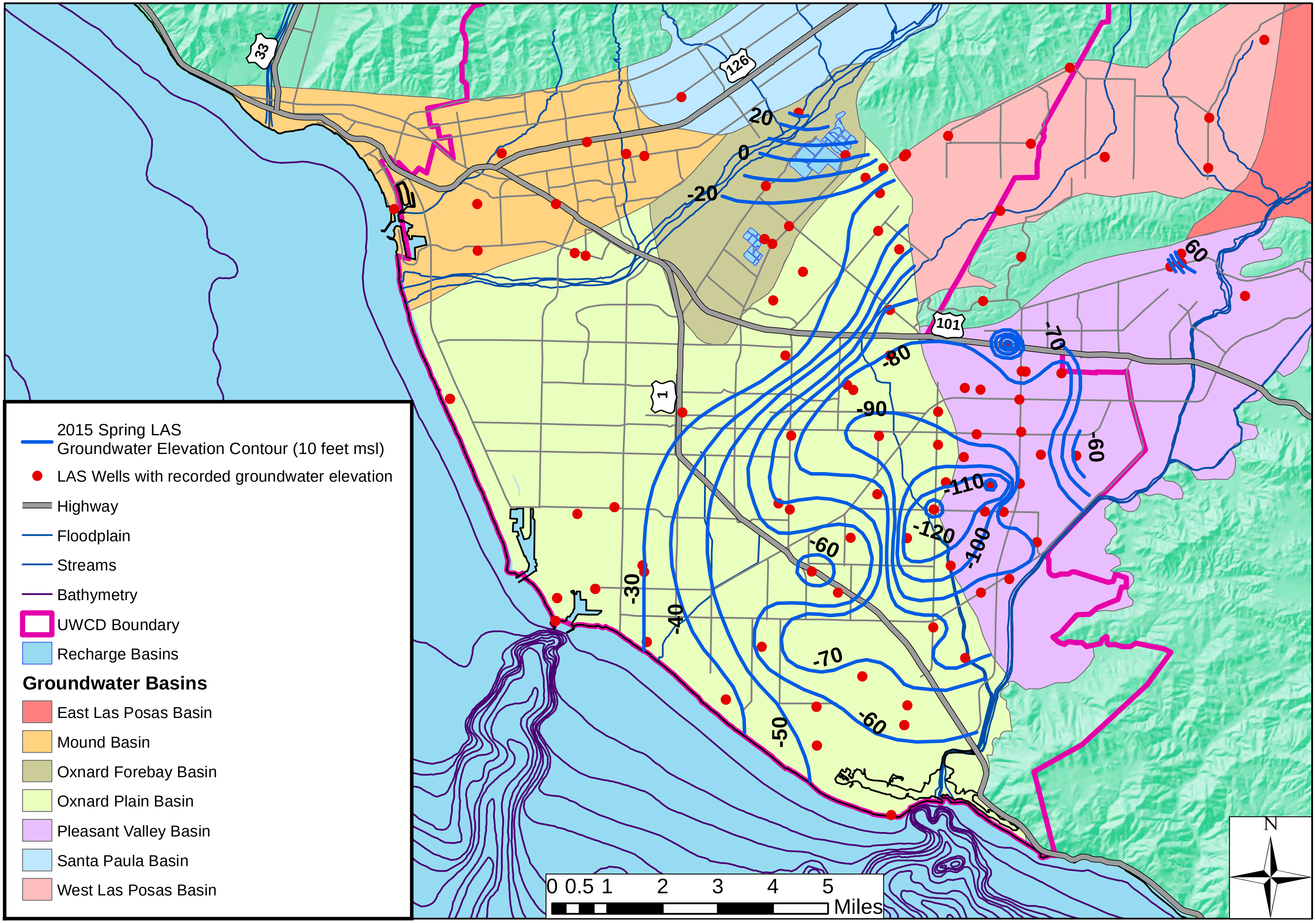


Figure 4.2.7. Spring 2015 groundwater elevations, Lower Aquifer System wells.

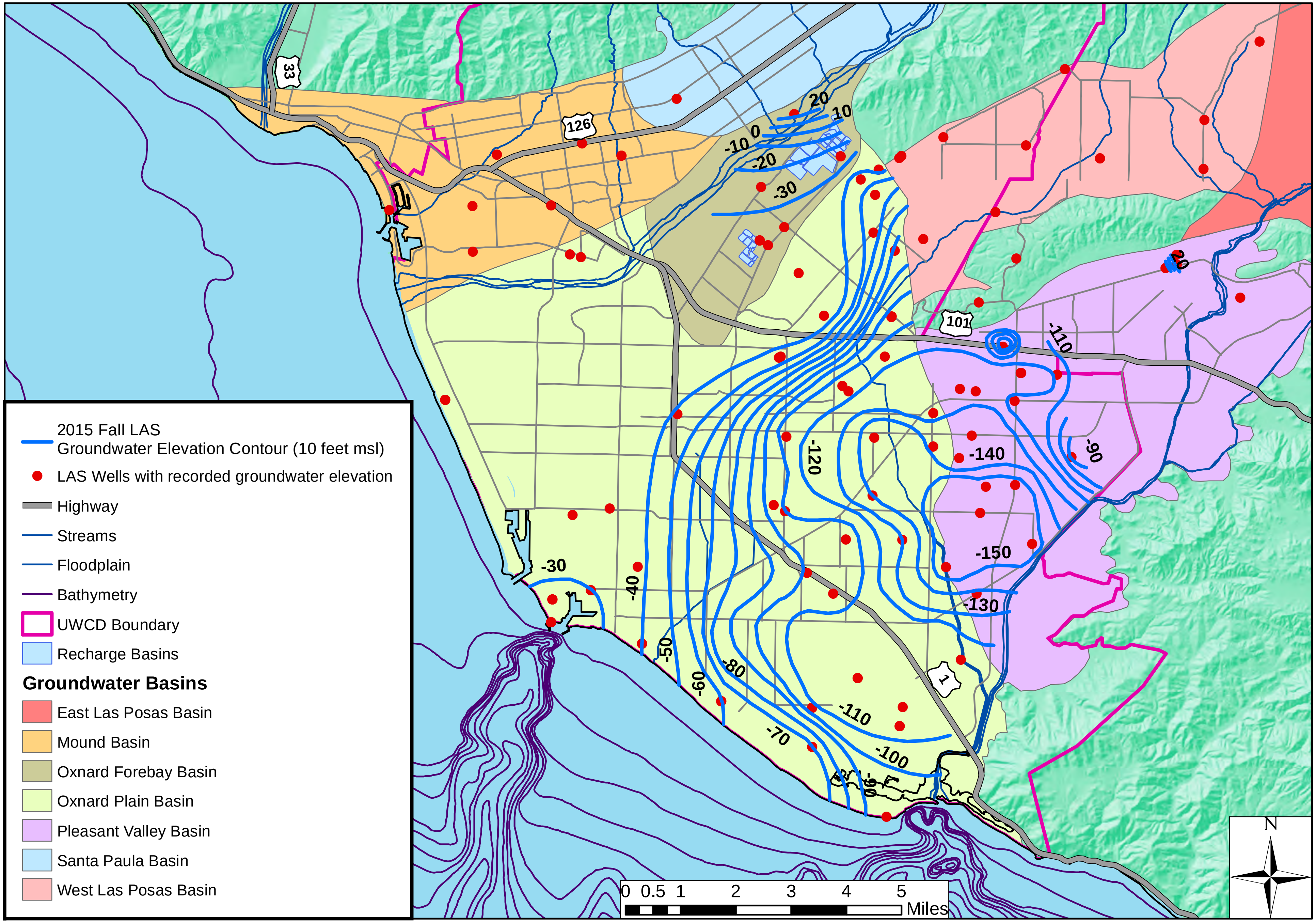


Figure 4.2.8. Fall 2015 groundwater elevations, Lower Aquifer System wells.

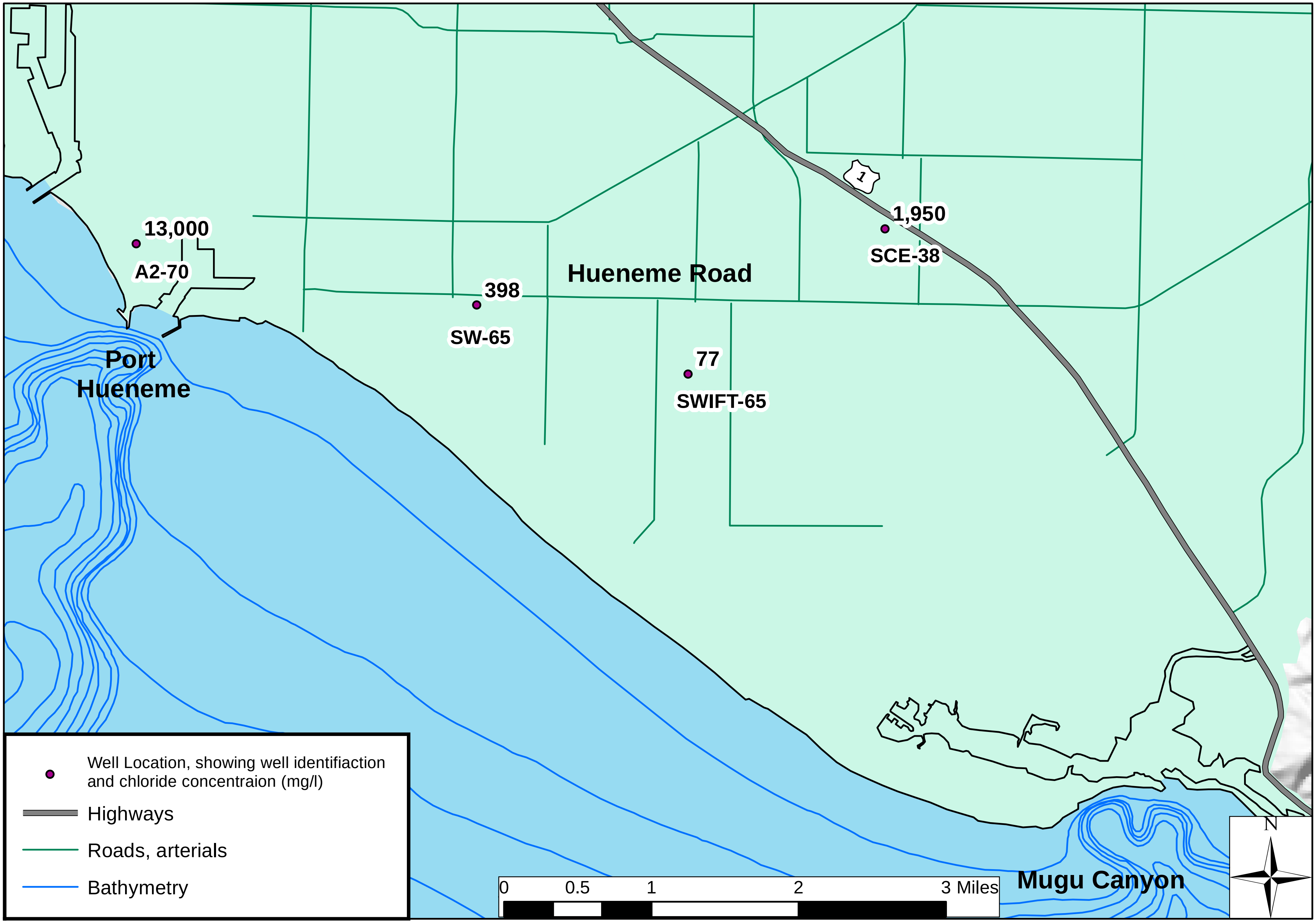


Figure 4.3.1. Semi-perched aquifer chloride concentrations, coastal monitoring wells, fall 2015.
Interpreted source of elevated chloride levels key: Black label = Background level.

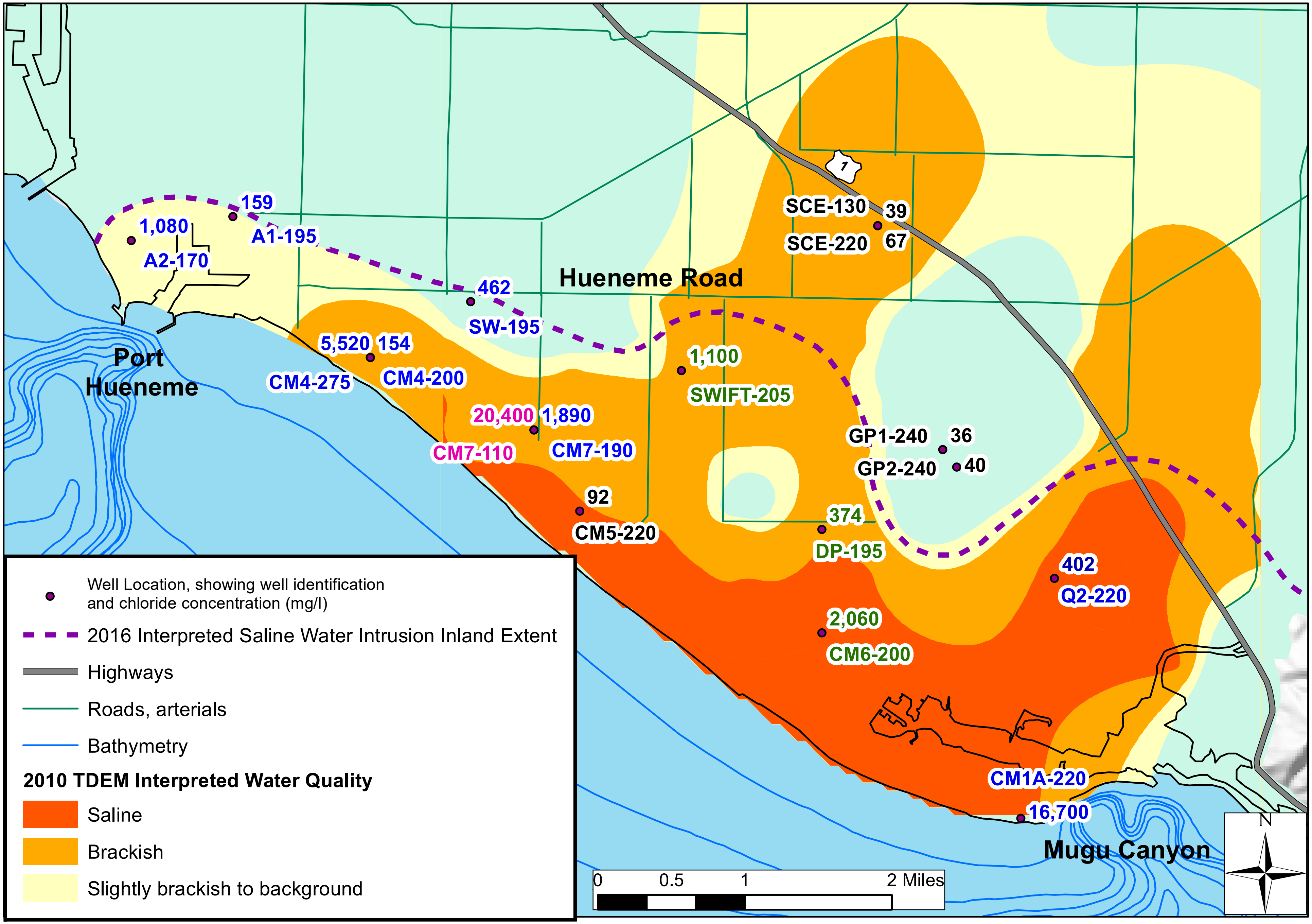


Figure 4.3.2. Oxnard aquifer chloride concentrations, coastal monitoring wells, fall 2015.
Interpreted source of elevated chloride levels key: Green label = Sediments; Blue label = Seawater; Pink label = Semi-perched water;
Black label = Background level.

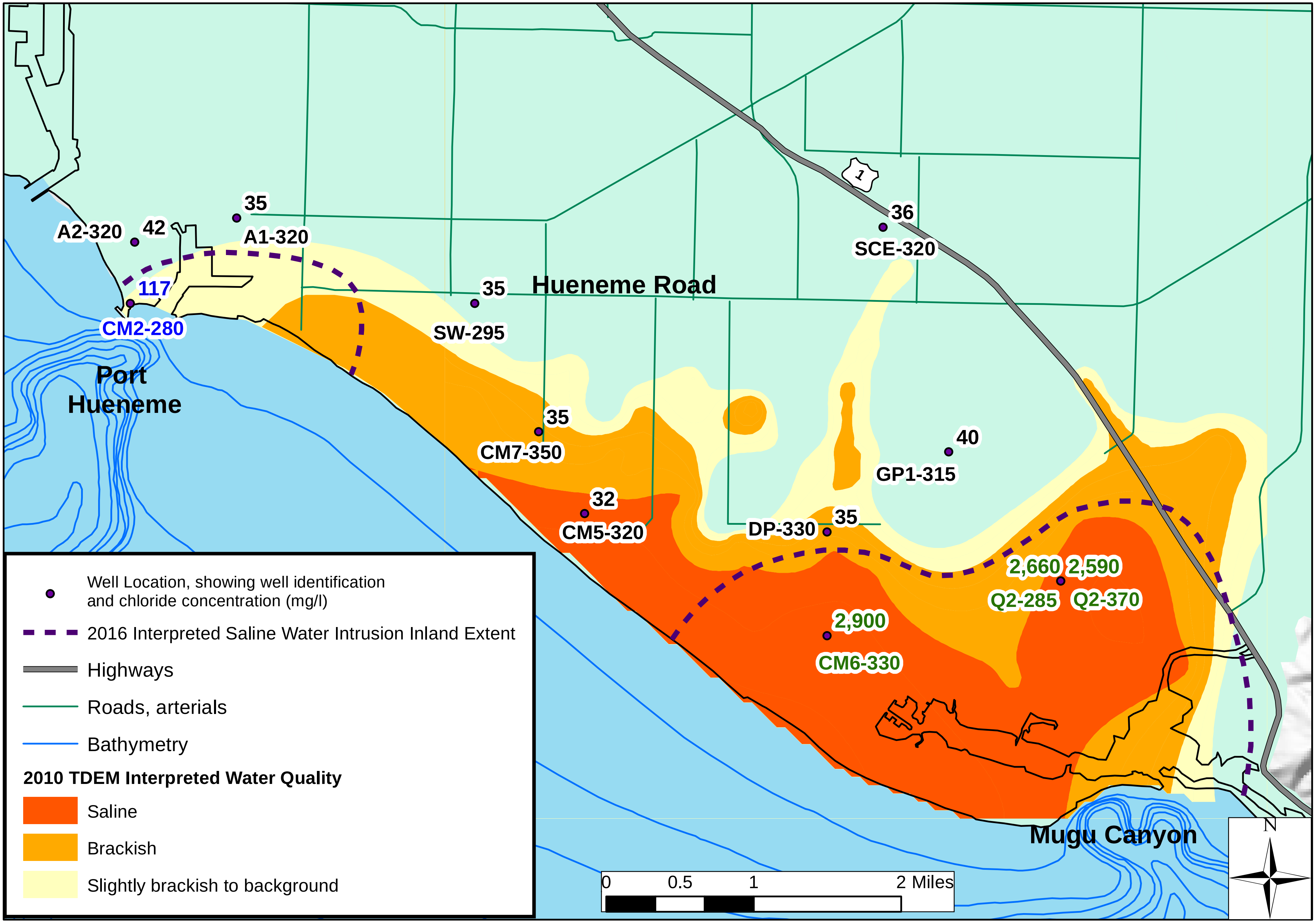


Figure 4.3.3. Mugu aquifer chloride concentrations, coastal monitoring wells, fall 2015.
Interpreted source of elevated chloride levels key: Green label = Sediments; Blue label = Seawater; Black label = Background level.

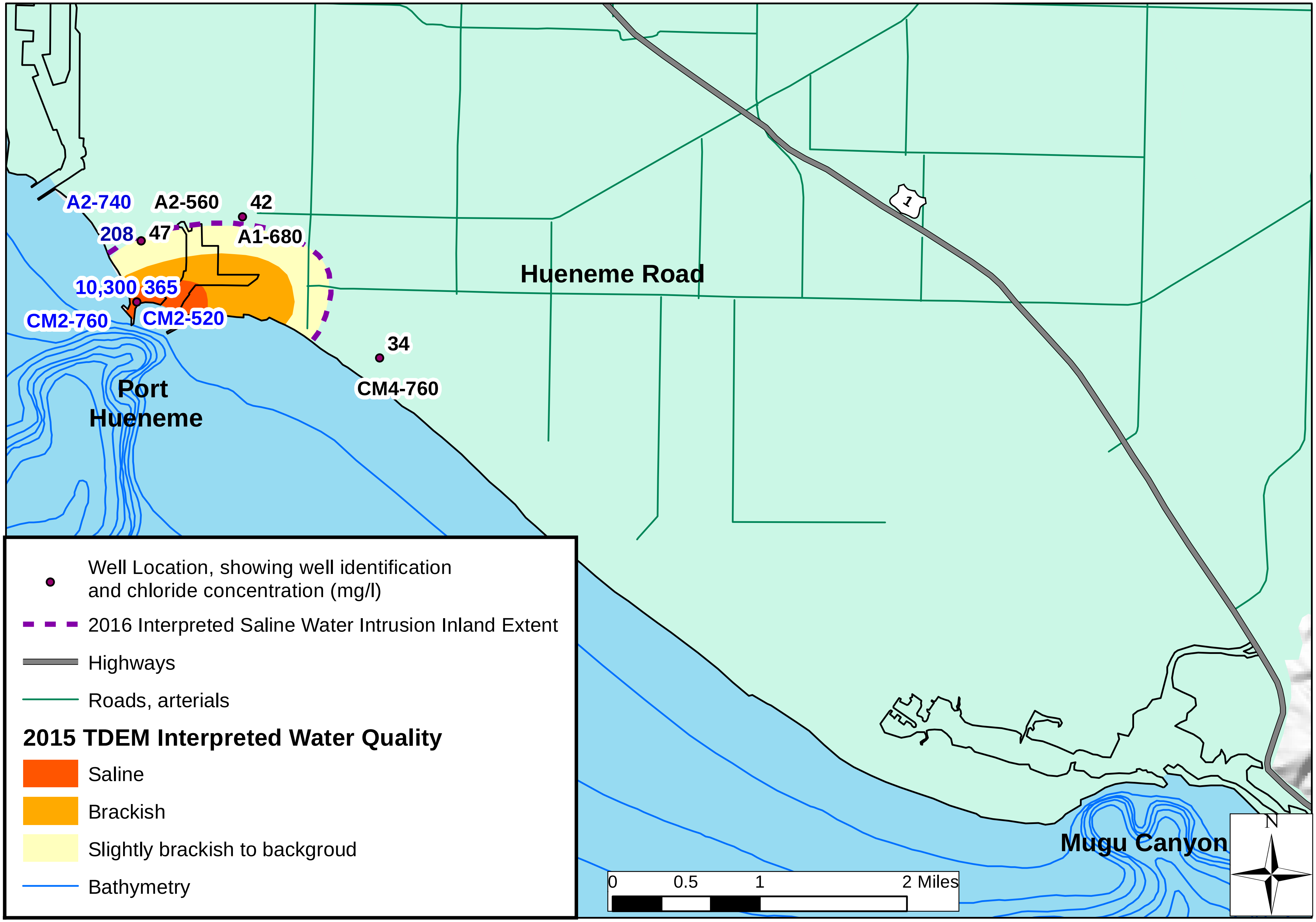


Figure 4.3.4. Hueneme aquifer chloride concentrations, coastal monitoring wells, fall 2015.
Interpreted source of elevated chloride levels key: Blue label = Seawater; Black label = Background level.

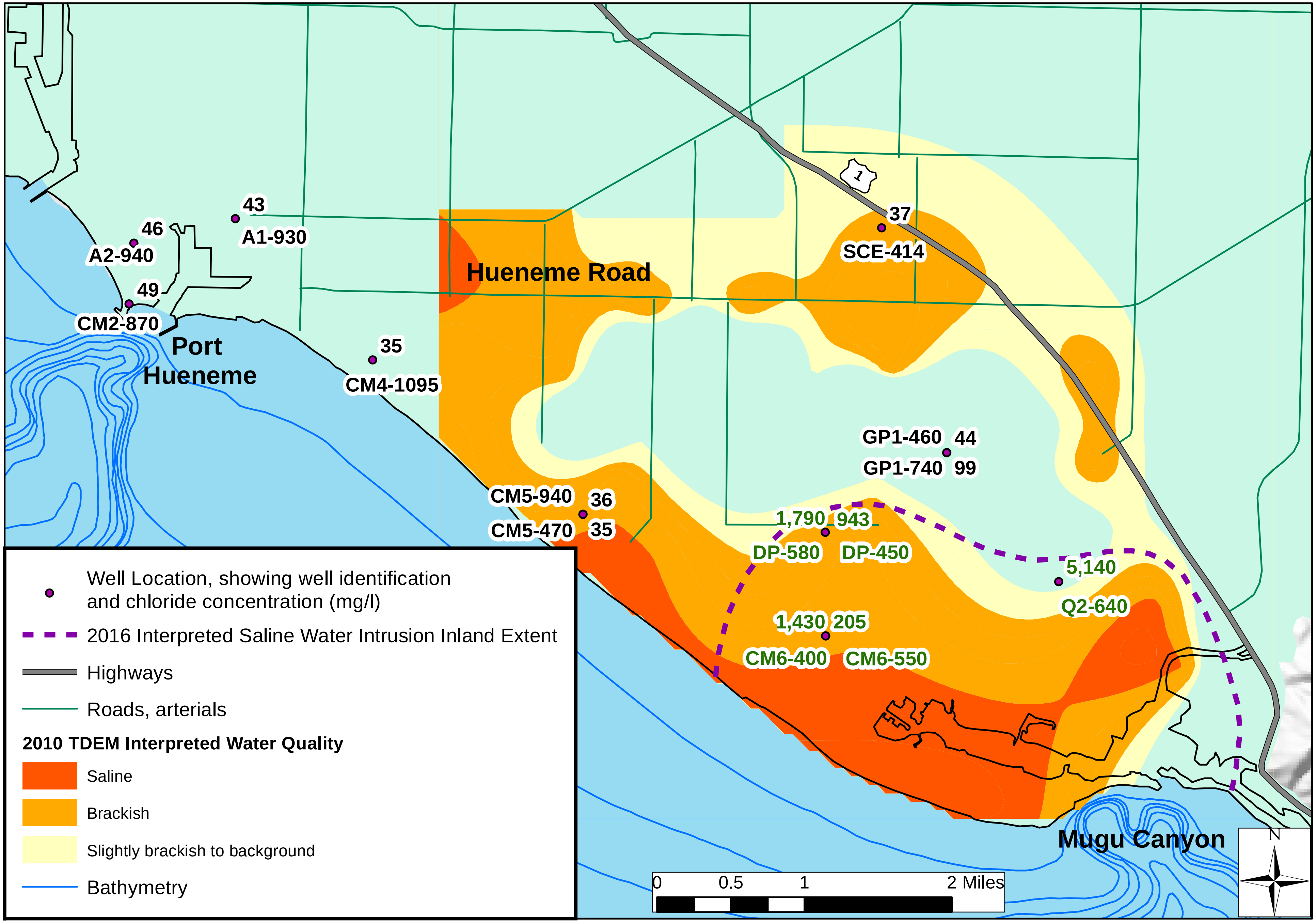


Figure 4.3.5. Fox Canyon aquifer chloride concentrations, coastal monitoring wells, fall 2015.
Interpreted source of elevated chloride levels key: Green label = Sediments; Black label = Background level.

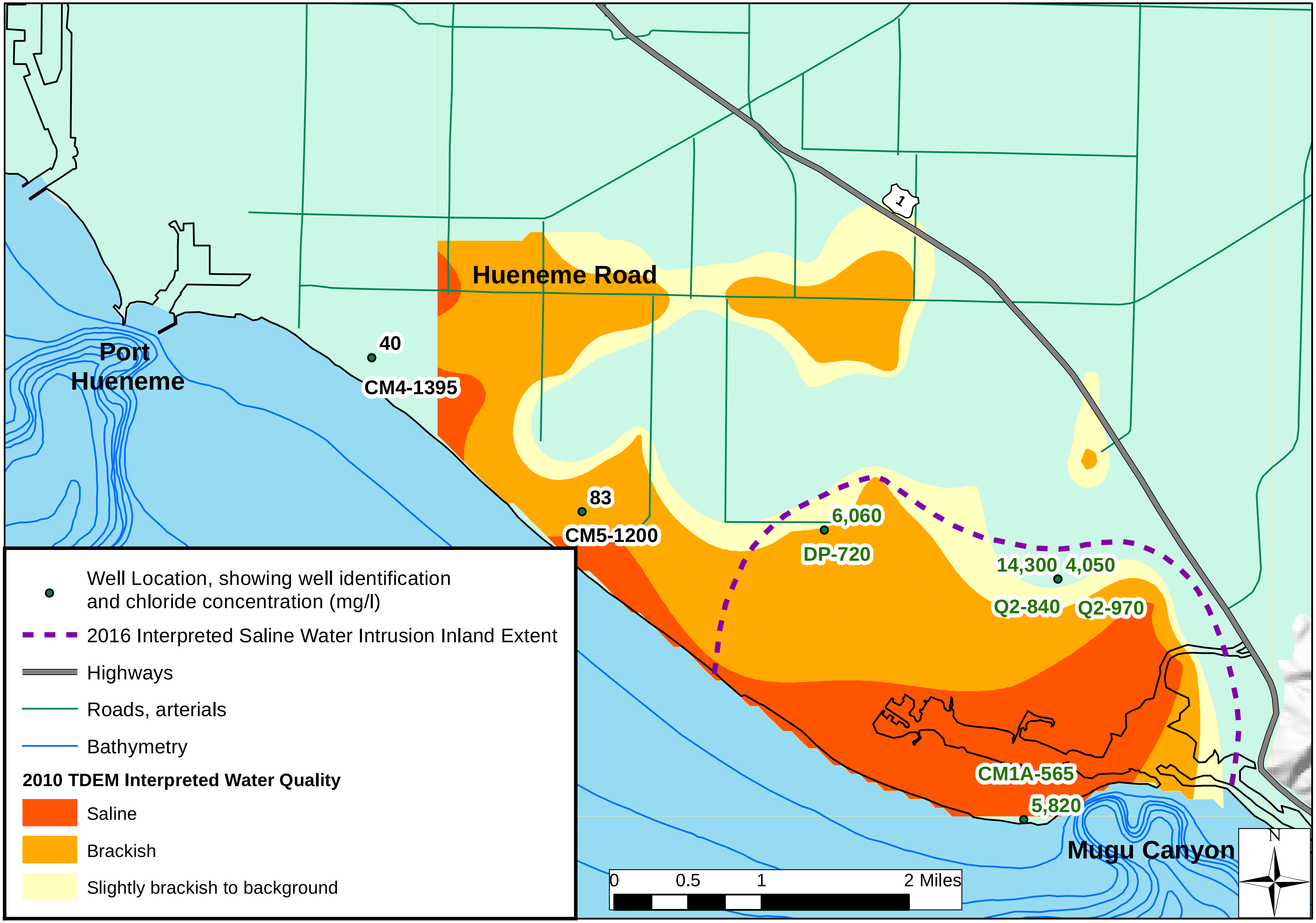


Figure 4.3.6. Grimes Canyon aquifer chloride concentrations, coastal monitoring wells, fall 2015.
Interpreted source of elevated chloride levels key: Green label = Sediments; Black label = Background level.

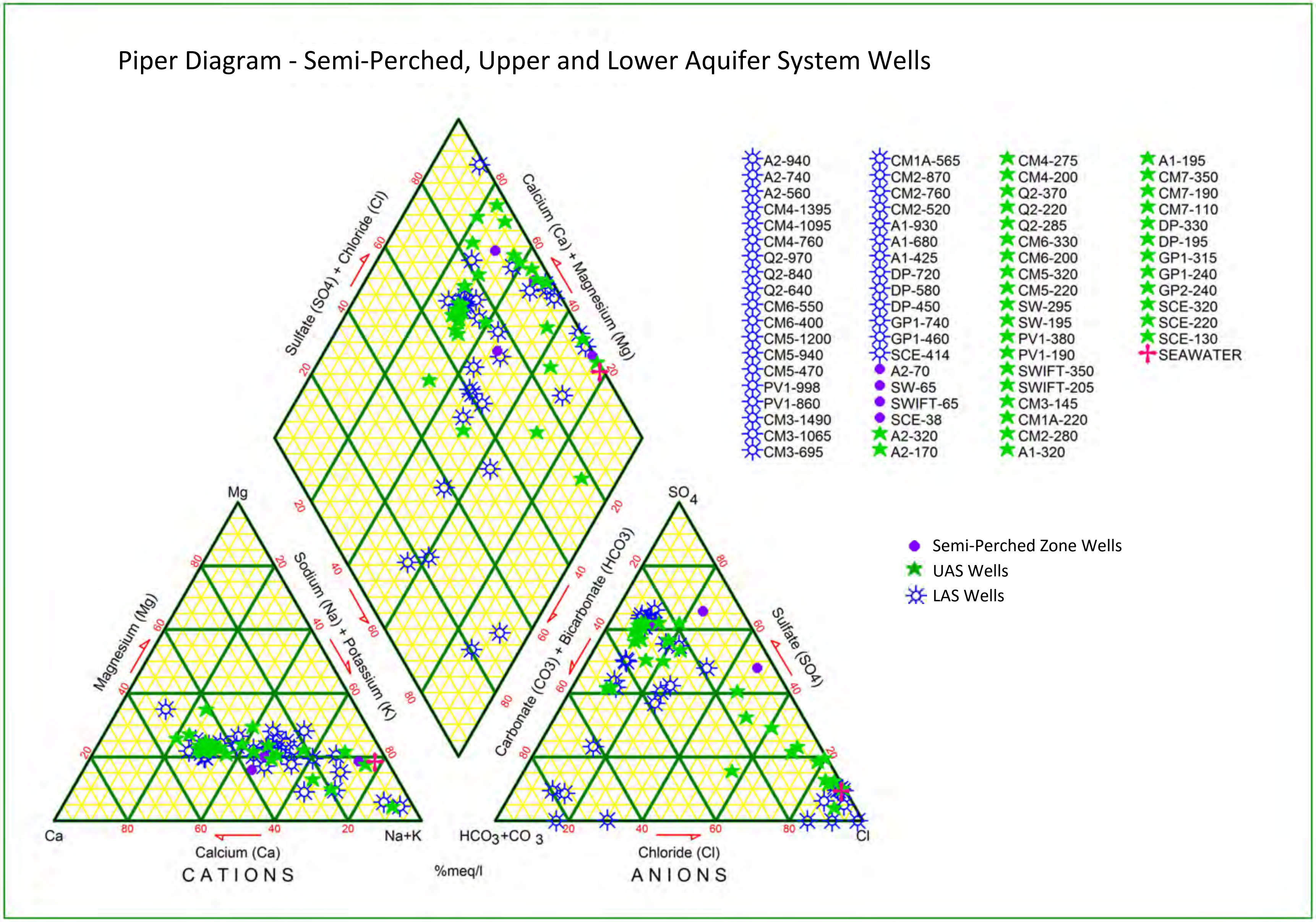


Figure 4.3.7. Piper diagram, fall 2014 and 2015 samples, coastal monitoring wells.

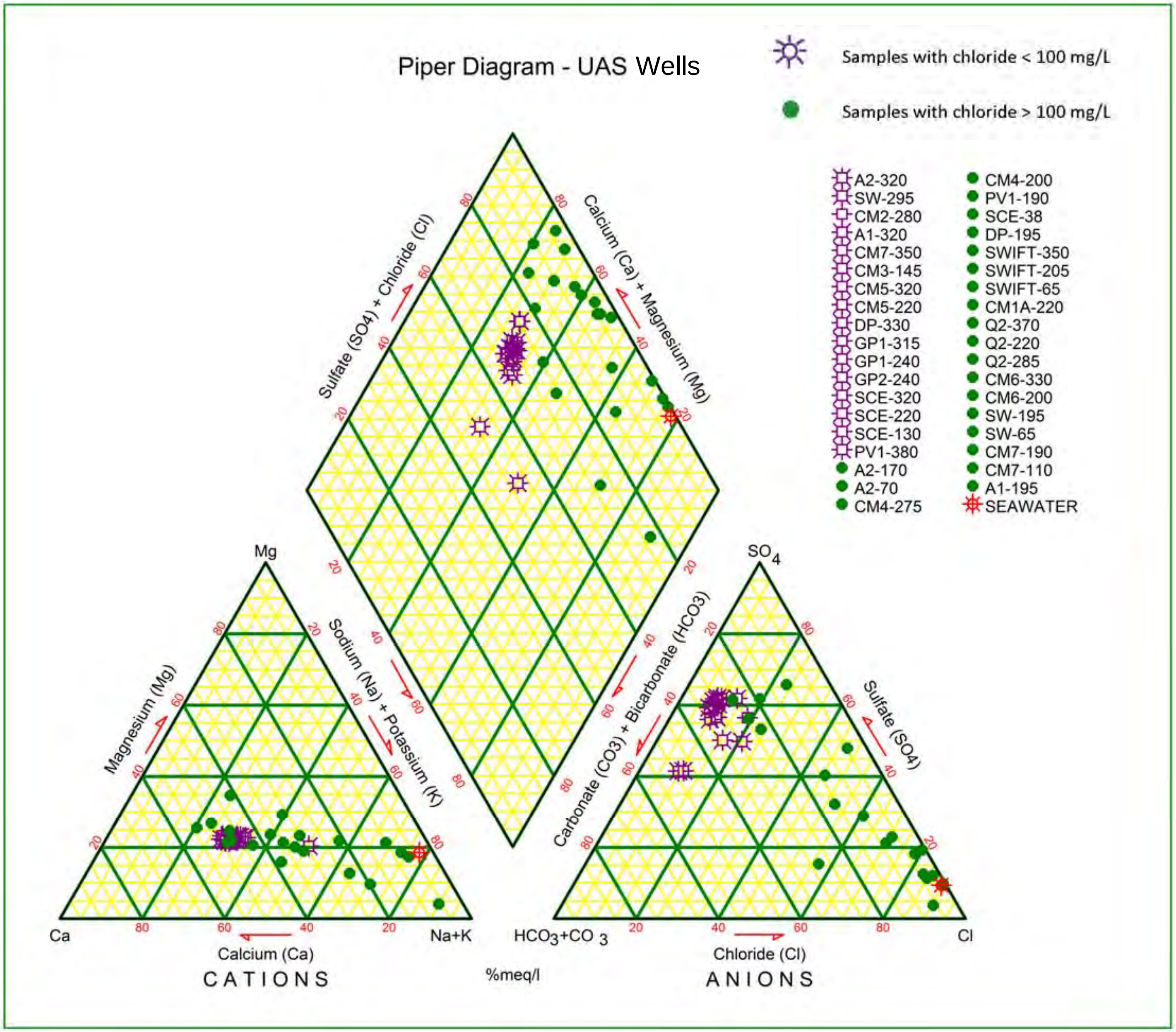


Figure 4.3.8. Piper diagram, fall 2014 and 2015 samples, Upper Aquifer System coastal monitoring wells.

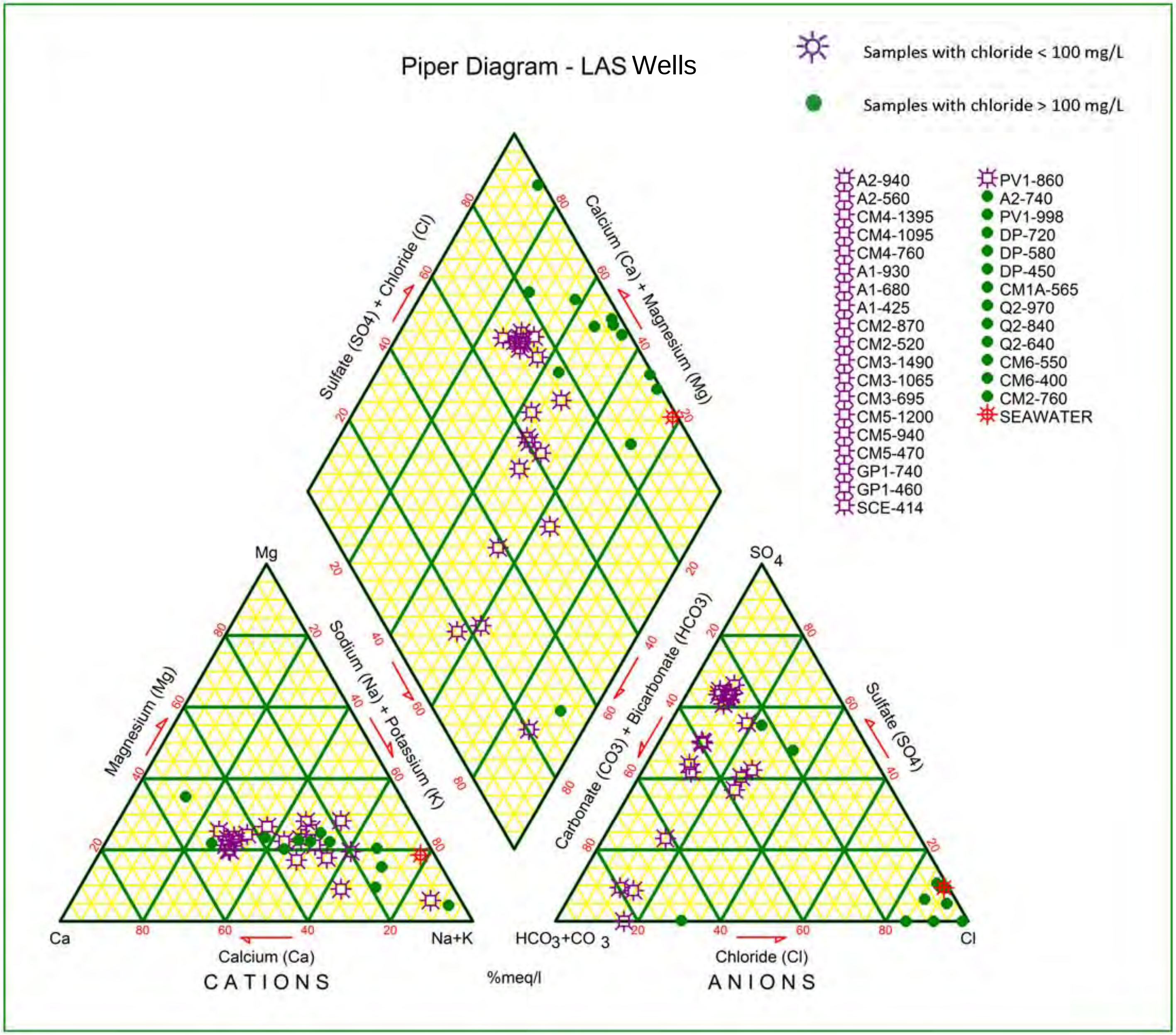


Figure 4.3.9. Piper diagram, fall 2014 and 2015 samples, Lower Aquifer System coastal monitoring wells.

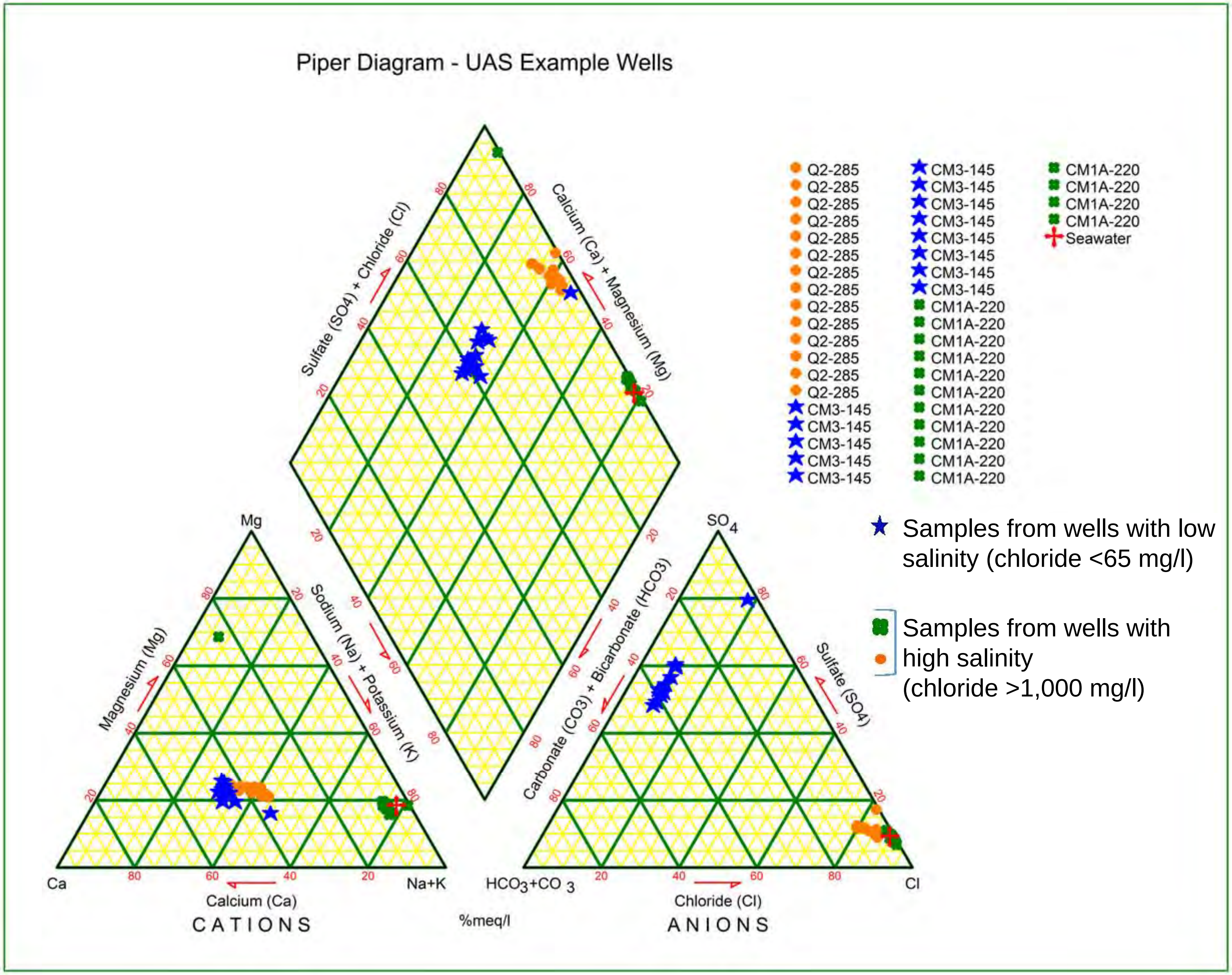


Figure 4.3.10. Piper diagram, selected Upper Aquifer System coastal monitoring wells; data 1989-2015.

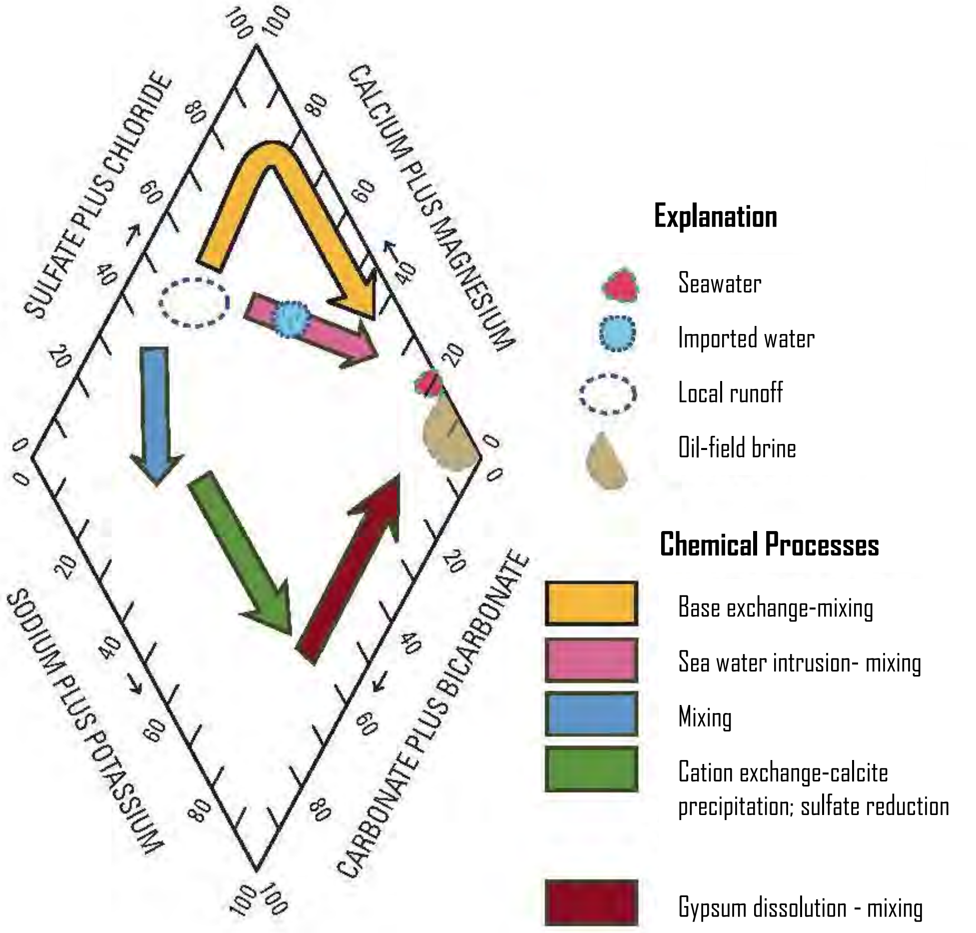


Figure 4.3.11. Piper diagram showing chemical processes typical of coastal aquifers (Hanson et al., 2009).

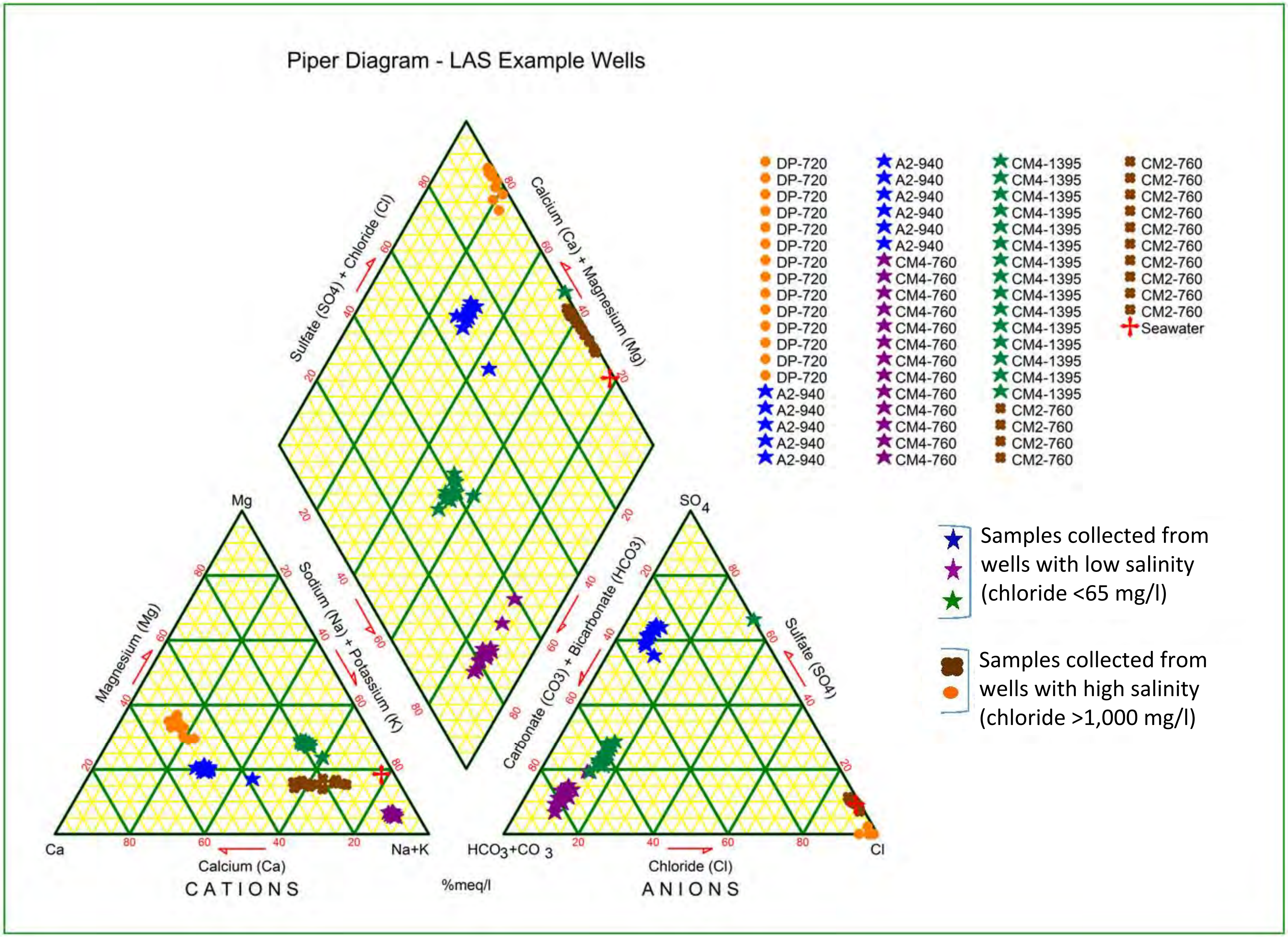
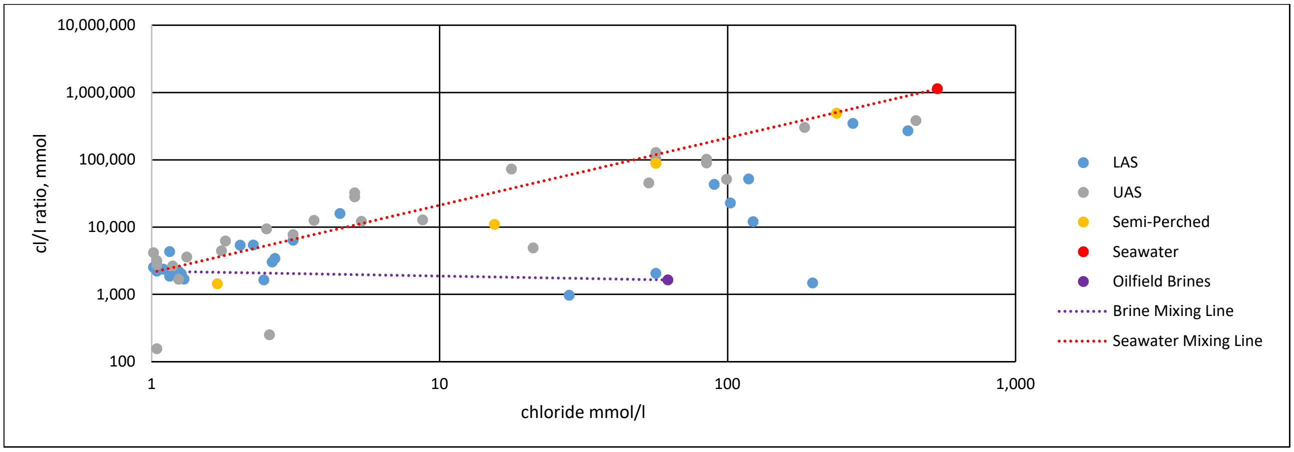
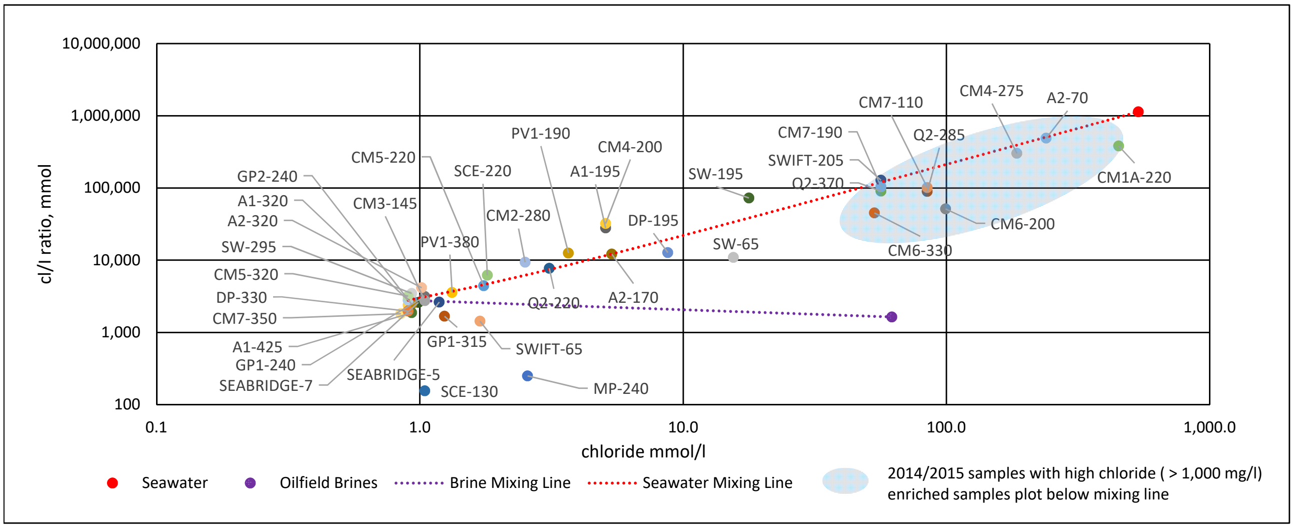


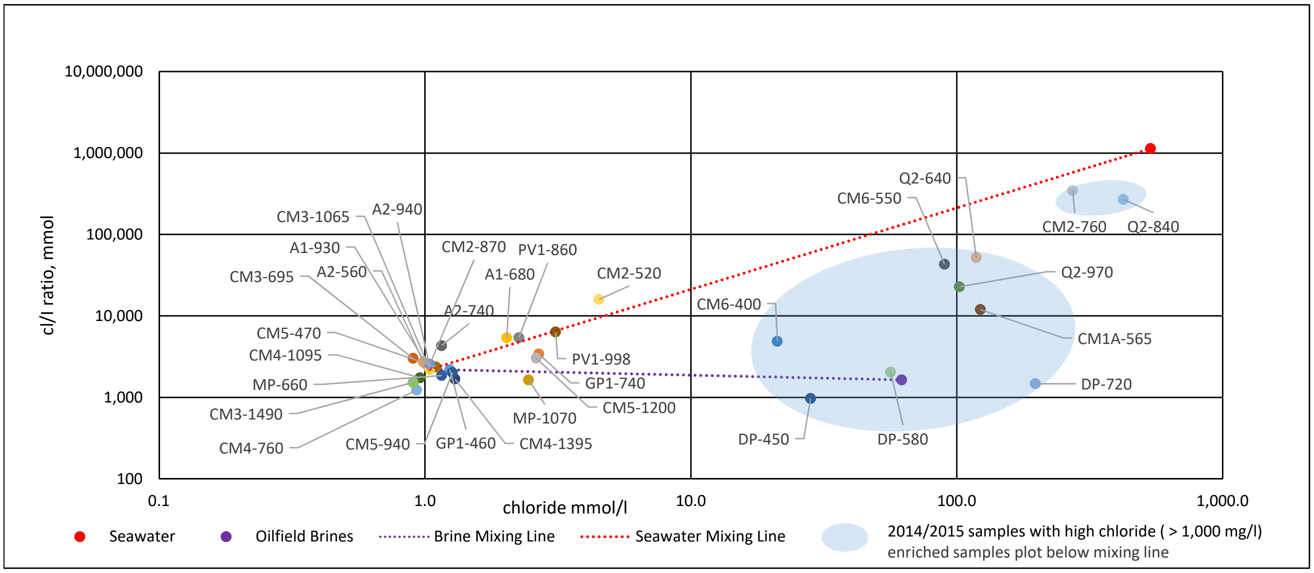
Figure 4.3.12. Piper diagram, selected Lower Aquifer System coastal monitoring wells; data 1989-2015.



A) Chloride to Iodide ratio as a function of Chloride in 2007 LAS and UAS samples, Oxnard Plain.



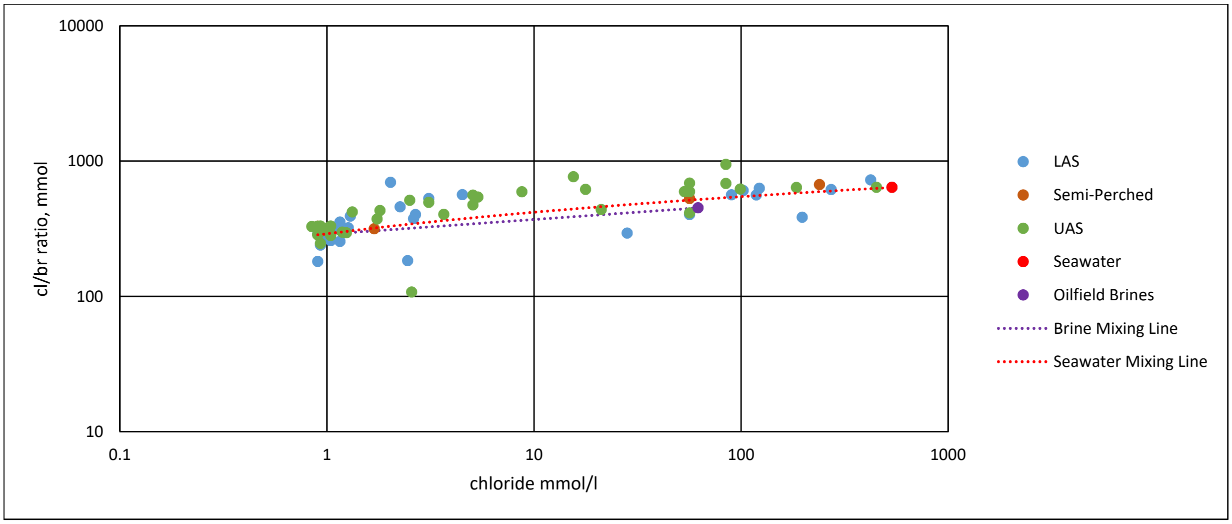
B) Chloride to Iodide ratio as a function of Chloride in 2007 UAS and Semi-Perched zone samples, Oxnard Plain.



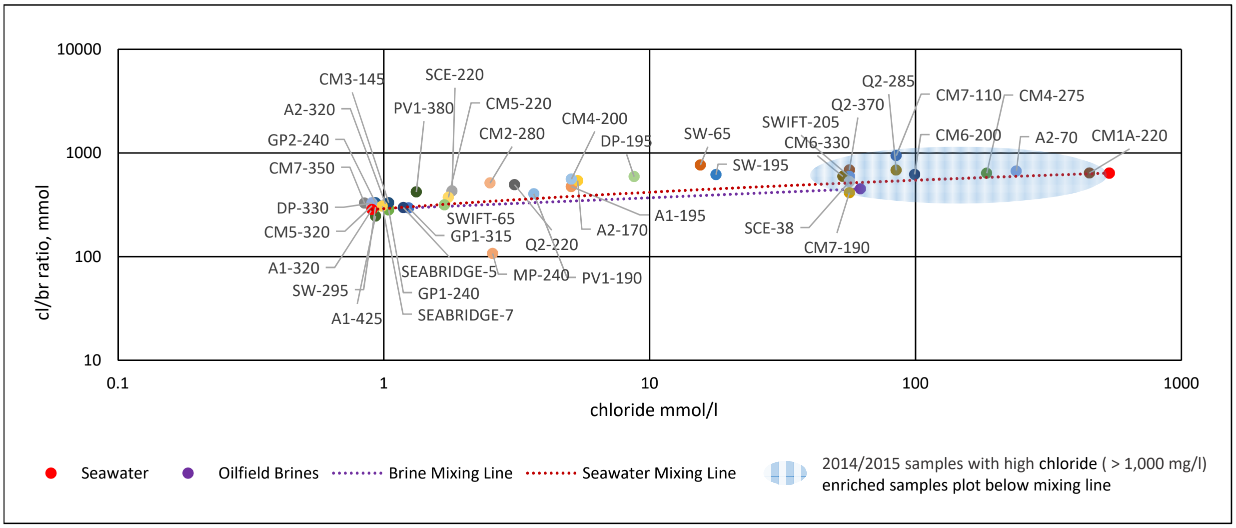
C) Chloride to Iodide ratio as a function of Chloride in 2007 LAS samples, Oxnard Plain.

Note: Chemistry of oilfield brine - mixture of water from four oil field production wells discharging at a single location (PV basin)
(data source Izbicki et al., 2005)

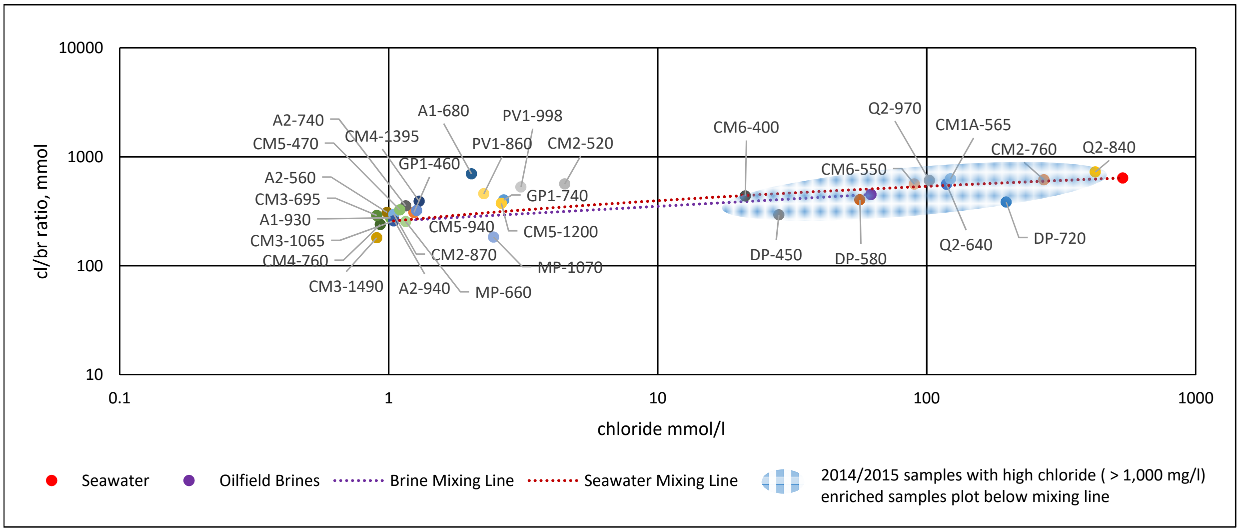
Figure 4.3.13. Chloride/Iodide molar ratio graphs for coastal monitoring wells; 2007 data.



A) Chloride to Bromide ratio as a function of Chloride in 2007 LAS and UAS samples, Oxnard Plain.



B) Chloride to Bromide ratio as a function of Chloride in 2007 UAS and Semi-Perched zone samples, Oxnard Plain.



C) Chloride to Bromide ratio as a function of Chloride in 2007 LAS samples, Oxnard Plain.

Note: Chemistry of oilfield brine - mixture of water from four oil field production wells discharging at a single location (PV basin)
(data source Izbicki et al., 2005)

Figure 4.3.14. Chloride/Bromide molar ratio graphs for coastal monitoring wells; 2007 data.

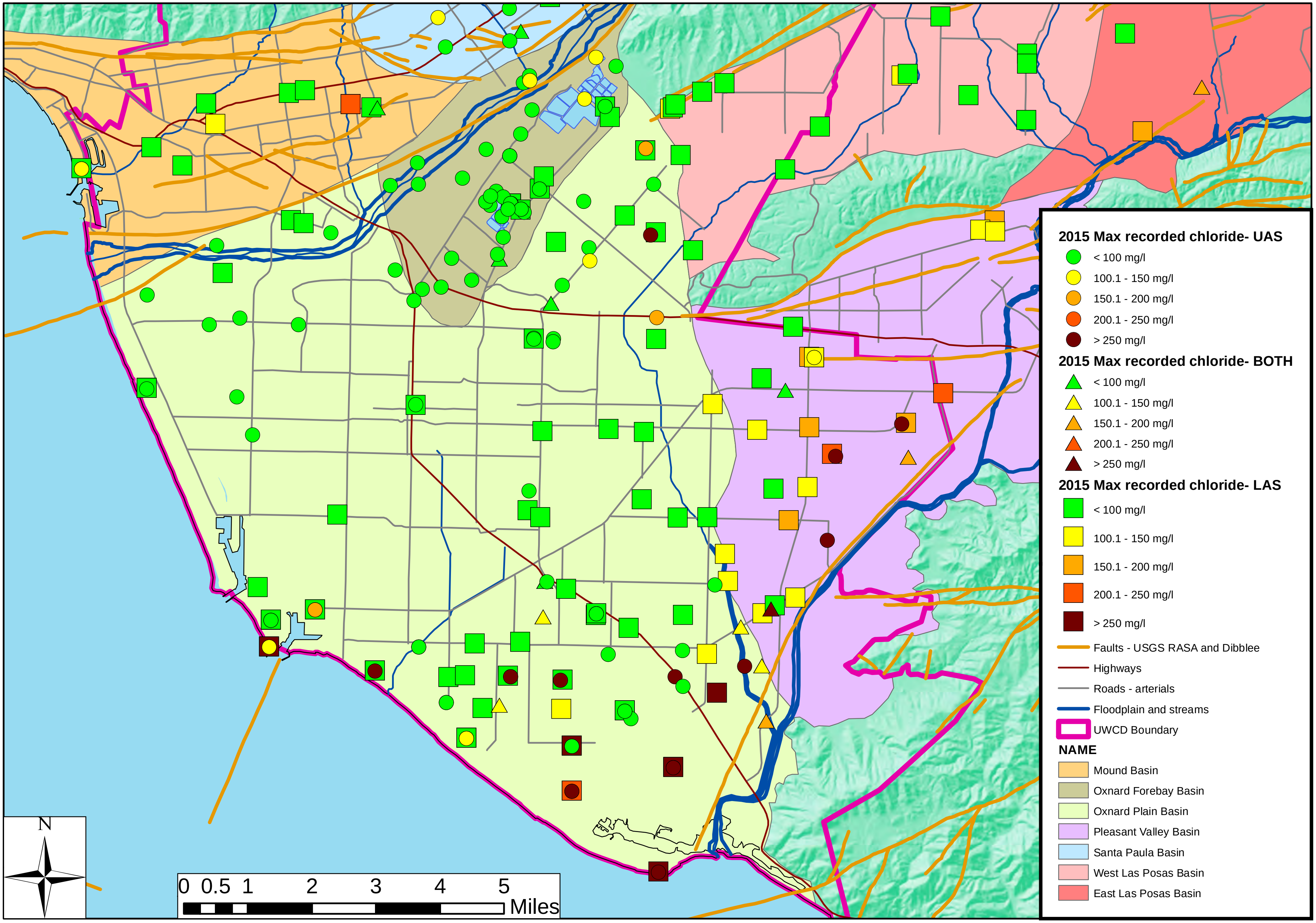


Figure 4.3.15. Maximum-recorded chloride concentrations, coastal basin wells, 2015.

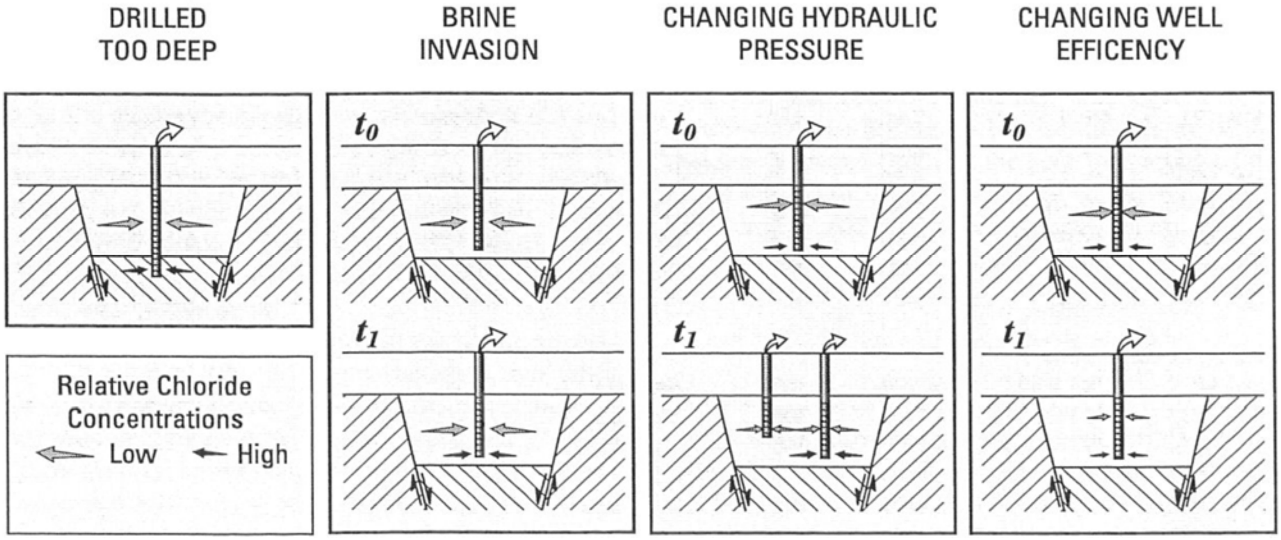


Figure 4.3.16. Possible sources of high-chloride water to wells, Pleasant Valley basin (from Izbicki et al., 2005b).

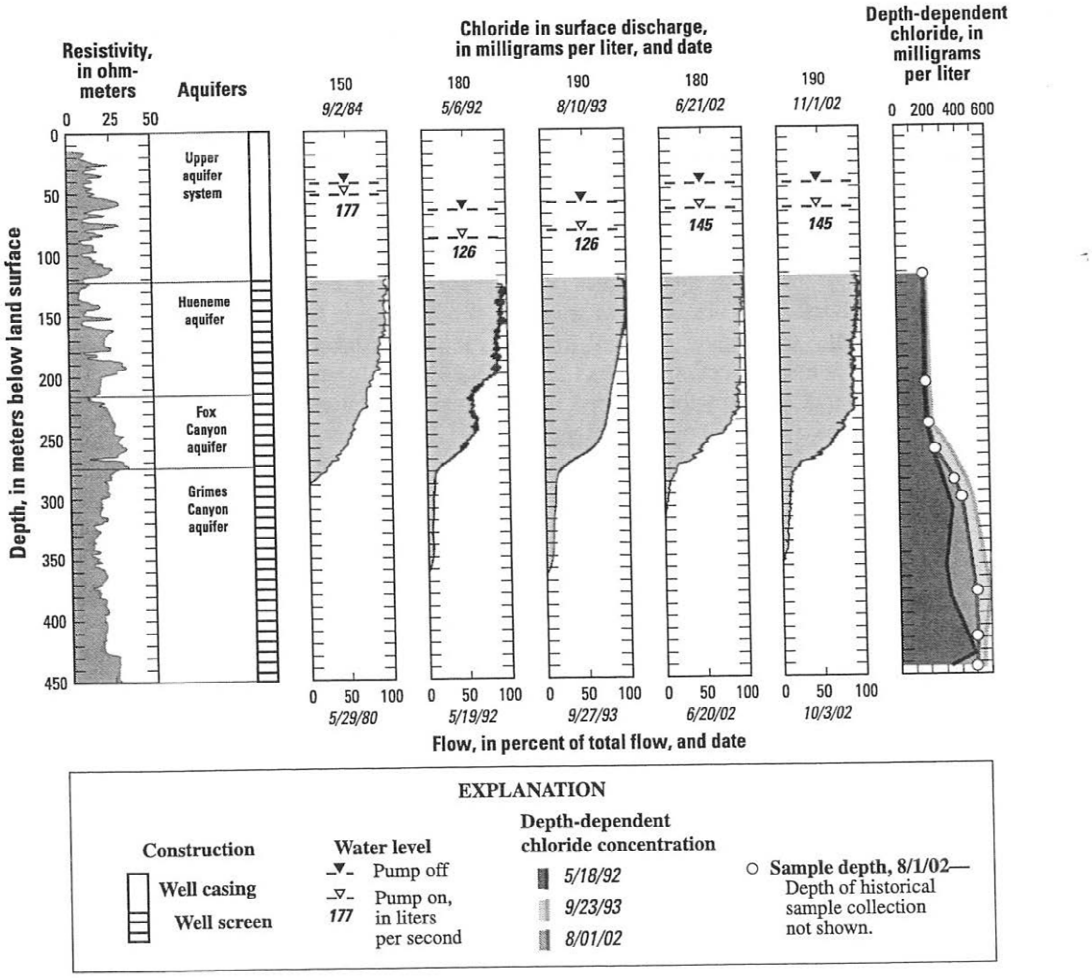


Figure 4.3.17. Flowmeter and depth-dependent chloride concentration data from well PVCWD #2; data 1980-2002 (from Izbicki et al., 2005b).

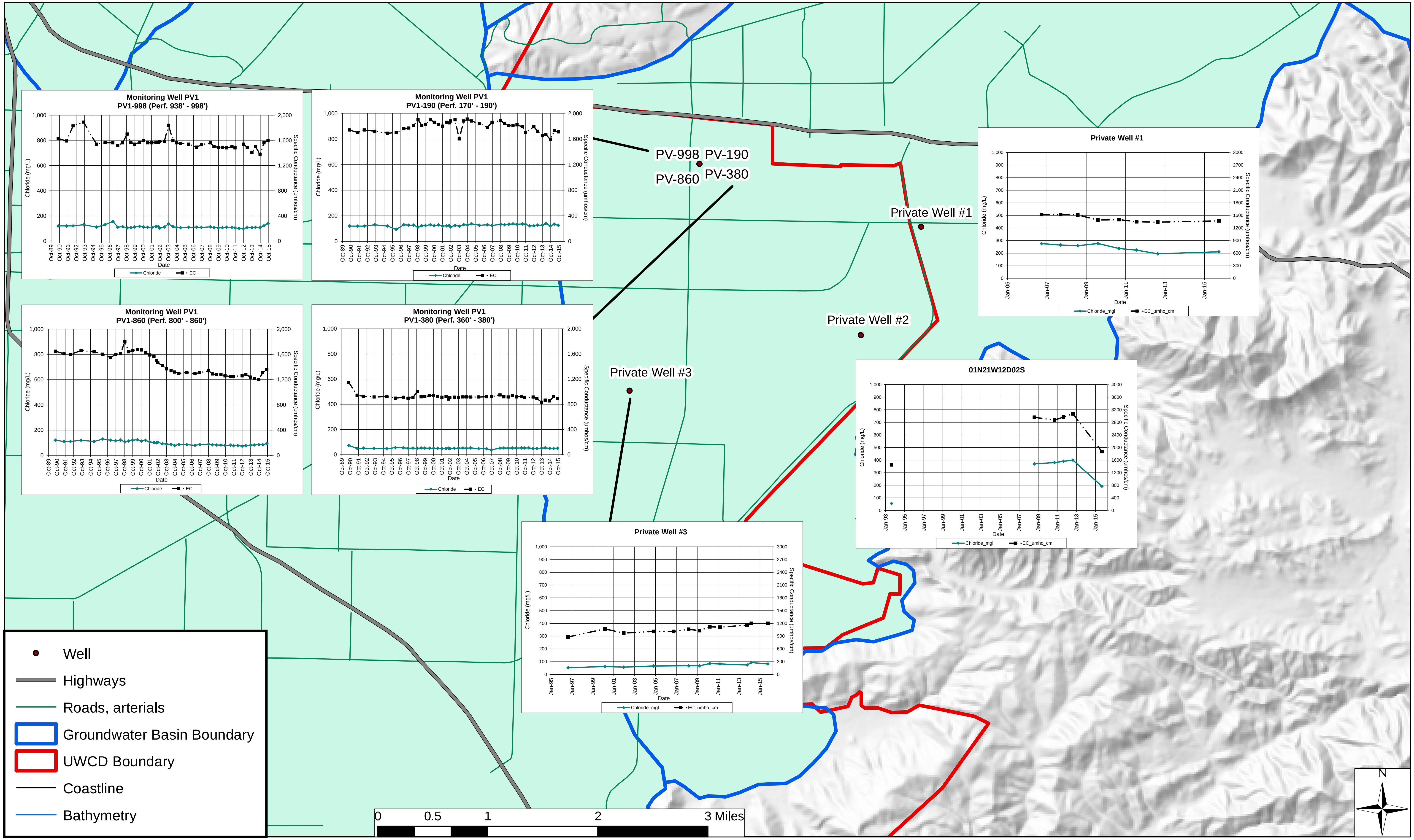


Figure 4.3.18. Chloride and Electrical Conductivity time series plots, PV1 well cluster and selected private wells, Pleasant Valley basin.

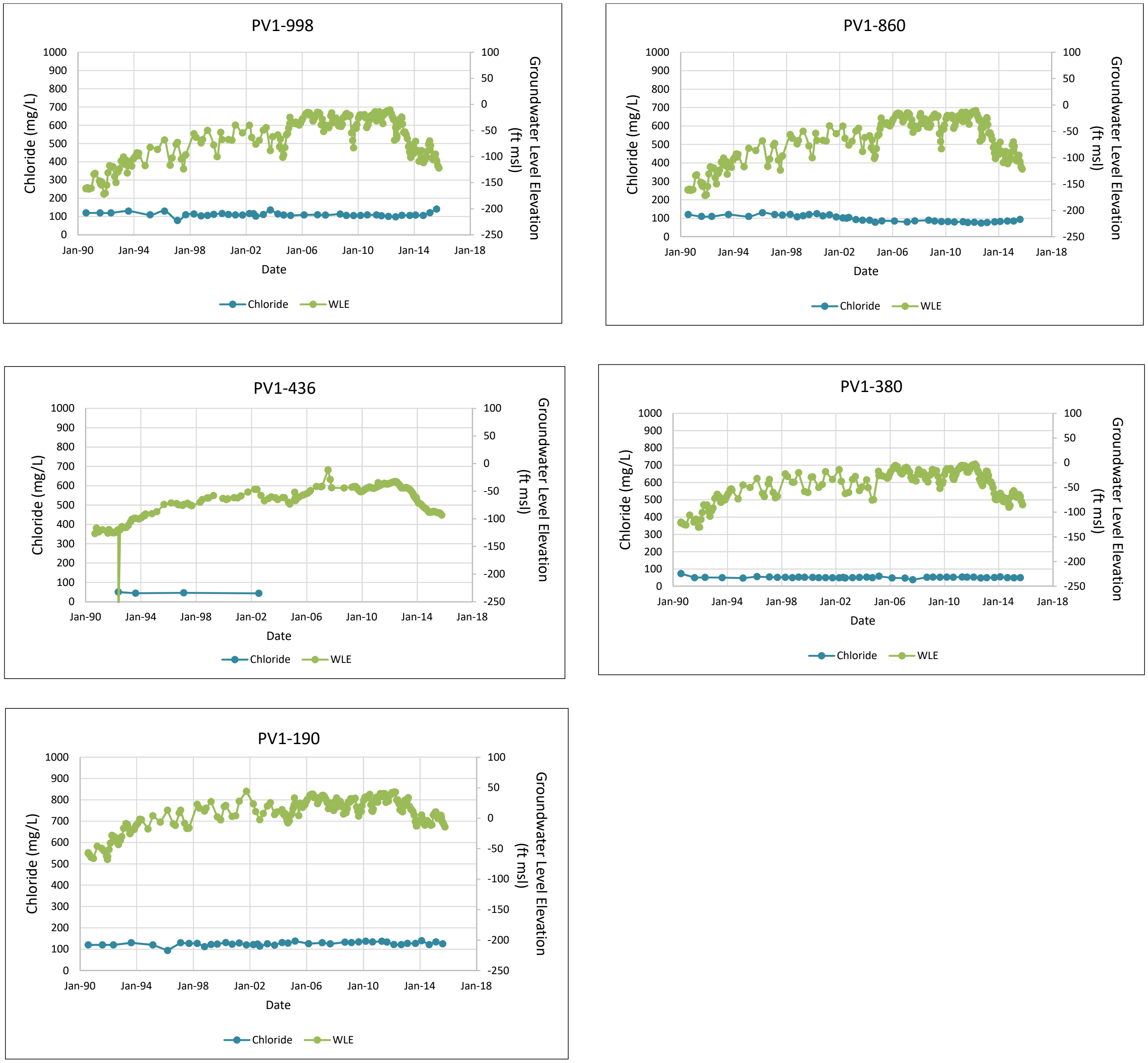


Figure 4.3.19. Chloride and groundwater elevation time series, PV1 well cluster.

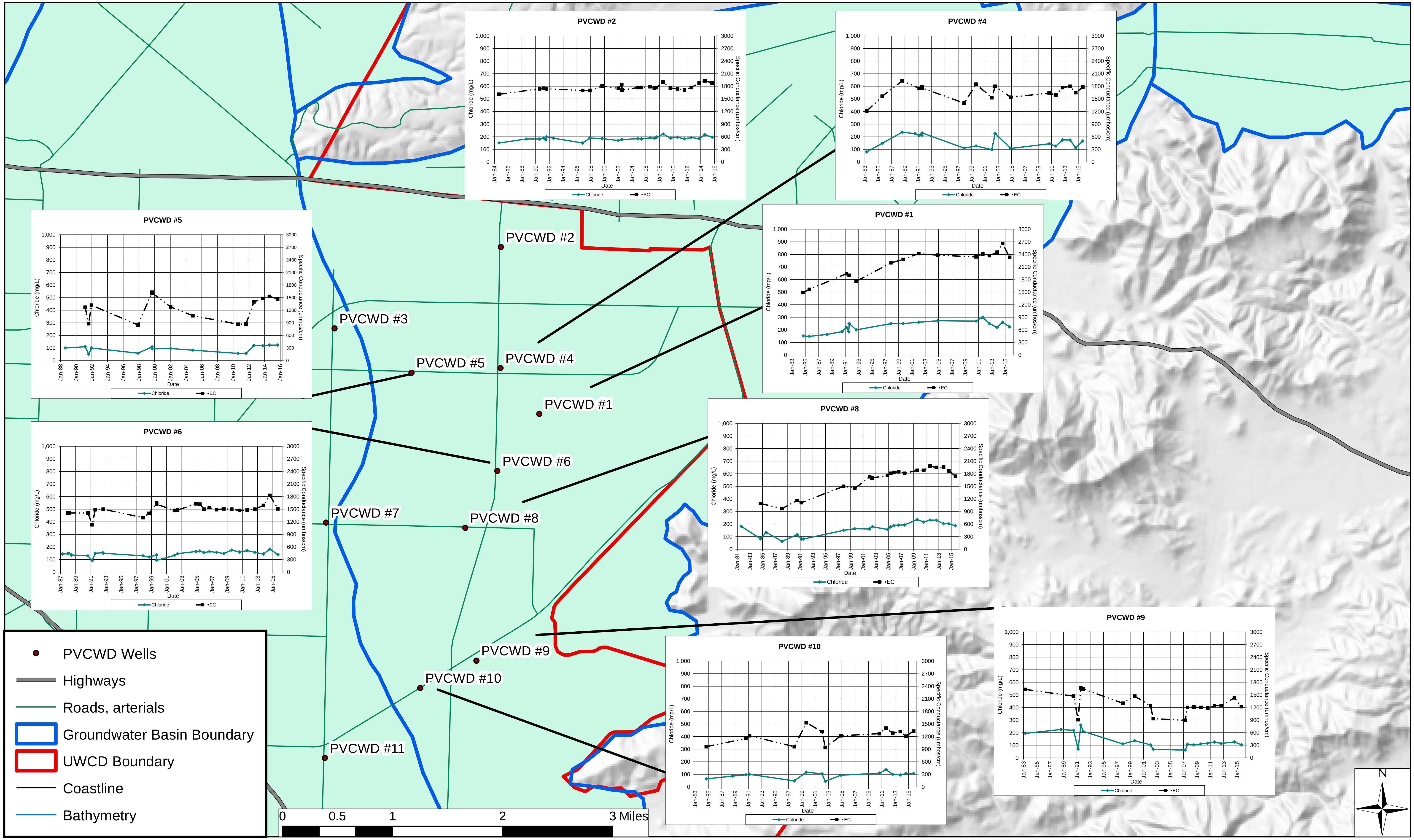


Figure 4.3.20. Chloride and Electrical Conductivity time series plots, Pleasant Valley County Water District wells.

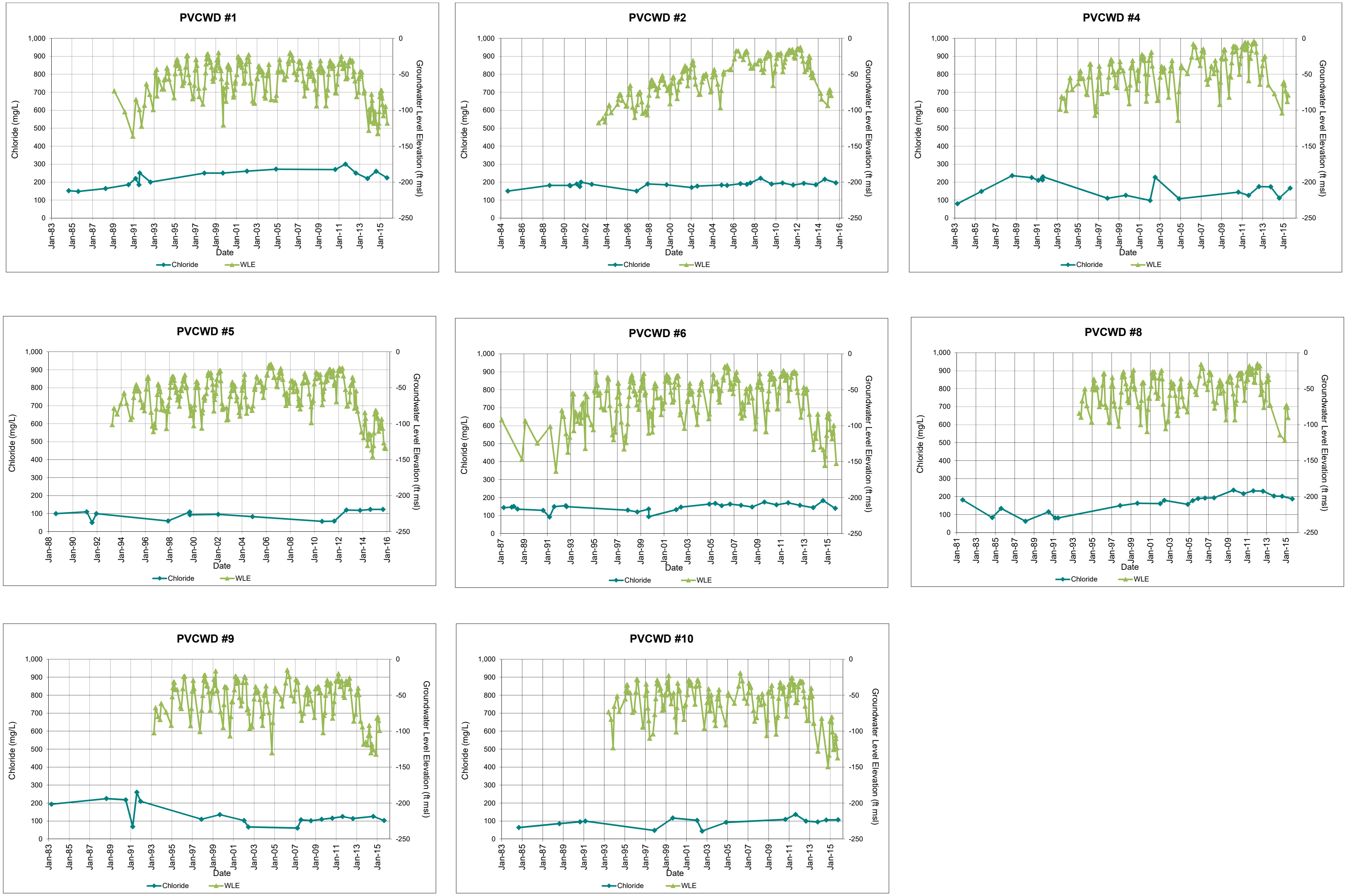
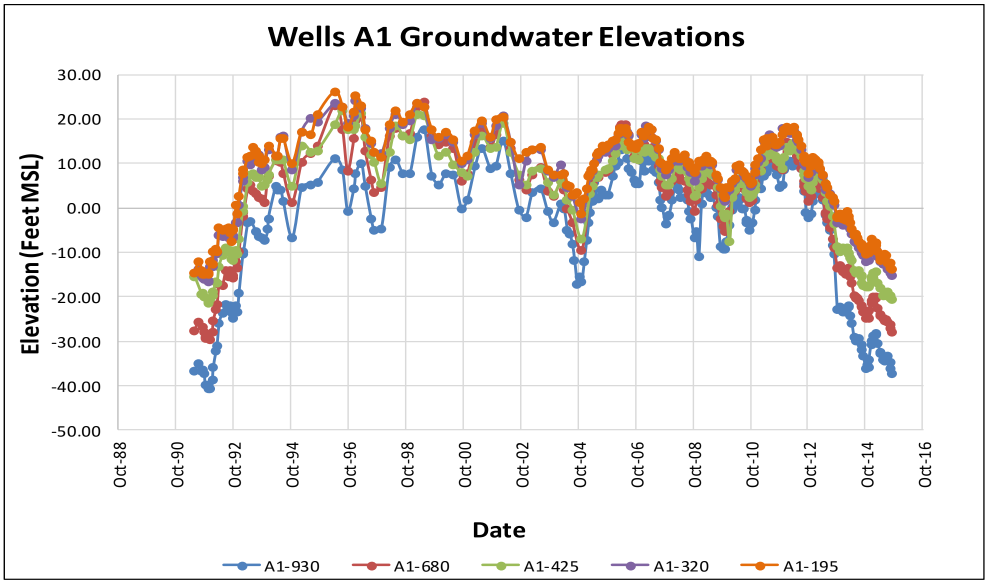
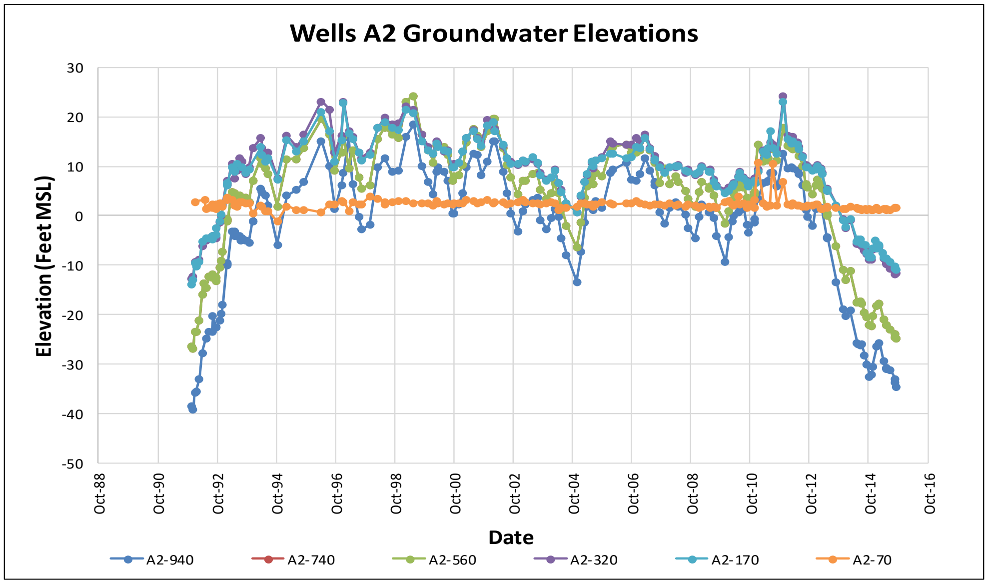


Figure 4.3.21. Chloride and groundwater elevation time series, Pleasant Valley County Water District wells.

APPENDICES

APPENDIX A, GROUNDWATER ELEVATIONS





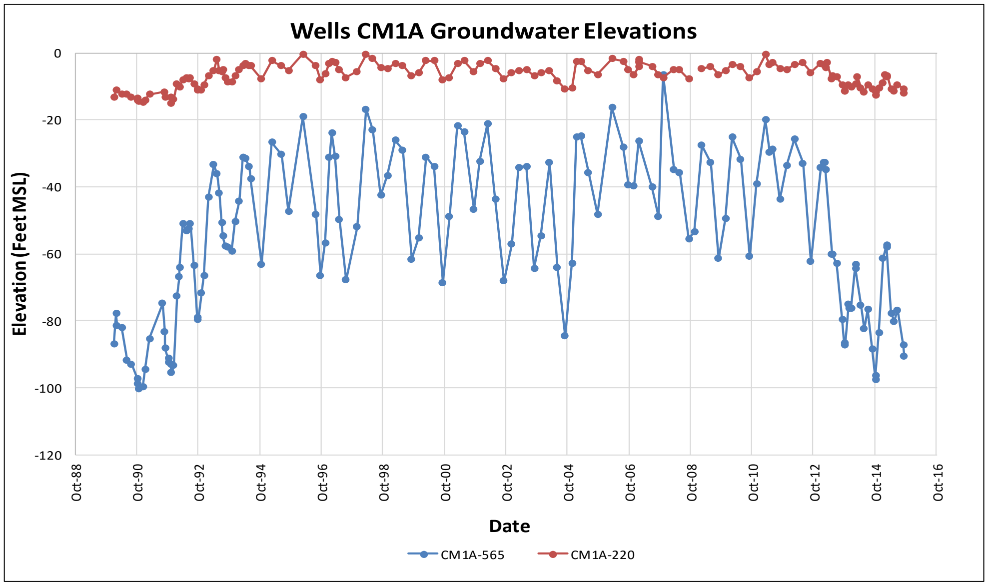
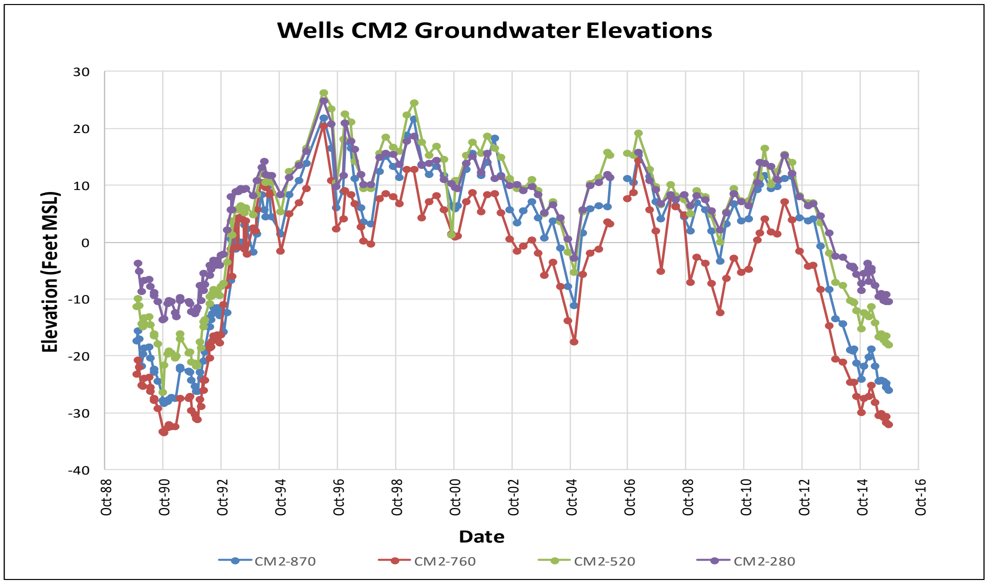
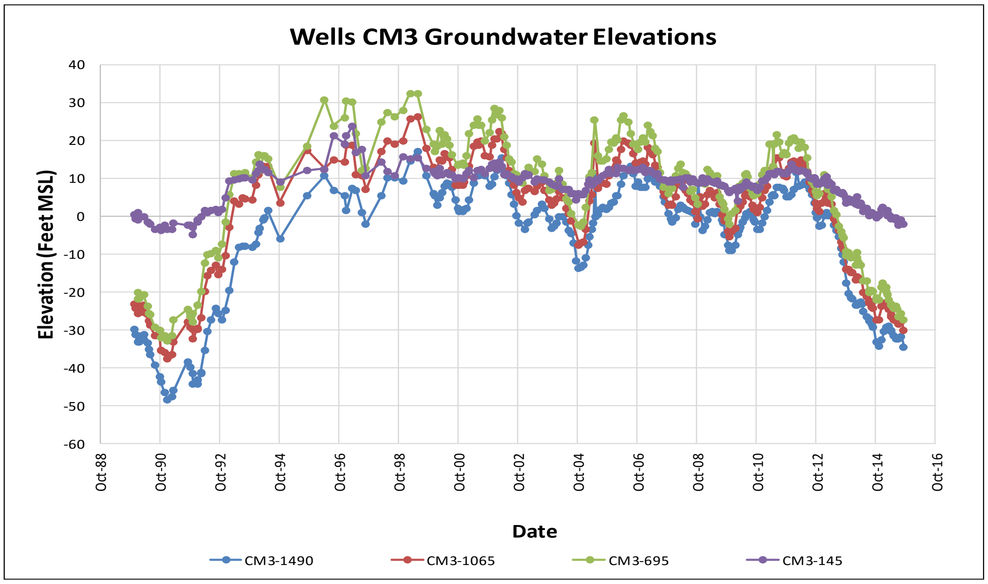


Figure A-1. Groundwater elevation time series, coastal monitoring wells.





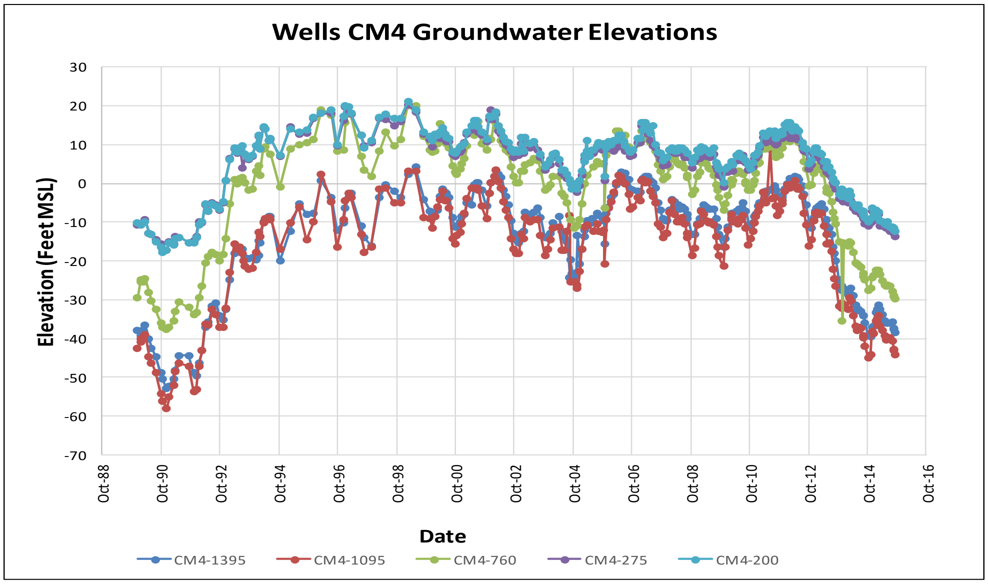
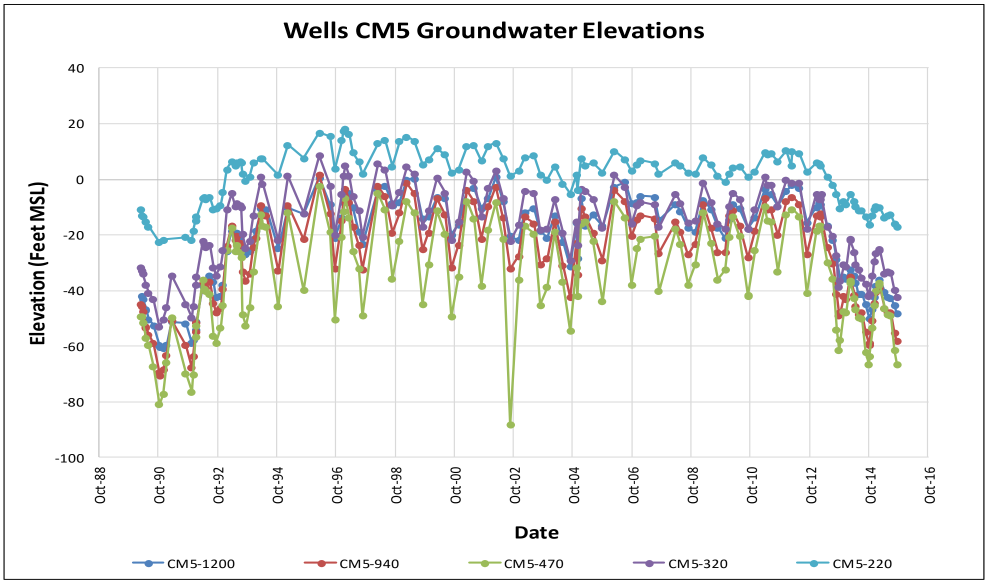
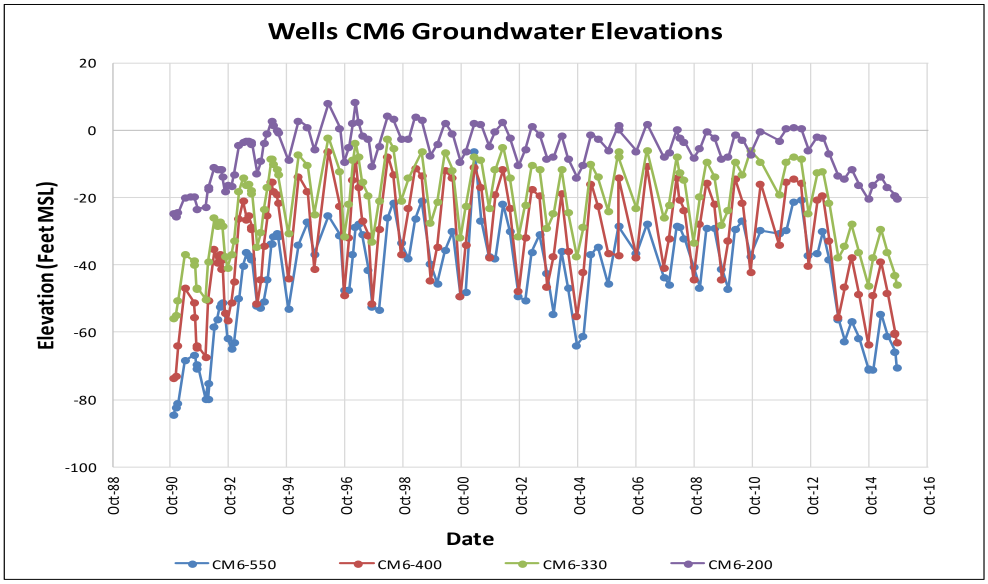


Figure A-1. Groundwater elevation time series, coastal monitoring wells.





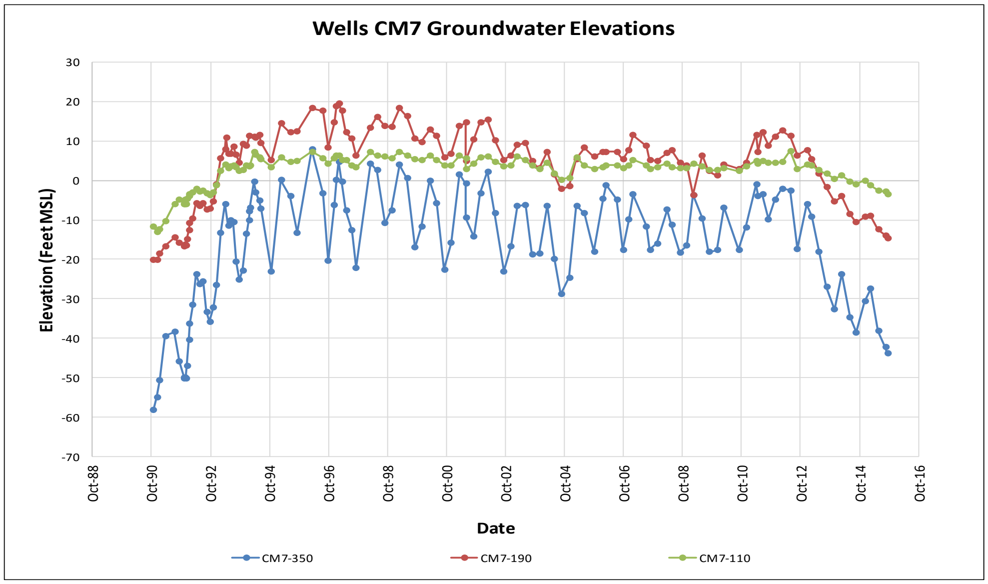
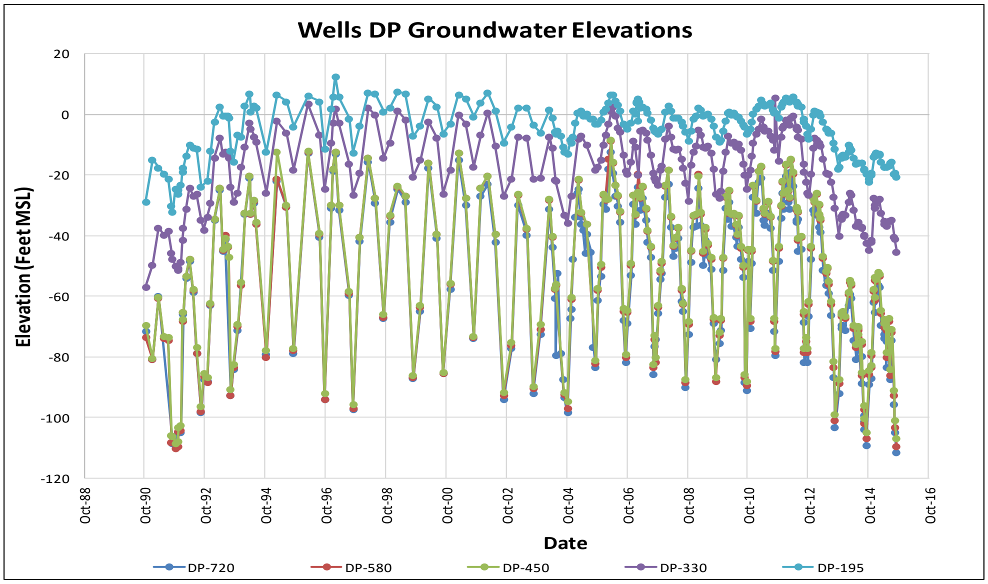
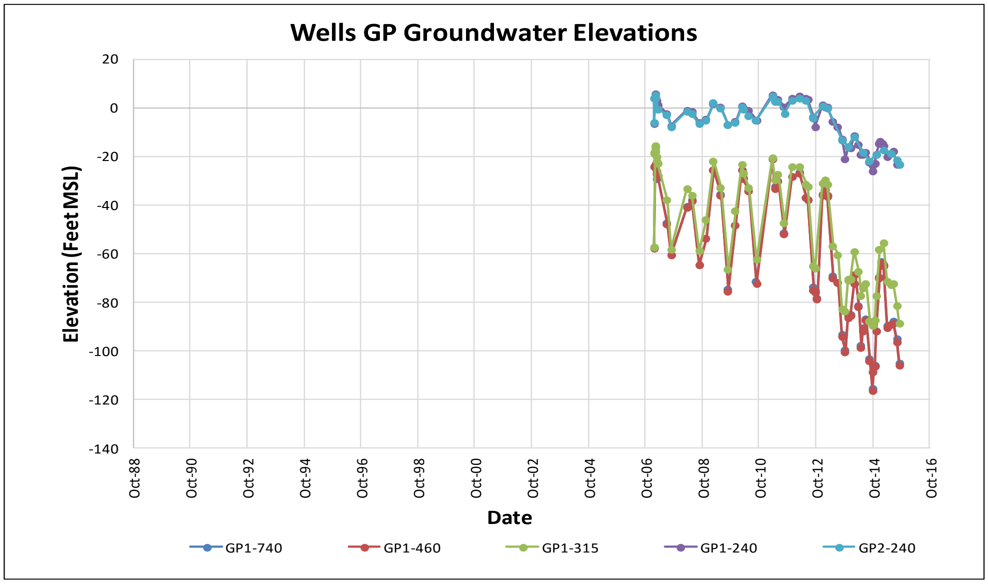


Figure A-1. Groundwater elevation time series, coastal monitoring wells.





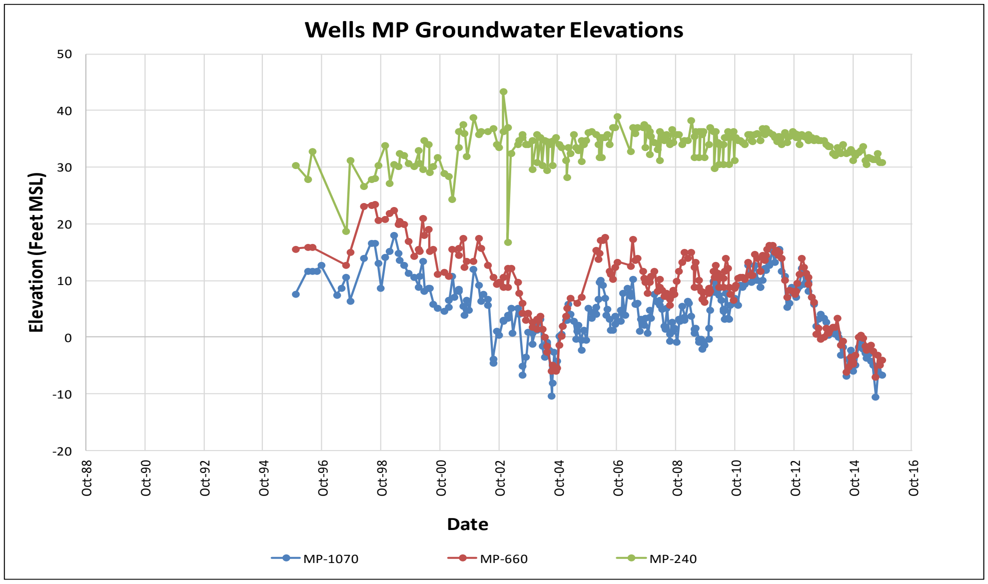


Figure A-1. Groundwater elevation time series, coastal monitoring wells.

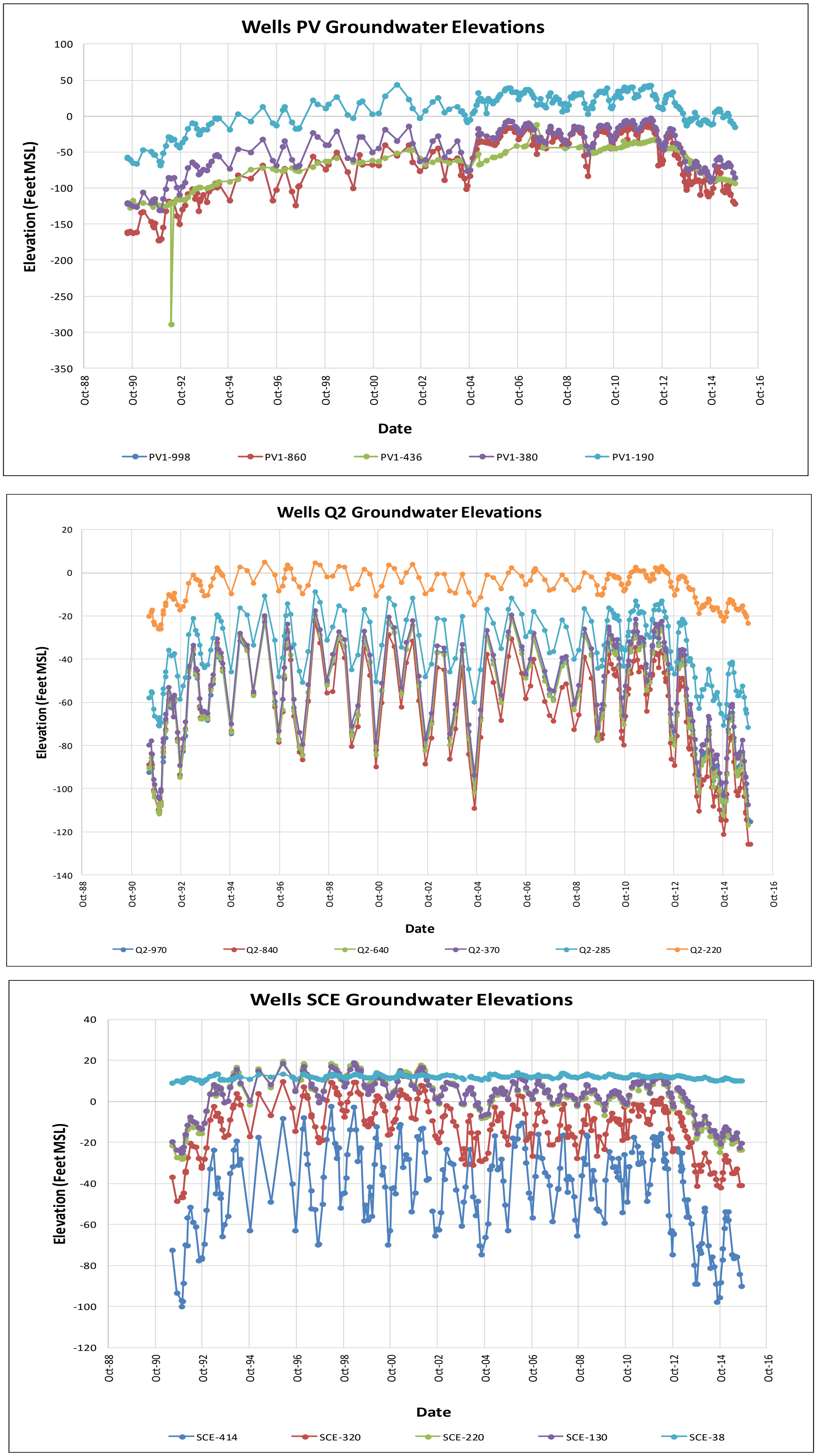
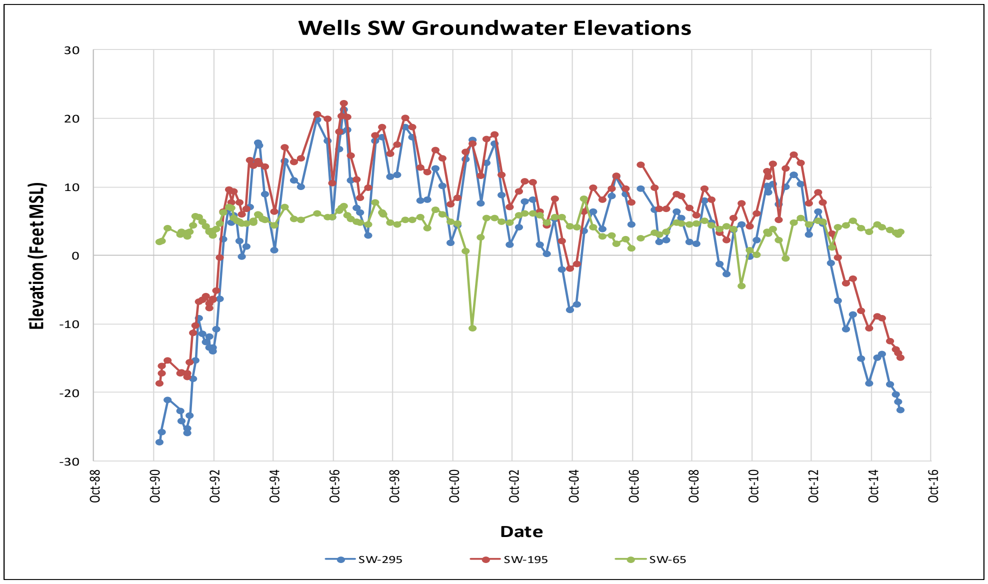


Figure A-1. Groundwater elevation time series, coastal monitoring wells.



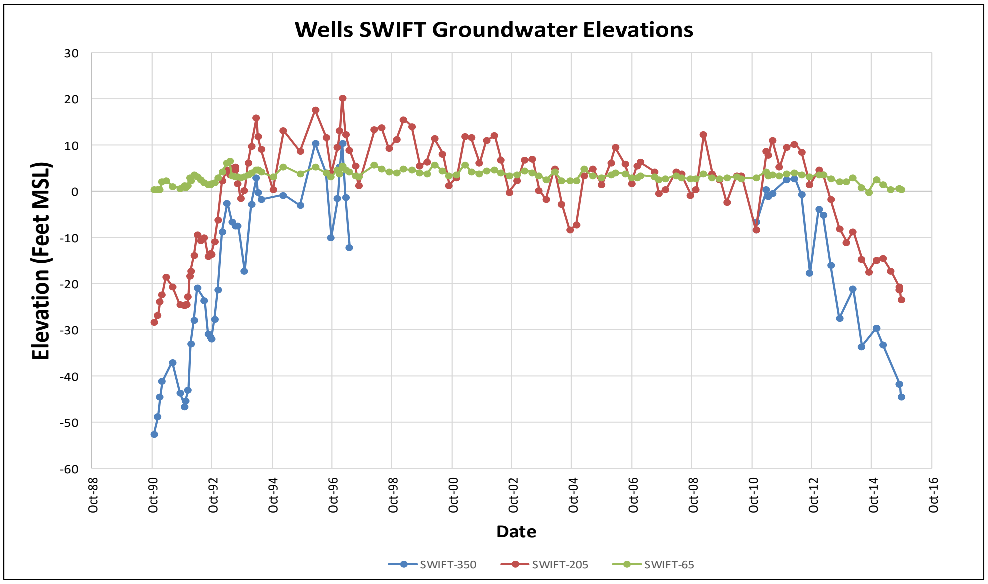


Figure A-1. Groundwater elevation time series, coastal monitoring wells.

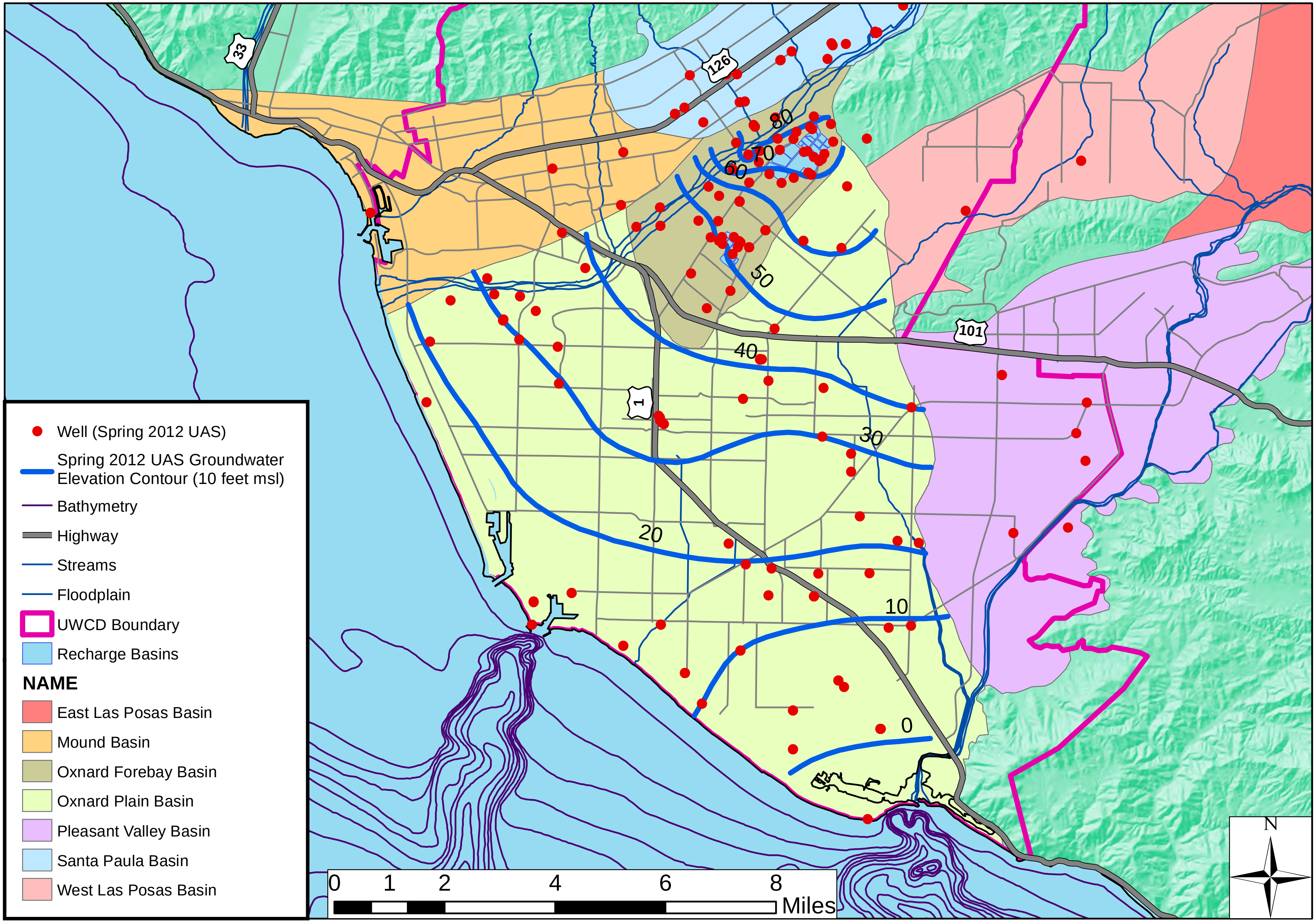


Figure A-2. Spring 2012 groundwater elevations, Upper Aquifer System wells.

APPENDIX B, WATER QUALITY

Table B-1

2015 general mineral water quality data, coastal monitoring wells

United Water Conservation District

State Well ID	Owner Well ID	Sample Date	Sample Time	Lab ID	Analysis Date	Analysis Time	THardCaCO3	Calcium	Magnesium	Potassium	Sodium	Tcations	TALKCaCO3	Hydroxide	Carbonate	Bicarbonate	Sulfate	Chloride	Nitrate	Fluoride	Tanions	Specific Conductivity	TDS	Boron	Copper	Iron	Manganese	Zinc	Nitrate as N	Nitrite as N	NO2+NO3 as N	Field Temp	pH Field
							mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	meq/L	umho/cm	mg/L	mg/L	ug/L	ug/L	ug/L	ug/L	mg/L	mg/L	mg/L	°F	
01N22W20M01S	A2-940	09/17/2015	12:22	440-121392-1	10/06/2015	09:45	456	130	31.9	4.61	92.7	13.3	211	-4	-4	211	391	45.7	-0.5	0.306	13.7	1,140	937	0.557	-2	296	187	-20	-0.11	-0.15	-0.15	70.7	7.7
01N22W20M02S	A2-740	09/17/2015	13:42	440-121392-2	10/06/2015	09:45	598	169	42.8	4.58	92.7	16.1	197	-4	-4	197	402	208	-0.5	0.38	18.2	1,420	1140	0.585	-2	498	343	-20	-0.11	-0.15	-0.15	69.1	7.5
01N22W20M03S	A2-560	09/17/2015	14:39	440-121392-3	10/06/2015	09:45	416	110	34.4	4.08	80.7	11.9	201	-4	-4	201	364	47.4	-0.5	0.727	13	1,020	837	0.638	-2	392	101	-20	-0.11	-0.15	-0.15	68.4	7.4
01N22W20M04S	A2-320	09/18/2015	08:41	440-121608-1	10/06/2015	09:45	430	118	32.7	4.39	82.7	12.3	210	-4	-4	210	361	42.2	-0.5	0.586	12.9	1,100	906	0.652	-2	757	165	-20	-0.11	-0.15	-0.15	66	7.4
01N22W20M05S	A2-170	09/18/2015	09:09	440-121608-2	10/06/2015	09:45	1040	205	128	17.1	620	48.1	230	-4	-4	230	445	1080	-2.5	0.759	44.2	4,860	3120	0.87	-2	845	323	-20	-0.55	-0.75	-0.75	66.9	7.4
01N22W20M06S	A2-70	09/18/2015	10:10	440-121608-3	10/06/2015	09:45	5360	633	918	136	6770	405	170	-4	-4	170	1850	13000	-50	0.452	410	45,000	28600	2.42	-10	17400	2450	-100	-11	-15	-15	68.9	7
01N22W28G01S	CM4-1395	09/18/2015	13:02	440-121607-1	10/06/2015	09:45	203	31.5	30.1	6.8	105	8.79	288	-4	-4	285	84.4	40.4	-0.5	0.258	8.66	810	531	0.335	-2	122	13.8	-20	-0.11	-0.15	-0.15	74.1	7
01N22W28G02S	CM4-1095	09/18/2015	14:52	440-121607-2	10/06/2015	09:45	281	63.8	29.6	6.51	110	10.6	233	-4	-4	233	235	35.3	-0.5	0.226	10.6	943	673	0.371	-2	170	26	-20	-0.11	-0.15	-0.15	72.7	7.6
01N22W28G03S	CM4-760	09/21/2015	10:05	440-121999-1	10/06/2015	09:45	58.3	13	6.25	29.7	159	8.84	427	-4	-4	424	39.5	33.8	-0.5	0.161	10.3	915	584	0.665	-2	496	28.3	-20	-0.11	-0.15	-0.15	70.5	7.8
01N22W28G04S	CM4-275	09/21/2015	10:47	440-121999-2	10/06/2015	09:45	5050	1260	463	30.7	2270	200	207	-4	-4	207	1050	5520	-50	0.291	182	18,300	16200	1.06	2.51	8140	2380	-20	-11	-15	-15	66.7	7
01N22W28G05S	CM4-200	09/21/2015	11:08	440-121999-3	10/06/2015	09:45	98.1	23.1	9.81	3.73	402	19.5	261	-4	-4	258	469	154	-0.5	1.52	19.4	1,860	1270	0.823	-2	-40	71.9	-20	-0.11	-0.15	-0.15	66.9	7.8
01N21W32Q02S	Q2-970	09/21/2015	13:04	440-121998-1	10/06/2015	09:45	3540	790	379	17.2	1580	140	180	-4	-4	180	672	4050	-50	0.115	132	12,400	10900	0.606	-2	-200	2120	-20	-11	-15	-15	70.9	8.2
01N21W32Q03S	Q2-840	09/21/2015	13:51	440-121998-2	10/06/2015	09:45	8350	1300	1240	82.3	7580	499	203	-4	-4	203	2030	14300	-50	0.168	448	47,200	37200	2.16	3.45	-400	110	-20	-11	-15	-15	75.6	7.9
01N21W32Q04S	Q2-640	09/21/2015	14:42	440-121998-3	10/06/2015	09:45	4450	916	526	32	2400	194	200	-4	-4	200	754	5140	-50	0.175	165	17,100	13100	0.872	2.21	574	160	-20	-11	-15	-15	75.9	7.9
01N21W32Q05S	Q2-370	09/22/2015	11:42	440-122145-1	10/06/2015	09:45	2620	590	278	13.4	1040	97.7	212	-4	-4	212	527	2590	-10	0.168	88.2	9,160	7710	0.499	-2	238	1330	-20	-2.2	-3	-3	72	7.9
01N21W32Q06S	Q2-220	09/22/2015	13:05	440-122145-2	10/06/2015	09:45	860	224	73.3	5.99	117	22.4	208	-4	-4	208	337	402	-1	0.331	22.5	2,350	1650	0.551	2.28	632	523	-20	-0.22	-0.3	-0.3	71.6	7.3
01N21W32Q07S	Q2-285	09/22/2015	13:35	440-122145-3	10/06/2015	09:45	2680	667	247	13.3	943	95	197	-4	-4	197	481	2660	-10	0.13	88.9	9,060	7360	0.44	-2	817	1960	-20	-2.2	-3	-3	73	7.2
01S22W01H01S	CM6-550	09/15/2015	14:38	440-120959-1	09/28/2015	10:16	73.6	13.2	9.86	17.2	372	18.1	692	-4	109	583	1.88	205	0.71	0.226	19.7	1,900	1200	1.63	-10	551	26.1	-100	0.16	-0.15	0.16	70.5	8.9
01S22W01H02S	CM6-400	09/16/2015	09:51	440-121218-1	09/28/2015	10:17	1250	288	129	19.5	485	46.6	213	-4	-4	213	139	1430	-2.5	0.217	47.5	4,500	3520	0.753	-2	-40	47.3	-20	-0.55	-0.75	-0.75	70.2	8
01S22W01H03S	CM6-330	09/16/2015	10:30	440-121218-2	09/28/2015	10:17	3970	1040	336	17.4	731	112	208	-4	-4	208	528	2900	-10	0.207	97.1	9,450	9970	0.679	-2	2010	3210	-20	-2.2	-3	-3	68.9	7.4
01S22W01H04S	CM6-200	09/16/2015	11:04	440-121218-3	09/28/2015	10:17	2350	575	223	16.7	690	77.5	234	-4	-4	234	116	2060	-5	0.281	65.2	7,330	7230	0.718	-2	2640	1750	-20	-1.1	-1.5	-1.5	68	7.5
01N22W35E01S	CM5-1200	09/11/2015	10:21	440-120630-1	09/23/2015	10:22	258	58.2	27.3	11.2	117	10.5	212	-4	6.19	206	166	83.1	-0.5	0.268	10	1,020	691	0.475	-2	50	68.5	-20	-0.11	-0.15	-0.15	74.1	8.2
01N22W35E02S	CM5-940	09/11/2015	11:37	440-120630-2	09/23/2015	10:22	305	59.2	38.1	6.92	113	11.2	227	-4	-4	224	224	35.5	-0.5	0.246	10.2	988	671	0.333	-2	96.9	83.4	-20	-0.11	-0.15	-0.15	74.1	8
01N22W35E03S	CM5-470	09/11/2015	12:18	440-120630-3	09/23/2015	10:22	150	36	14.6	4.62	84	6.77	291	-4	8.28	283	-0.5	34.7	-0.5	0.198	6.8	606	392	0.453	-2	146	48.1	-20	-0.11	-0.15	-0.15	68.4	8
01N22W35E04S	CM5-320	09/11/2015	12:42	440-120630-4	09/23/2015	10:22	375	99.1	31	5.15	82.3	11.2	271	-4	13.9	257	190	32.1	-0.5	0.469	10.3	987	667	0.66	-2	-40	98	-20	-0.11	-0.15	-0.15	68.2	8.1
01N22W35E05S	CM5-220	09/11/2015	13:20	440-120630-5	09/23/2015	10:22	478	127	39.1	5.2	97.4	13.9	223	-4	-4	223	297	91.5	-0.5	0.49	13.2	1,250	910	0.67	-2	67	213	-20	-0.11	-0.15	-0.15	67.5	8
01N22W27C02S	SW-295	09/09/2015	09:13	440-120553-1	09/23/2015	10:22	266	62.9	26.5	16.2	114	10.7	260	-4	9.19	251	185	35.1	-0.5	0.291	10.1	964	652	0.684	-2	-40	32.7	-20	-0.11	-0.15	-0.15	67.3	8
01N22W27C03S	SW-195	09/09/2015	09:56	440-120553-2	09/23/2015	10:22	549	142	47.2	7.49	444	30.5	243	-4	-4	243	553	462	-1	0.68	29.4	3,110	1970	0.828	-2	348	382	-20	-0.22	-0.3	-0.3	66.9	7.3
01N22W27C04S	SW-65	09/09/2015	10:17	440-120553-3	09/23/2015	10:22	1740	477	134	15.1	345	50.2	307	-4	-4	307	1500	398	-1	0.246	48.6	4,210	3390	1.12	3.19	5630	1250	-20	-0.22	-0.3	-0.3	68	7.3
02N21W34G02S	PV1-998	09/02/2015	09:38	440-119743-1	09/16/2015	11:06	474	121	41.8	5.22	169	17	243	-4	-4	243	466	141	-0.5	0.391	18.5	1,600	1240	0.608	2.53	-40	30.6	-20	-0.11	-0.15	-0.15	72.9	8.1
02N21W34G03S	PV1-860	09/02/2015	11:52	440-119743-2	09/16/2015	11:06	369	98.4	29.9	4.59	158	14.4	224	-4	-4	224	379	93.9	-0.5	0.391	15	1,360	998	0.545	-2	109	52.4	-20	-0.11	-0.15	-0.15	72.9	8
02N21W34G04S	PV1-380	09/02/2015	12:44	440-119743-3	09/16/2015	11:06	327	86.1	27.3	3.65	74.3	9.87	183	-4	-4	183	213	49.8	3.41	0.391	9.57	892	704	0.252	2.42	395	60.9	-20	0.771	-0.15	0.771	70.5	8.3
02N21W34G05S	PV1-190	09/02/2015	13:33	440-119743-4	09/16/2015	11:06	691	192	51.6	4.53	133	19.7	214	-4	-4	214	547	125	79.4	0.29	20.5	1,710	1380	0.572	-2	-40	-1	-20	17.9	-0.15	17.9	71.6	7.2
01N22W26J04S	SWIFT-205	09/22/2015	14:52	440-122164-1	09/22/2015	14:52												1100				4,730	3680									69.4	7.1
01N22W26J05S	SWIFT-65	09/22/2015	15:08	440-122164-2	09/22/2015	15:08												77.1				1,860	1550									68.9	7.6
01N23W01C02S	CM3-1490	09/23/2015	08:39	440-122309-1	09/23/2015	08:39												32.8				791	518									70.2	8
01N23W01C03S	CM3-1065	09/23/2015	09:27	440-122309-2	09/23/2015	09:27												37.1				1,200	940									69.3	7.8
01N23W01C04S	CM3-695	09/23/2015	10:58	440-122309-3	09/23/2015	10:58												32.9				1,060	840									66.6	7.8
01N23W01C05S	CM3-145	09/23/2015	11:35	440-122309-4	09/23/2015	11:35												39.6				1,080	848									66.9	8.3
01S21W08L03S	CM1A-565	09/29/2015	09:10	440-122820-1	09/29/2015	09:10												5820				18,500	14200									73.8	7.7
01S21W08L04S	CM1A-220	09/29/2015	09:24	440-122820-2	09/29/2015	09:24												16700				50,600	31300									65.1	7.2
01N22W29D01S	CM2-870	09/16/2015	13:22	440-121214-1	09/28/2015	10:17	396	92	40.4	12.2	99.2	12.5	195	-4	4.44	191	392	48.7	-0.5	0.236	13.4	1,100	869	0.372	-2	153	72.7	-20	-0.11	-0.15	-0.15	66.2	8.2
01N22W29D02S	CM2-760	09/16/2015	13:54	440-121214-2	09/28/2015	10:17	4860	947	606	35.4	5260	327	213	-4	-4	213	1570	10300	-50	0.167	327	32,100	24200	1.93	3.29	6080	2680	-20	-11	-15	-15	68.5	7.3
01N22W29D03S	CM2-520	09/17/2015	09:39	440-121387-1	09/17/2015	09:39												365				1,810	1460									65.7	7.6
01N22W29D04S	CM2-280	09/17/2015	10:00	440-121387-2	09/17/2015	10:00												117				1,290	1020									64	7.8
01N22W20J04S	A1-930	09/14/2015	11:08	440-120848-1	09/14/2015	11:08												42.9				1,140	860									69.6	8
01N22W20J05S	A1-680	09/14/2015	11:42	440-120848-2	09/14/2015	11:42												41.8				1,110	840									68.7	7.9
01N22W20J06S	A1-425	09/14/2015	12:20	440-120848-3	09/14/2015	12:20												35.3				987	623									67.3	19.6
01N22W20J07S	A1-320	09/14/2015	12:47	440-120848-4	09/14/2015	12:47												34.9				1,090	817									65.5	7.9
01N22W20J08S	A1-195	09/14/2015	13:02	440-120848-5	09/14/2015	13:02												159				1,820	1460									65.8	7.6
01N22W27R03S	CM7-350	09/10/2015	13:41	440-120506-1	09/10/2015	13:41												35.1				1,070	842									67.5	7.9
01N22W27R04S	CM7-190	09/10/2015	14:23	440-120506-2	09/10/2015	14:23												1890				6,870	5770									65.5	7.4
01N22W27R05S	CM7-110	09/10/2015	14:52	440-120506-3	09/10/2015	14:52												20400				80,400	49800									65.7	7.3

Table B-1 (continued)

2015 general mineral water quality data, coastal monitoring wells

United Water Conservation District

State Well ID	Owner Well ID	Sample Date	Sample Time	Lab ID	Analysis Date	Analysis Time	THardCaCO3	Calcium	Magnesium	Potassium	Sodium	Tcations	TALKCaCO3	Hydroxide	Carbonate	Bicarbonate	Sulfate	Chloride	Nitrate	Fluoride	Tanions	Specific Conductivity	TDS	Boron	Copper	Iron	Manganese	Zinc	Nitrate as N	Nitrite as N	NO2+NO3 as N	Field Temp	pH Field
							mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	meq/L	umho/cm	mg/L	mg/L	ug/L	ug/L	ug/L	ug/L	mg/L	mg/L	mg/L	°F	
01N22W36K05S	DP-720	09/08/2015	08:49	440-120204-1	09/08/2015	08:49												6060				18,300	14200									71.6	7.3
01N22W36K06S	DP-580	09/08/2015	09:33	440-120204-2	09/08/2015	09:33												1790				6,190	4320									70.3	7.7
01N22W36K07S	DP-450	09/08/2015	10:08	440-120204-3	09/08/2015	10:08												943				3,880	2150									69.1	8.1
01N22W36K08S	DP-330	09/08/2015	10:39	440-120204-4	09/08/2015	10:39												34.6				1,080	781									68	7.8
01N22W36K09S	DP-195	09/08/2015	11:01	440-120204-5	09/08/2015	11:01												374				1,920	1160									66.7	7.8
01N21W31A09S	GP2-240	09/09/2015	10:41	440-120557-1	09/09/2015	10:41												39.7				1,090	871									69.6	7.4
01N21W31A05S	GP1-740	09/04/2015	09:04	440-119970-1	09/04/2015	09:04												99.1				1,080	786									74.7	8
01N21W31A06S	GP1-460	09/04/2015	09:57	440-119970-2	09/04/2015	09:57												43.5				748	465									71.1	8.2
01N21W31A07S	GP1-315	09/04/2015	10:57	440-119970-3	09/04/2015	10:57												40.1				1,040	779									68.9	8
01N21W31A08S	GP1-240	09/04/2015	11:27	440-119970-4	09/04/2015	11:27												36.1				1,070	781									68.7	7.8
01N21W19L10S	SCE-414	09/01/2015	09:22	440-119602-1	09/01/2015	09:22												37.4				1,110	858									67.8	8
01N21W19L11S	SCE-320	09/01/2015	09:57	440-119602-2	09/01/2015	09:57												35.6				1,110	851									67.6	7.9
01N21W19L12S	SCE-220	09/01/2015	10:22	440-119602-3	09/01/2015	10:22												67.2				1,240	962									67.1	7.9
01N21W19L13S	SCE-130	09/01/2015	10:58	440-119602-4	09/01/2015	10:58												39.1				1,110	856									66.2	7.8
01N21W19L14S	SCE-38	09/01/2015	10:01	440-119602-5	09/01/2015	10:01												1950				10,700	8940									67.3	6.8

Notes:

NA = Not Analysed

Non-detects are reported as the negative value of the detection level

Table B-2
2014 general mineral water quality data, coastal monitoring wells
United Water Conservation District

State Well ID	Owner Well ID	Sample Date	Sample Time	Lab ID	Analysis Date	Analysis Time	THardCaCO3	Calcium	Magnesium	Potassium	Sodium	Tcations	TALKCaCO3	Hydroxide	Carbonate	Bicarbonate	Sulfate	Chloride	Nitrate	Fluoride	Tanions	Specific Conductivity	TDS	Boron	Copper	Iron	Manganese	Zinc	Nitrate as N	Nitrite as N	NO2+NO3 as N	Field Temp	pH Field
							mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	meq/L	umho/cm	mg/L	mg/L	ug/L	ug/L	ug/L	ug/L	mg/L	mg/L	mg/L	°F	
01N23W01C02S	CM3-1490	9/12/14	11:48	440-88034-1	9/25/14	18:47	159.00	47.90	9.57	3.90	125.00	8.69	221.00	-4.00	-4.00	219.00	156.00	32.80	-0.50	0.26	8.60	796	537.00	0.43	-2.00	81.30	68.10	-20.00	-0.11	-0.15	-0.15	71.10	8.50
01N23W01C03S	CM3-1065	9/12/14	15:08	440-88034-2	9/25/14	18:47	486.00	138.00	34.20	5.27	96.30	14.00	228.00	-4.00	-4.00	228.00	416.00	36.40	-0.50	0.35	14.30	1,240	995.00	0.53	-2.00	295.00	192.00	-20.00	-0.11	-0.15	-0.15	70.50	7.60
01N23W01C04S	CM3-695	9/12/14	16:17	440-88034-3	9/25/14	18:47	432.00	116.00	34.30	4.39	88.00	12.60	203.00	-4.00	-4.00	203.00	354.00	32.30	-0.50	0.60	12.40	1,090	855.00	0.65	-2.00	936.00	182.00	-20.00	-0.11	-0.15	-0.15	68.20	7.40
01N23W01C05S	CM3-145	9/12/14	13:13	440-88034-4	9/25/14	18:47	441.00	120.00	34.60	4.19	91.60	12.90	231.00	-4.00	-4.00	231.00	345.00	38.80	-0.50	0.62	12.90	1,140	886.00	0.69	-2.00	813.00	138.00	42.10	-0.11	-0.15	-0.15	71.10	7.80
01N22W26J03S	SWIFT-350	9/15/14	11:45	440-88124-1	9/26/14	14:46	1160.00	316.00	90.80	5.99	134.00	29.20	203.00	-4.00	-4.00	203.00	446.00	691.00	-2.50	0.48	32.90	1,560	2630.00	0.65	-2.00	837.00	609.00	-20.00	-0.55	-0.75	-0.75	67.60	7.30
01N22W26J04S	SWIFT-205	9/15/14	12:20	440-88124-2	9/26/14	14:46	1660.00	448.00	131.00	12.50	431.00	52.30	214.00	-4.00	-4.00	214.00	608.00	1380.00	-5.00	0.48	55.80	3,430	4370.00	0.76	-2.00	1390.00	975.00	-20.00	-1.10	-1.50	-1.50	68.40	7.10
01N22W26J05S	SWIFT-65	9/15/14	12:46	440-88124-3	9/26/14	14:46	600.00	149.00	55.50	15.00	236.00	22.60	376.00	-4.00	-4.00	376.00	707.00	107.00	-1.00	0.33	25.20	1,270	1620.00	1.06	-2.00	1030.00	264.00	-20.00	-0.22	-0.30	-0.30	67.80	7.60
01N22W20J04S	A1-930	9/3/14	11:47	440-87115-1	9/15/14	11:46	389.00	99.10	34.40	14.10	80.40	11.60	221.00	-4.00	-4.00	221.00	488.00	56.00	-0.50	0.29	16.20	1,190	835.00	0.54	-2.00	380.00	112.00	-20.00	-0.11	-0.15	-0.15	70.50	8.00
01N22W20J05S	A1-680	9/3/14	13:05	440-87115-2	9/15/14	11:46	418.00	117.00	30.70	4.62	78.00	11.90	203.00	-4.00	-4.00	203.00	391.00	47.90	-0.50	0.43	13.60	1,160	825.00	0.62	10.60	311.00	179.00	-20.00	-0.11	-0.15	-0.15	69.40	7.60
01N22W20J06S	A1-425	9/4/14	11:14	440-87350-1	9/16/14	16:35	272.00	55.20	32.60	36.10	94.50	10.50	293.00	-4.00	-4.00	293.00	223.00	39.10	-0.50	0.17	11.60	1,090	649.00	0.49	-2.00	419.00	41.50	-20.00	-0.11	-0.15	-0.15	68.20	7.90
01N22W20J07S	A1-320	9/4/14	11:55	440-87350-2	9/16/14	16:35	403.00	106.00	33.30	8.74	82.90	11.90	242.00	-4.00	-4.00	242.00	313.00	40.90	-0.50	0.27	12.50	1,140	773.00	0.67	-2.00	310.00	103.00	-20.00	-0.11	-0.15	-0.15	66.60	7.70
01N22W20J08S	A1-195	9/4/14	12:29	440-87350-3	9/16/14	16:35	594.00	123.00	69.70	6.01	174.00	19.60	251.00	-4.00	-4.00	251.00	451.00	114.00	14.20	0.65	17.90	1,780	1380.00	0.81	-2.00	-0.04	45.80	-20.00	3.21	-0.15	3.21	67.10	7.50
02N23W15J01S	MP-1070	10/28/14	9:53	440-91564-1	11/10/14	14:52	609.00	169.00	45.10	4.81	160.00	19.30	334.00	-4.00	-4.00	334.00	560.00	87.50	-0.50	0.37	20.80	1,680	1280.00	0.70	-2.00	1450.00	334.00	-20.00	-0.11	-0.15	-0.15	68.40	7.70
02N23W15J02S	MP-660	10/28/14	10:25	440-91564-2	11/10/14	14:52	451.00	123.00	35.10	4.33	93.90	13.20	255.00	-4.00	-4.00	255.00	390.00	43.00	-0.50	0.37	14.50	1,250	919.00	0.45	-2.00	1310.00	109.00	-20.00	-0.11	-0.15	-0.15	65.70	7.60
02N23W15J03S	MP-240	10/28/14	9:31	440-91564-3	11/10/14	14:52	1860.00	350.00	238.00	18.00	362.00	53.30	1010.00	-4.00	-4.00	1010.00	1530.00	99.60	-2.50	0.55	54.90	4,140	3280.00	2.70	-2.00	737.00	1930.00	-20.00	-0.55	-0.75	-0.75	63.70	6.60
01N22W27R03S	CM7-350	9/10/14	9:47	440-87818-1	9/23/14	15:47	430.00	117.00	33.30	4.59	83.90	12.40	222.00	-4.00	-4.00	222.00	362.00	37.90	-0.50	0.53	13.10	1,170	833.00	0.67	-2.00	121.00	284.00	-20.00	-0.11	-0.15	-0.15	67.80	7.30
01N22W27R04S	CM7-190	9/10/14	10:20	440-87818-2	9/23/14	15:47	3370.00	734.00	374.00	15.50	481.00	88.70	169.00	-4.00	-4.00	169.00	769.00	2440.00	-10.00	0.55	88.30	8,290	8470.00	0.82	-2.00	4070.00	1480.00	-20.00	-2.20	-3.00	-3.00	66.60	7.00
01N22W27R05S	CM7-110	9/10/14	11:34	440-87818-3	9/23/14	15:47	9170.00	1180.00	1510.00	102.00	9080.00	581.00	312.00	-4.00	-4.00	312.00	5740.00	17500.00	-50.00	0.48	621.00	57,300	41000.00	5.93	-10.00	27500.00	5430.00	-100.00	-11.00	-15.00	-15.00	67.50	6.40
01S21W08L03S	CM1A-565	9/25/14	10:13	440-88977-1	10/7/14	12:27	4490.00	894.00	549.00	42.40	2100.00	182.00	269.00	-4.00	-4.00	269.00	393.00	5370.00	-50.00	0.20	165.00	17,300	12300.00	1.03	2.17	-0.40	49.20	-20.00	-11.00	-15.00	-15.00	75.00	7.10
01S21W08L04S	CM1A-220	9/25/14	10:53	440-88977-2	10/7/14	12:27	6210.00	683.00	1090.00	274.00	8870.00	517.00	169.00	-4.00	-4.00	169.00	2290.00	15400.00	-50.00	0.20	484.00	53,500	34900.00	3.16	-10.00	9700.00	723.00	-100.00	-11.00	-15.00	-15.00	66.90	7.30
01N22W36K05S	DP-720	9/9/14	10:29	440-87704-1	9/19/14	14:39	8550.00	2050.00	835.00	32.40	565.00	196.00	148.00	-4.00	-4.00	148.00	-50.00	5980.00	-50.00	0.13	172.00	17,600	13900.00	0.65	3.91	11300.00	2160.00	-20.00	-11.00	-15.00	-15.00	72.00	6.90
01N22W36K06S	DP-580	9/9/14	11:43	440-87704-2	9/19/14	14:39	1730.00	431.00	159.00	19.40	475.00	55.70	253.00	-4.00	-4.00	253.00	-10.00	1610.00	-10.00	0.18	50.40	5,930	3860.00	0.99	-2.00	2010.00	491.00	-20.00	-2.20	-3.00	-3.00	72.00	7.40
01N22W36K07S	DP-450	9/9/14	12:51	440-87704-3	9/19/14	14:39	470.00	125.00	38.30	11.70	539.00	33.10	330.00	-4.00	-4.00	330.00	-2.50	1080.00	-2.50	0.29	37.10	3,780	2110.00	1.14	-2.00	442.00	99.30	-20.00	-0.55	-0.75	-0.75	71.00	7.80
01N22W36K08S	DP-330	9/9/14	14:06	440-87704-4	9/19/14	14:39	413.00	114.00	31.10	3.72	80.30	11.80	218.00	-4.00	-4.00	218.00	344.00	41.30	-0.50	0.42	12.70	1,120	793.00	0.59	-2.00	443.00	338.00	-20.00	-0.11	-0.15	-0.15	69.40	7.40
01N22W36K09S	DP-195	9/9/14	15:00	440-87704-5	9/19/14	14:39	246.00	66.20	19.60	5.07	268.00	16.70	282.00	-4.00	-4.00	282.00	122.00	332.00	-0.50	0.63	17.60	1,850	1040.00	0.59	-2.00	154.00	242.00	-20.00	-0.11	-0.15	-0.15	68.20	7.50
01N21W31A05S	GP1-740	9/18/14	10:45	440-88439-1	9/30/14	18:45	350.00	85.10	33.50	6.51	118.00	12.30	238.00	-4.00	-4.00	238.00	218.00	98.60	-0.50	0.32	12.10	1,060	735.00	0.33	-2.00	55.10	26.20	-20.00	-0.11	-0.15	-0.15	74.80	7.70
01N21W31A06S	GP1-460	9/18/14	11:43	440-88439-2	9/30/14	18:45	161.00	32.50	19.40	11.90	107.00	8.19	345.00	-4.00	-4.00	345.00	30.40	38.00	-0.50	0.28	8.61	704	478.00	0.43	-2.00	80.70	106.00	-20.00	-0.11	-0.15	-0.15	73.20	7.80
01N21W31A07S	GP1-315	9/17/14	15:01	440-88354-1	9/29/14	15:55	393.00	104.00	32.00	3.55	81.60	11.50	236.00	-4.00	-4.00	236.00	327.00	48.20	-0.50	0.38	12.90	1,030	801.00	0.49	-2.00	228.00	238.00	-20.00	-0.11	-0.15	-0.15	71.10	7.60
01N21W31A08S	GP1-240	9/18/14	12:28	440-88439-3	9/30/14	18:45	452.00	125.00	34.00	3.76	83.10	12.70	245.00	-4.00	-4.00	245.00	351.00	35.50	-0.50	0.46	13.20	1,060	830.00	0.63	-2.00	377.00	235.00	-20.00	-0.11	-0.15	-0.15	69.80	7.60
01N21W31A09S	GP2-240	9/18/14	14:48	440-88437-1	9/30/14	18:45	462.00	128.00	34.60	3.79	85.90	13.10	232.00	-4.00	-4.00	232.00	364.00	36.40	-0.50	0.43	13.30	1,070	847.00	0.64	-2.00	416.00	231.00	-20.00	-0.11	-0.15	-0.15	69.10	7.50
01N21W19L10S	SCE-414	9/15/14	14:15	440-88122-1	9/26/14	14:46	433.00	117.00	34.10	3.58	79.70	12.20	222.00	-4.00	-4.00	222.00	369.00	46.00	-0.50	0.41	13.40	813	879.00	0.59	-2.00	464.00	216.00	-20.00	-0.11	-0.15	-0.15	70.30	7.60
01N21W19L11S	SCE-320	9/15/14	15:05	440-88122-2	9/26/14	14:46	436.00	120.00	33.30	3.38	79.50	12.30	226.00	-4.00	-4.00	226.00	379.00	39.30	-0.50	0.33	13.50	810	905.00	0.56	-2.00	377.00	323.00	-20.00	-0.11	-0.15	-0.15	69.40	7.50
01N21W19L12S	SCE-220	9/16/14	13:42	440-88249-1	9/29/14	12:17	507.00	140.00	38.30	4.26	88.40	14.10	210.00	-4.00	-4.00	210.00	417.00	67.40	-0.50	0.50	14.80	1,150	940.00	0.67	-2.00	72.70	333.00	-20.00	-0.11	-0.15	-0.15	68.70	7.50
01N21W19L13S	SCE-130	9/16/14	14:47	440-88249-2	9/29/14	12:17	438.00	117.00	35.40	3.83	81.50	12.40	244.00	-4.00	-4.00	244.00	337.00	48.80	-0.50	0.60	13.30	1,050	803.00	0.67	45.60	1600.00	375.00	-20.00	-0.11	-0.15	-0.15	68.50	7.50
01N21W19L14S	SCE-38	9/16/14	15:18	440-88249-3	9/29/14	12:17	3570.00	1010.00	256.00	15.90	1380.00	132.00	376.00	-4.00	-4.00	376.00	3020.00	2200.00	-25.00	0.41	133.00	9,030	8420.00	3.91	6.78	734.00	2280.00	-20.00	-5.50	-7.50	-7.50	70.20	7.00
02N21W34G02S	PV1-998	9/19/14	10:44	440-88560-1	9/19/14	10:44												106.00				1,380	1100.00									72.30	8.30
02N21W34G03S	PV1-860	9/19/14	12:23	440-88560-2	9/19/14	12:23												84.80				1,200	934.00									72.50	8.30
02N21W34G04S	PV1-380	9/19/14	13:48	440-88560-3	9/19/14	13:48												49.30				853	645.00									71.10	8.50
02N21W34G05S	PV1-190	9/19/14	14:47	440-88560-4	9/19/14	14:47												121.00				1,590	1390.00									69.30	8.10
01N22W27C02S	SW-295	9/23/14	13:07	440-88692-1	9/23/14	13:07												35.20				860	574.00									66.40	8.50
01N22W27C03S	SW-195	9/23/14	13:35	440-88692-2	9/23/14	13:35												548.00				2,970	2050.00									65.70	7.90
01N22W27C04S	SW-65	9/23/14	14:07	440-88692-3	9/23/14	14:07												433.00				3,620	3150.00									66.60	7.70
01N22W35E01S	CM5-1200	9/17/14	10:32	440-88352-1	9/17/14	10:32												82.50				887	702.00									73.60	8.30
01N22W35E02S	CM5-940	9/17/14	11:06	440-88352-2	9/17/14	11:06												38.30				865	705.00									72.30	8.20
01N22W35E03S	CM5-470	9/17/14	12:14	440-88352-3	9/17/14	12:14												34.00				556	382.00									68.50	8.30
01N22W35E04S	CM5-320	9/17/14	13:11	440-88352-4	9/17/14	13:11												33.80				872	734.00									67.60	8.30
01N22W35E05S	CM5-220	9/17/14	13:40	440-88352-5	9/17/14	13:40												109.00				1,100	992.00									66.90	8.20
01S22W01H01S	CM6-550	10/16/14	16:12	440-90805-1	10/16/14	16:12												262.00				2,250	1320.00									69.10	8.80
01S22W01H02S	CM6-400	10/14/14	11:09	440-90463-1	10/14/14	11:09												1190.00				4,500	3220.00									69.40	8.00
01S22W01H03S	CM6-330	10/14/14	12:05	440-90463-2	10/14/14	12:05												2640.00				8,900	8130.00									68.20	7.50
01S22W01H04S	CM6-200	10/14/14	12:59	440-90463-3	10/14/14	12:59												1900.00				6,740	5030.00									67.50	7.50
01N21W32Q02S	Q2-970	9/22/14	10:47	440-88614-1	9/22/14	10:47												4720.00				11,100	8670.00									72.50	8.40
01N21W32Q03S	Q2-840	9/22/14	11:41	440-88614-2	9/22/14	11:41												16400.00				41,200	34100.00									78.40	7.60
01N21W32Q04S	Q2-640	9/22/14	12:38	440-88614-3	9/22/14	12:38												6120.00				15,400	12300.00									77.20	7.70
01N21W32Q05S	Q2-370	9/22/14	13:28	440-88614-4	9/22/14	13:28												3090.00				7,790	6990.00									72.70	7.90
01N21W32Q06S	Q2-220	9/23/14	10:39	440-88691-1	9/23/14	10:39												496.00				2,560	1840.00									69.30	7.80
01N21W32Q07S	Q2-285	9/23/14	10:08	440-88691-2	9/23/14	10:08												2690.00				8,400	7740.00									70.90	7.80

Table B-2 (continued)
2014 general mineral water quality data, coastal monitoring wells
United Water Conservation District

State Well ID	Owner Well ID	Sample Date	Sample Time	Lab ID	Analysis Date	Analysis Time	THardCaCO3	Calcium	Magnesium	Potassium	Sodium	Tcations	TALKCaCO3	Hydroxide	Carbonate	Bicarbonate	Sulfate	Chloride	Nitrate	Fluoride	Tanions	Specific Conductivity	TDS	Boron	Copper	Iron	Manganese	Zinc	Nitrate as N	Nitrite as N	NO2+NO3 as N	Field Temp	pH Field
							mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	meq/L	umho/cm	mg/L	mg/L	ug/L	ug/L	ug/L	ug/L	mg/L	mg/L	mg/L	°F	
01N22W28G01S	CM4-1395	9/10/14	13:40	440-87860-1	9/10/14	13:40												43.40				855	521.00									75.00	8.30
01N22W28G02S	CM4-1095	9/10/14	14:30	440-87860-2	9/10/14	14:30												36.90				1,010	665.00									72.30	8.30
01N22W28G03S	CM4-760	9/11/14	16:35	440-87953-1	9/11/14	16:35												36.20				985	585.00									67.80	8.90
01N22W28G04S	CM4-275	9/10/14	15:11	440-87860-3	9/10/14	15:11												6040.00				17,700	15900.00									65.70	7.50
01N22W28G05S	CM4-200	9/11/14	13:45	440-87953-2	9/11/14	13:45												147.00				1,900	1240.00									65.70	8.50
01N22W20M01S	A2-940	9/5/14	12:01	440-87408-1	9/5/14	12:01												41.50				1,170	987.00									69.10	8.10
01N22W20M02S	A2-740	9/5/14	13:05	440-87408-2	9/5/14	13:05												179.00				1,520	1210.00									68.50	7.80
01N22W20M03S	A2-560	9/8/14	10:38	440-87518-1	9/8/14	10:38												35.90				1,090	825.00									66.40	7.10
01N22W20M04S	A2-320	9/8/14	11:01	440-87518-2	9/8/14	11:01												41.30				1,120	853.00									65.50	7.30
01N22W20M05S	A2-170	9/8/14	11:53	440-87518-3	9/8/14	11:53												289.00				2,060	1490.00									65.50	7.20
01N22W20M06S	A2-70	9/8/14	12:27	440-87518-4	9/8/14	12:27												11600.00				39,800	23600.00									67.10	7.70
01N22W29D01S	CM2-870	9/4/14	14:21	440-87352-1	9/16/14	16:35	392.00	92.20	39.30	10.80	91.20	12.10	198.00	-4.00	-4.00	198.00	427.00	36.80	-0.50	0.24	13.90	1,210	838.00	0.37	-2.00	198.00	72.70	-20.00	-0.11	-0.15	-0.15	69.30	8.00
01N22W29D02S	CM2-760	9/4/14	15:36	440-87352-2	9/16/14	16:35	4810.00	953.00	591.00	34.00	4930.00	312.00	224.00	-4.00	-4.00	224.00	1270.00	11400.00	-25.00	0.17	352.00	34,400	22500.00	1.94	-4.00	6200.00	2900.00	-40.00	-5.50	-7.50	-7.50	69.30	7.20
01N22W29D03S	CM2-520	9/5/14	14:22	440-87409-1	9/17/14	15:51	544.00	144.00	45.10	4.49	84.80	14.70	200.00	-4.00	-4.00	200.00	214.00	98.60	-0.50	0.66	11.30	1,420	1070.00	0.64	-2.00	827.00	147.00	-20.00	-0.11	-0.15	-0.15	66.60	6.70
01N22W29D04S	CM2-280	9/5/14	15:36	440-87409-2	9/17/14	15:51	495.00	134.00	38.80	4.71	85.10	13.70	212.00	-4.00	-4.00	212.00	381.00	93.50	-0.50	0.52	14.80	1,240	949.00	0.67	-2.00	645.00	181.00	-20.00	-0.11	-0.15	-0.15	65.70	6.90

Notes:

NA = Not Analysed

Non-detects are reported as the negative value of the detection level

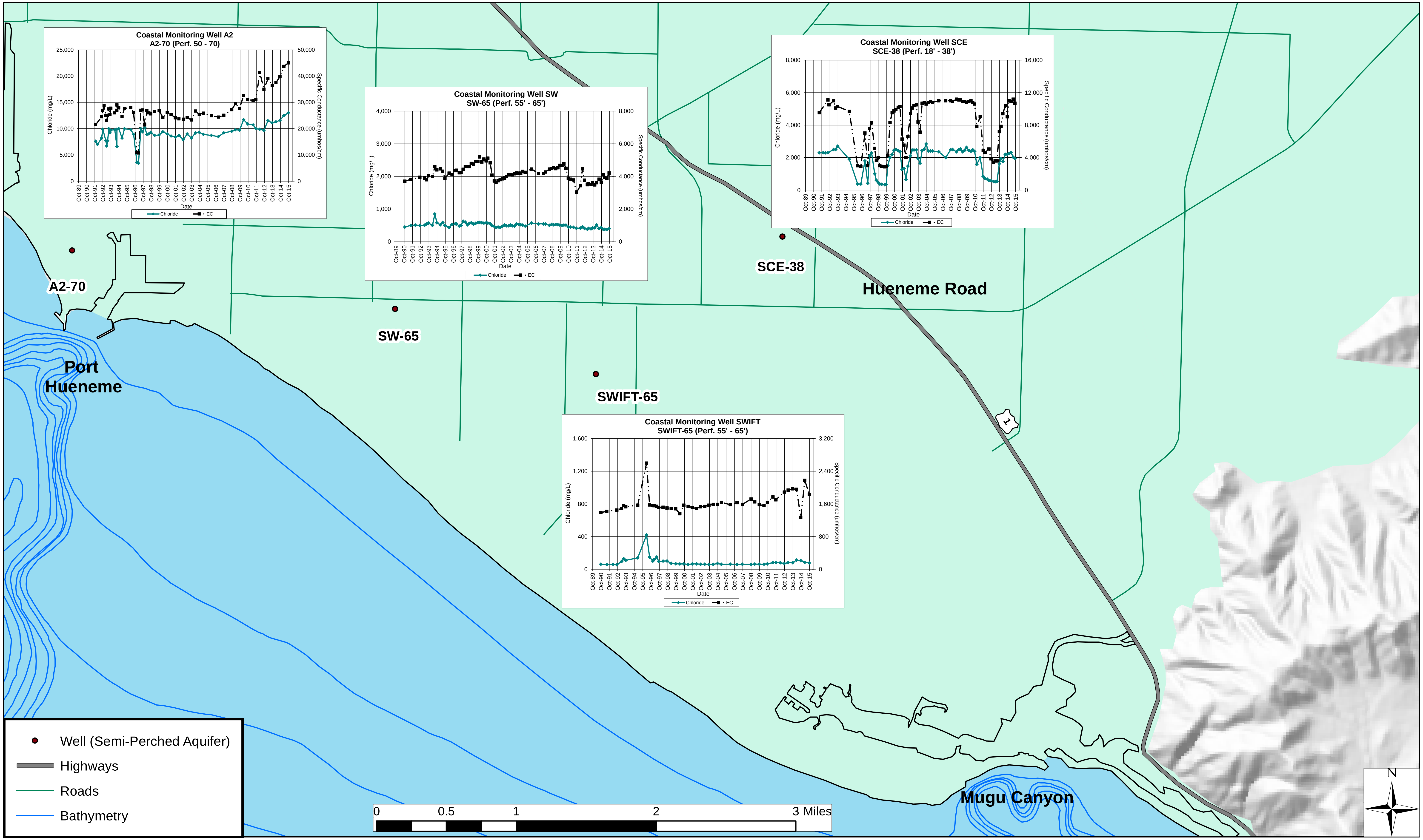


Figure B-1. Chloride and Electrical Conductivity time series plots, Semi-perched aquifer monitoring wells.

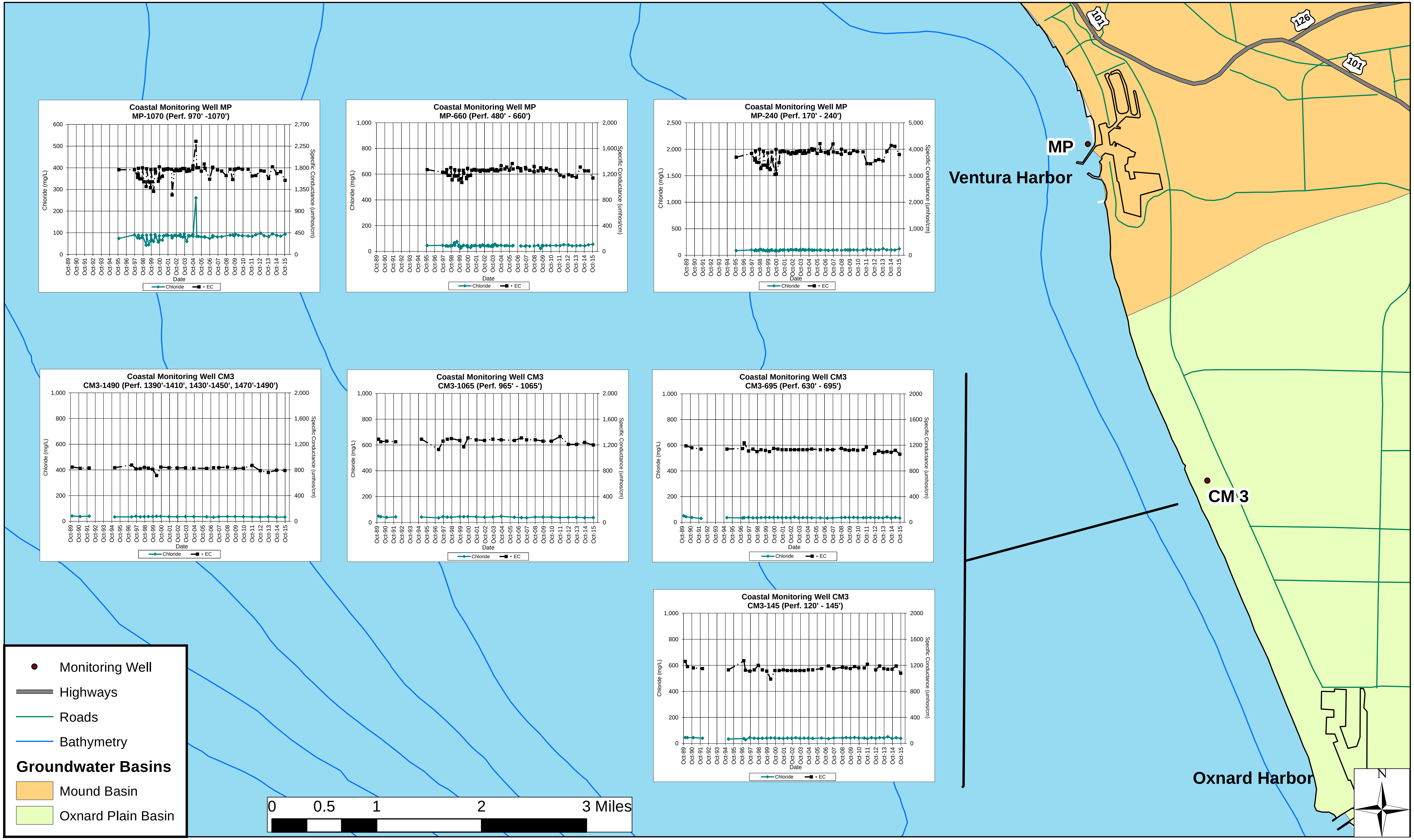


Figure B-2. Chloride and Electrical Conductivity time series plots, North West Oxnard Plain and Mound basin monitoring wells.

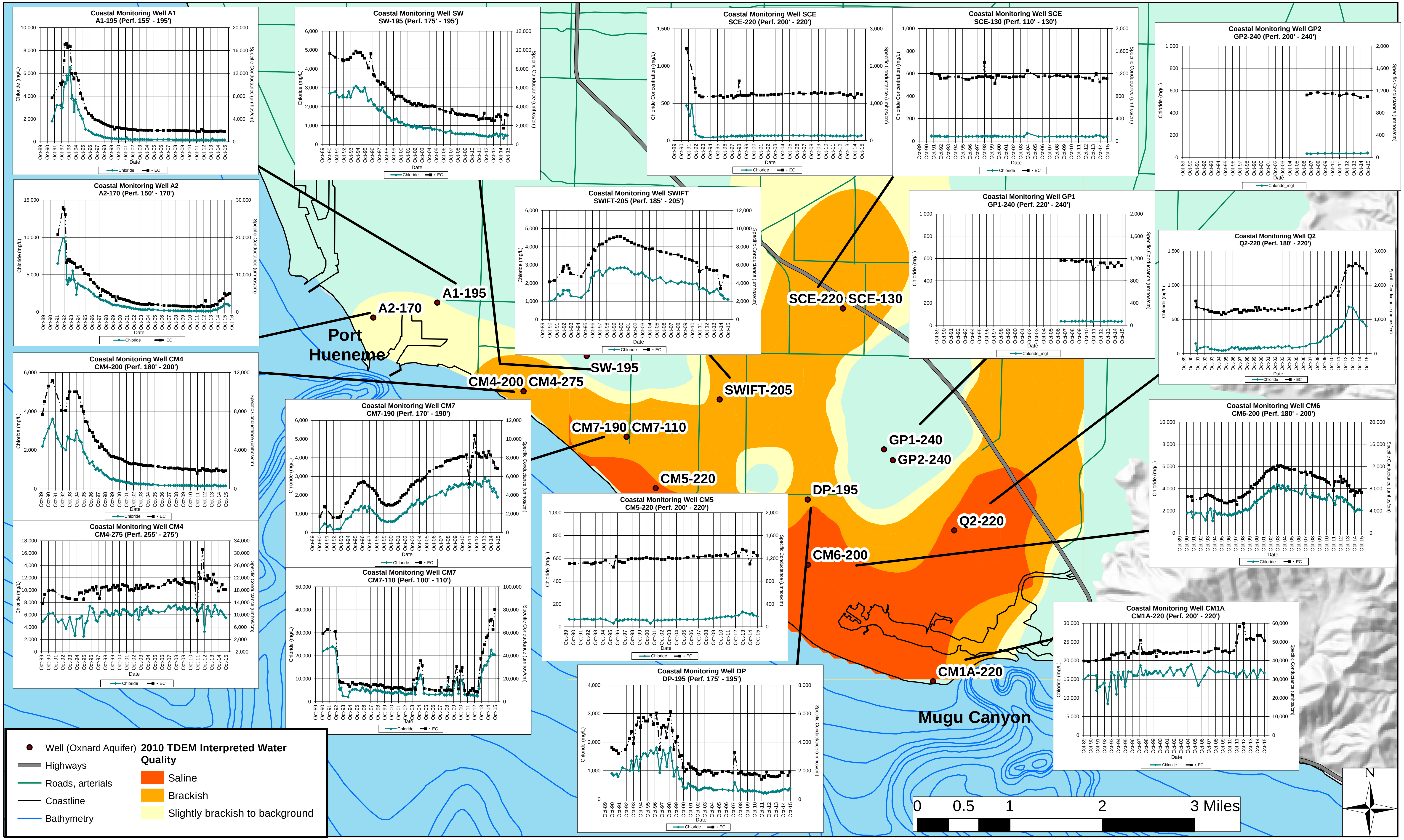


Figure B-3. Chloride and Electrical Conductivity time series plots, Oxnard aquifer monitoring wells.

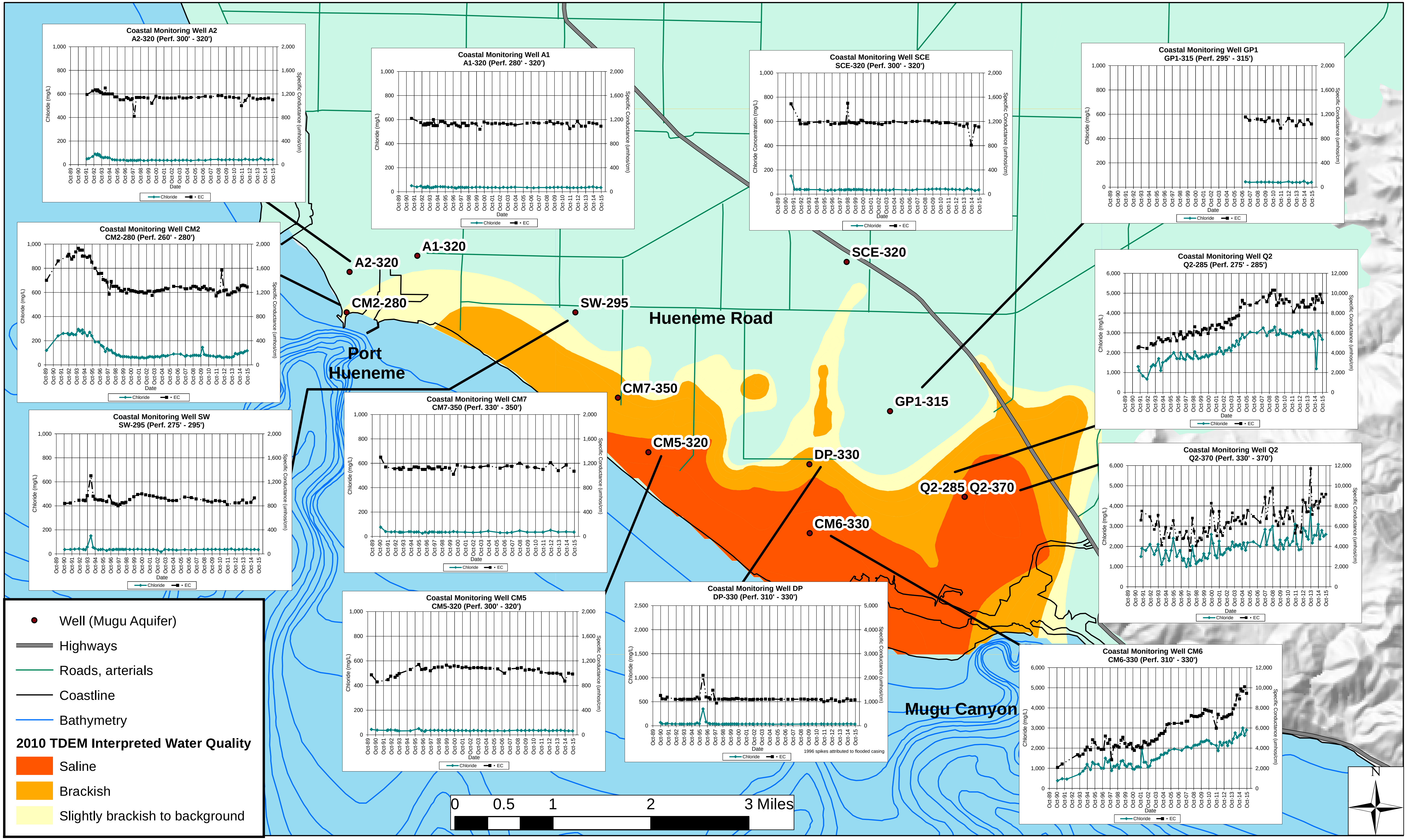


Figure B-4. Chloride and Electrical Conductivity time series plots, Mugu aquifer monitoring wells.

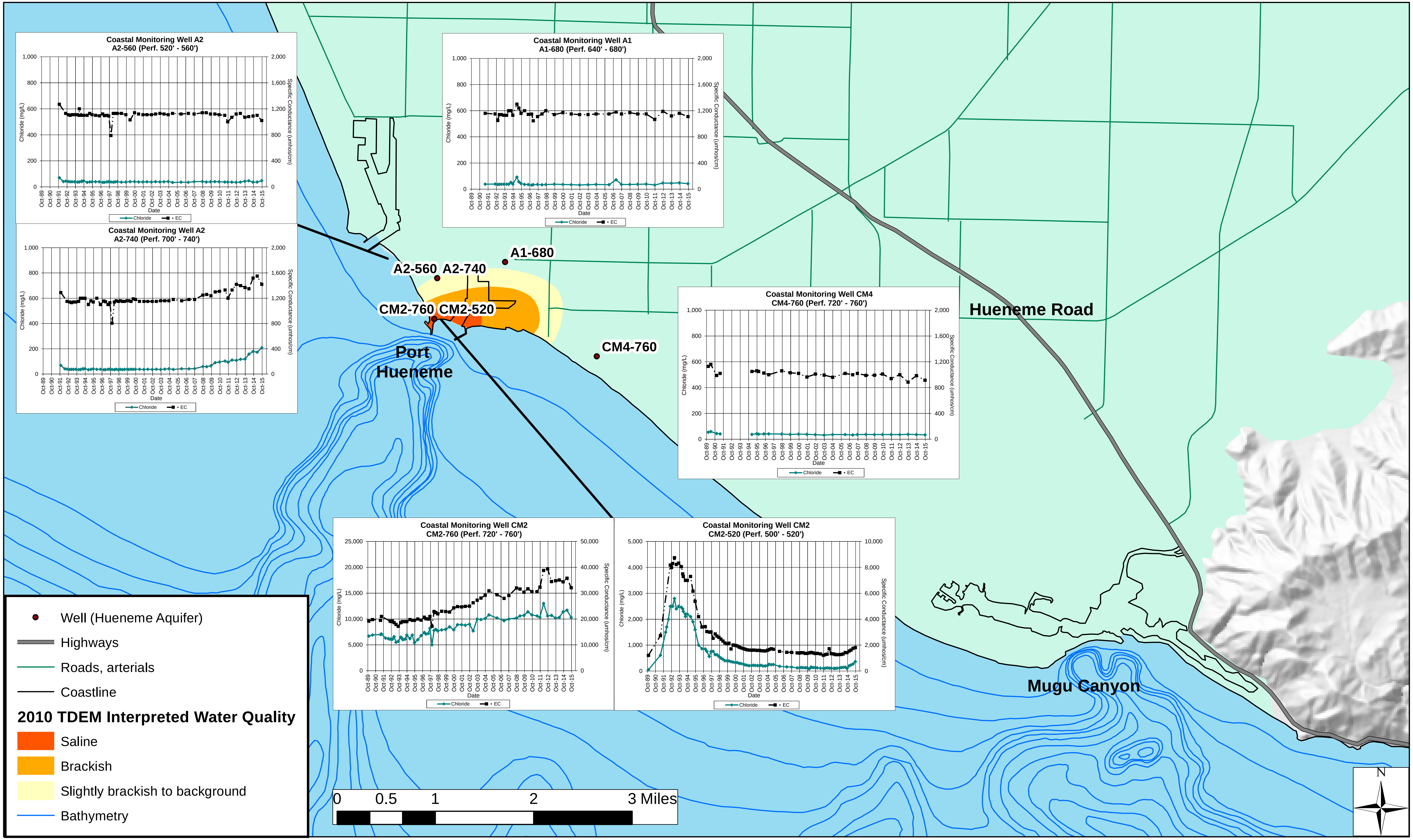


Figure B-5. Chloride and Electrical Conductivity time series plots, Hueneme aquifer monitoring wells.

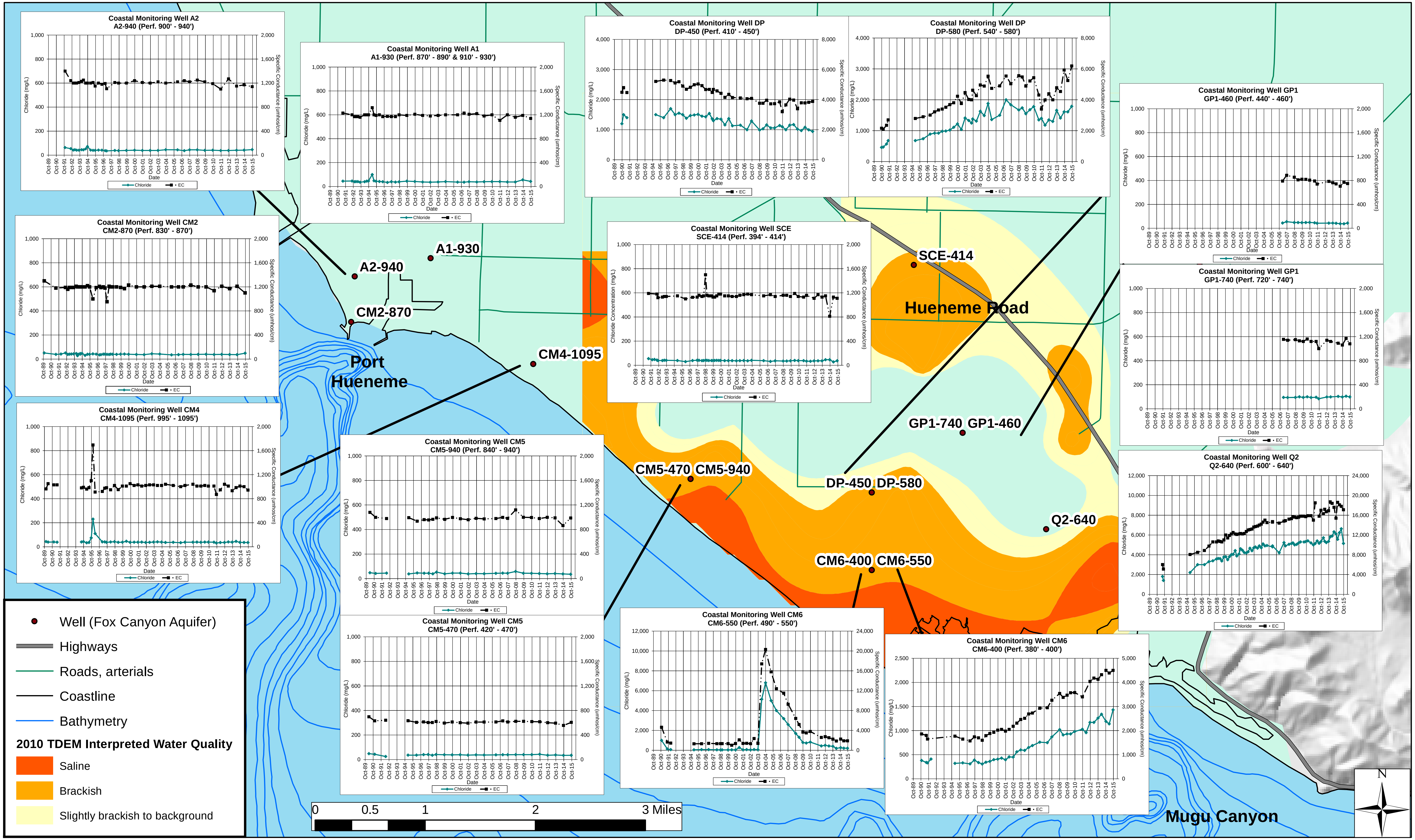


Figure B-6. Chloride and Electrical Conductivity time series plots, Fox Canyon aquifer monitoring wells.

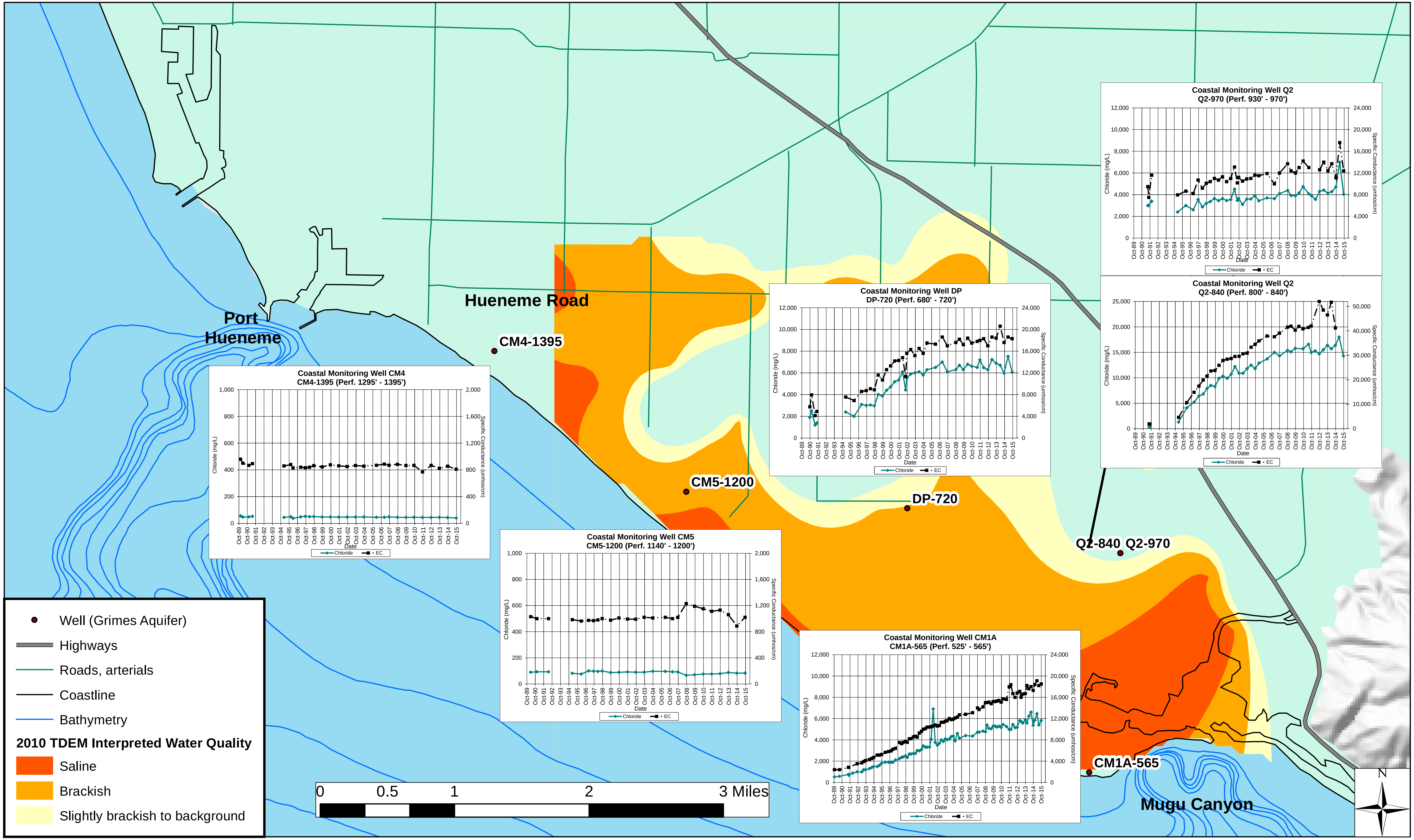


Figure B-7. Chloride and Electrical Conductivity time series plots, Grimes Canyon aquifer monitoring wells.

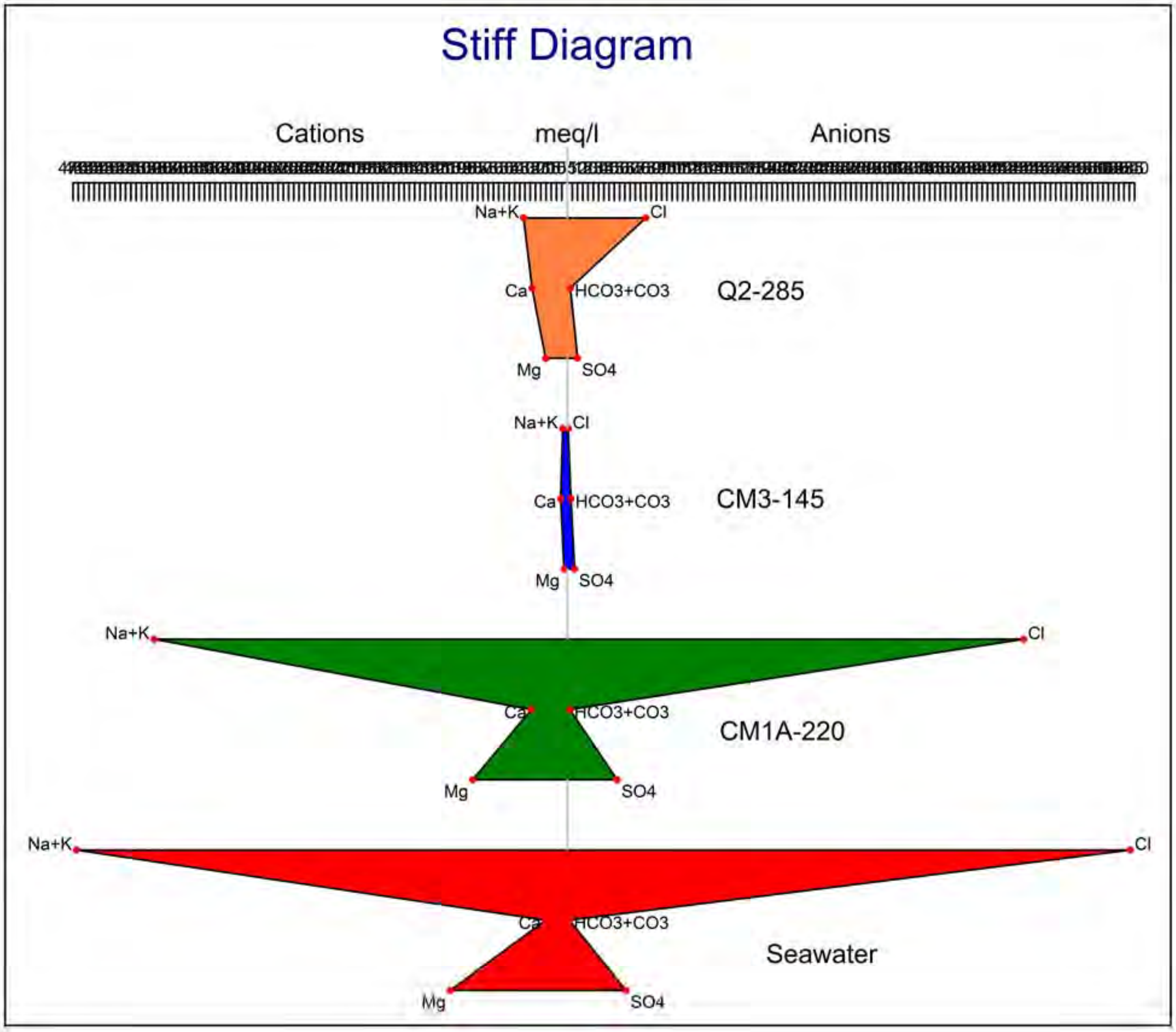


Figure B-8. Stiff diagrams for selected Upper Aquifer System coastal monitoring wells.

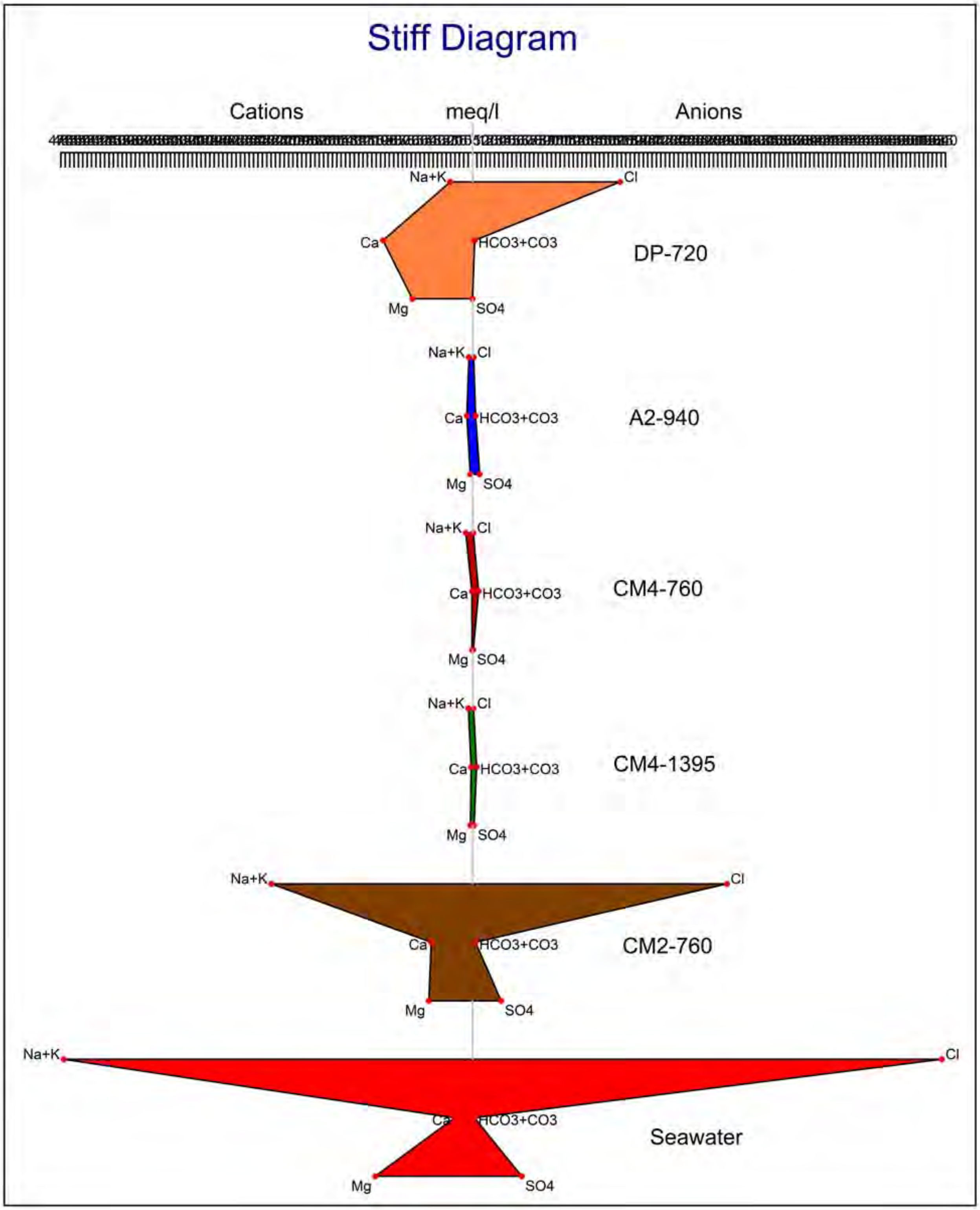


Figure B-9. Stiff diagrams for selected Lower Aquifer System coastal monitoring wells.

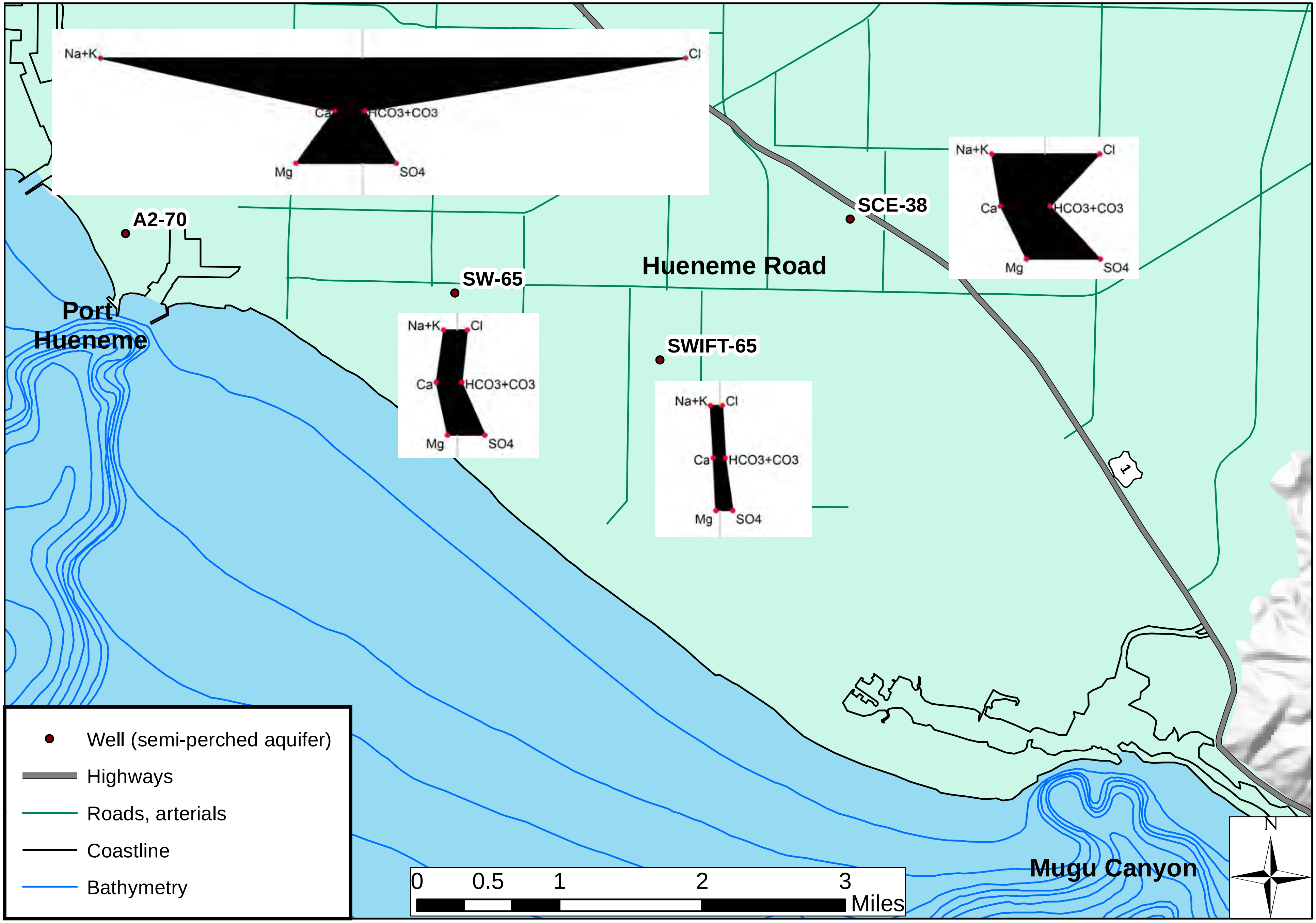


Figure B-10. Stiff diagrams for semi-perched aquifer coastal monitoring wells; data 2014 and 2015.

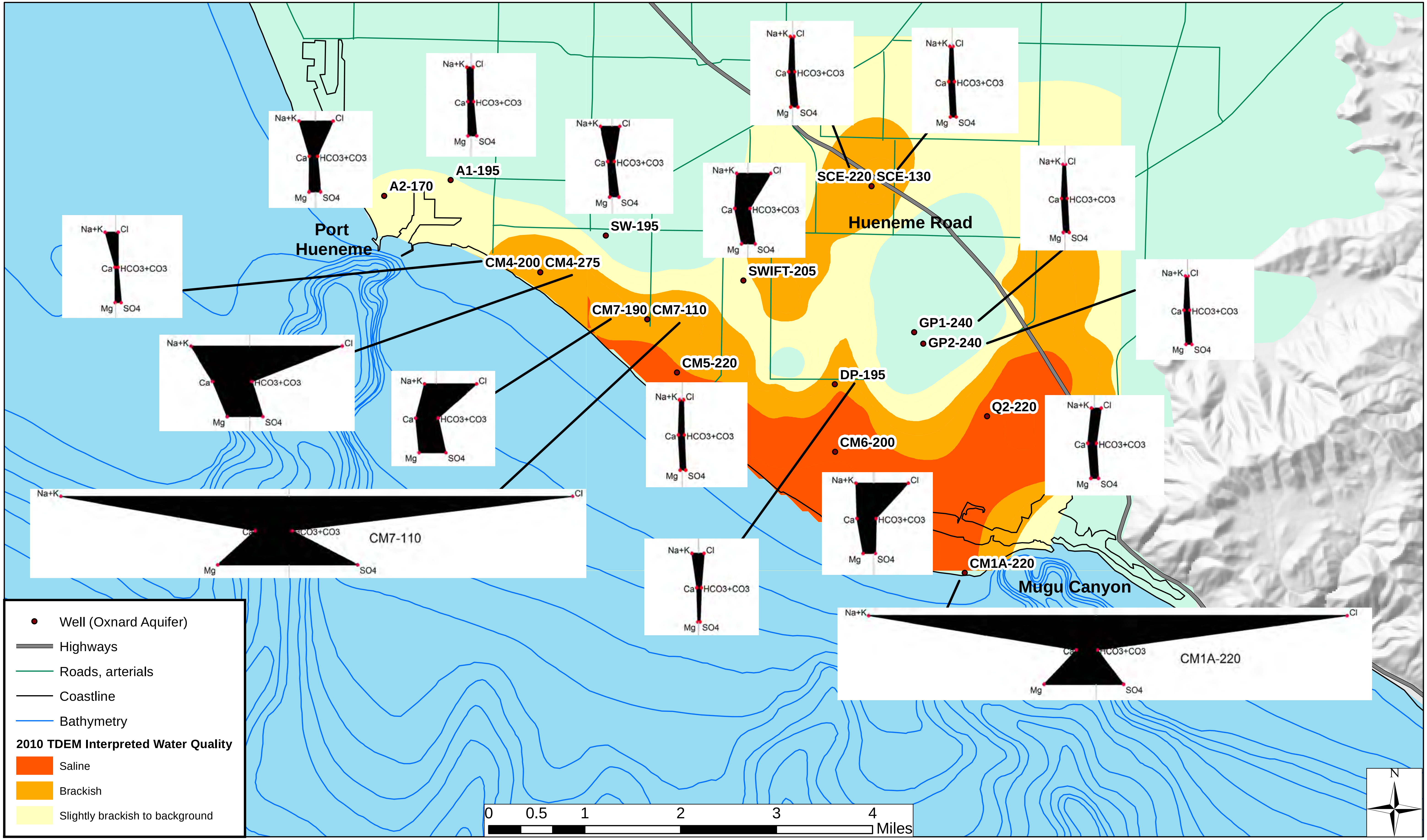


Figure B-11. Stiff diagrams for Oxnard aquifer coastal monitoring wells; data 2014 and 2015.

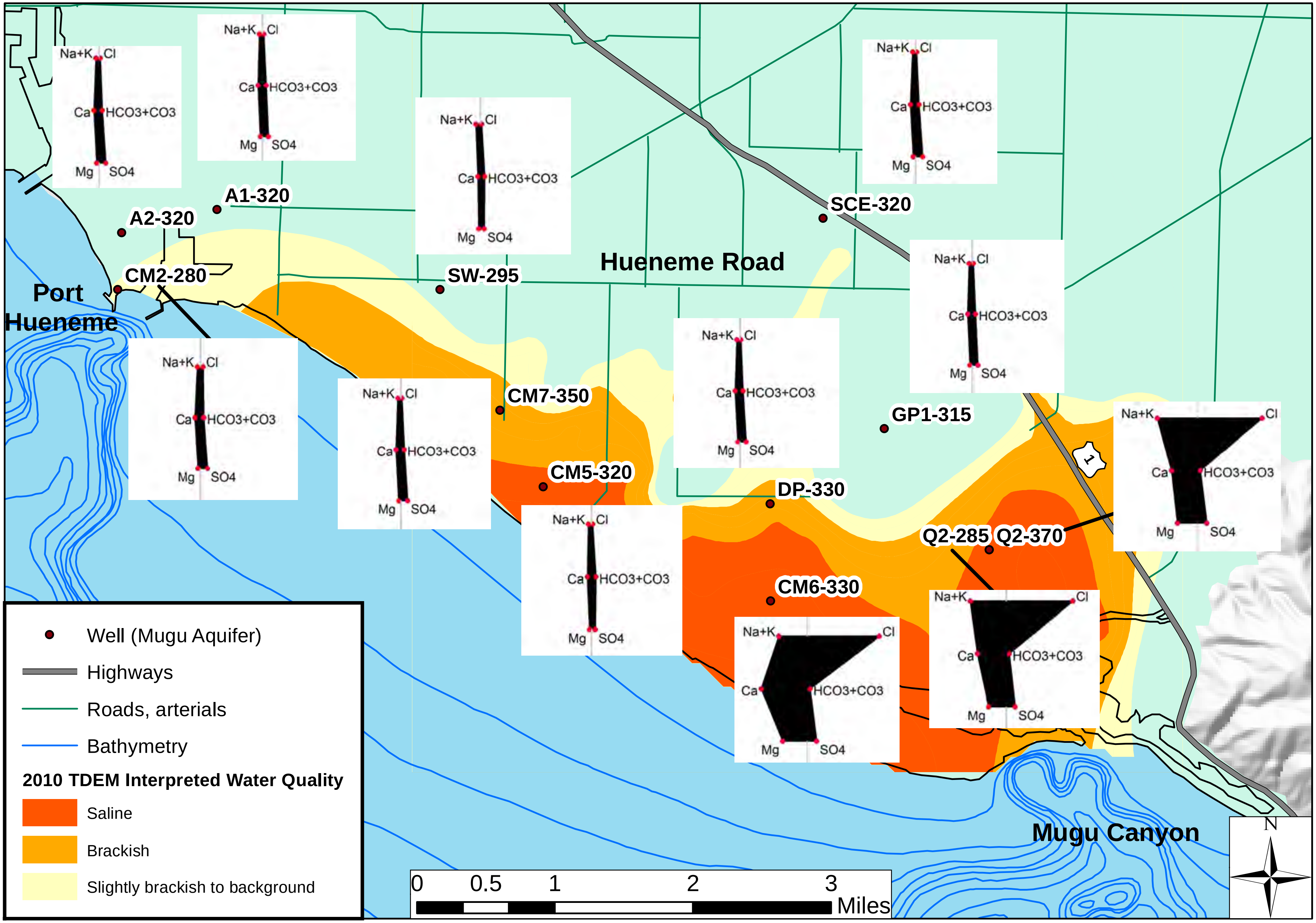


Figure B-12. Stiff diagrams for Mugu aquifer coastal monitoring wells; data 2014 and 2015.

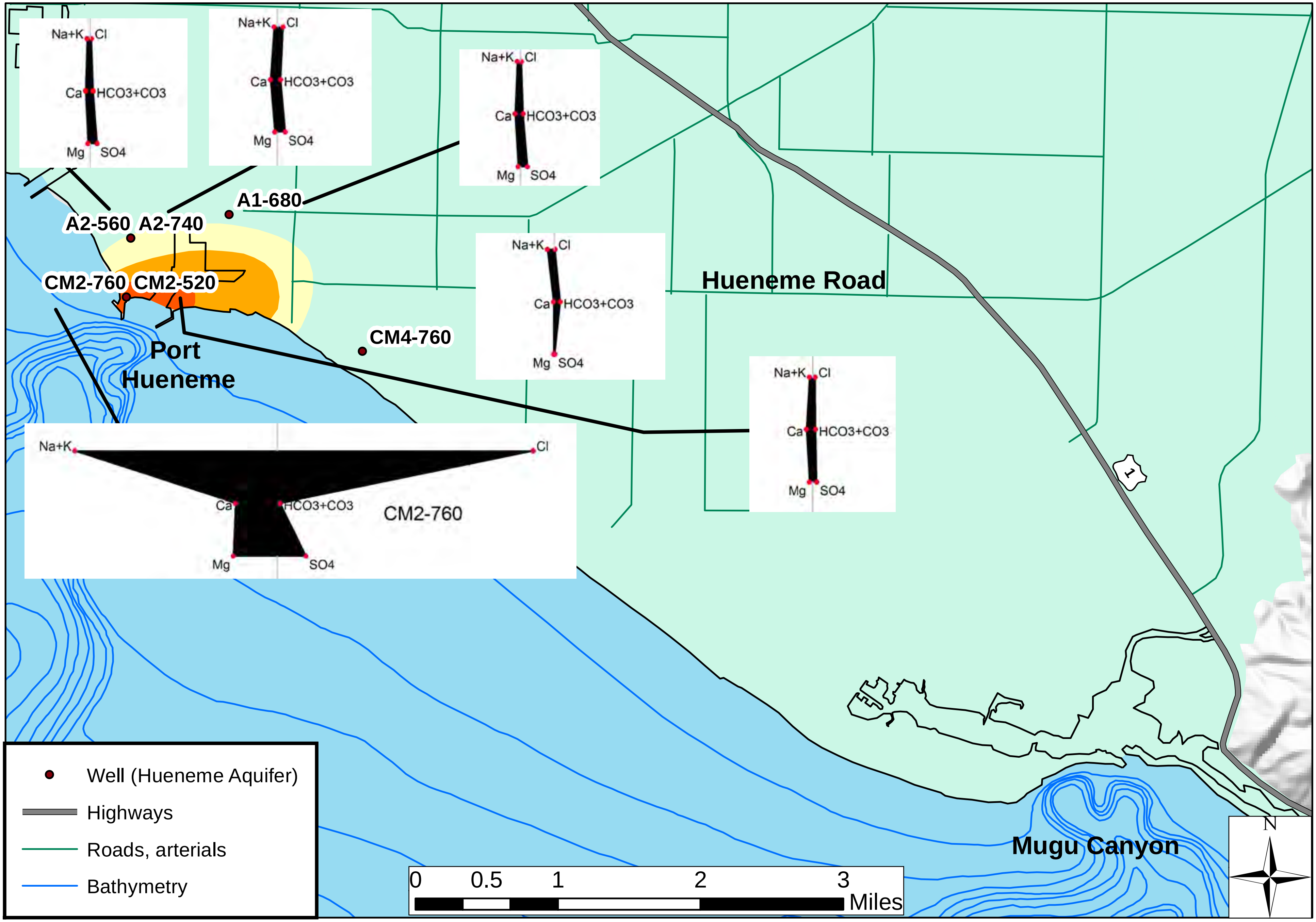


Figure B-13. Stiff diagrams for Hueneme aquifer coastal monitoring wells; data 2014 and 2015.

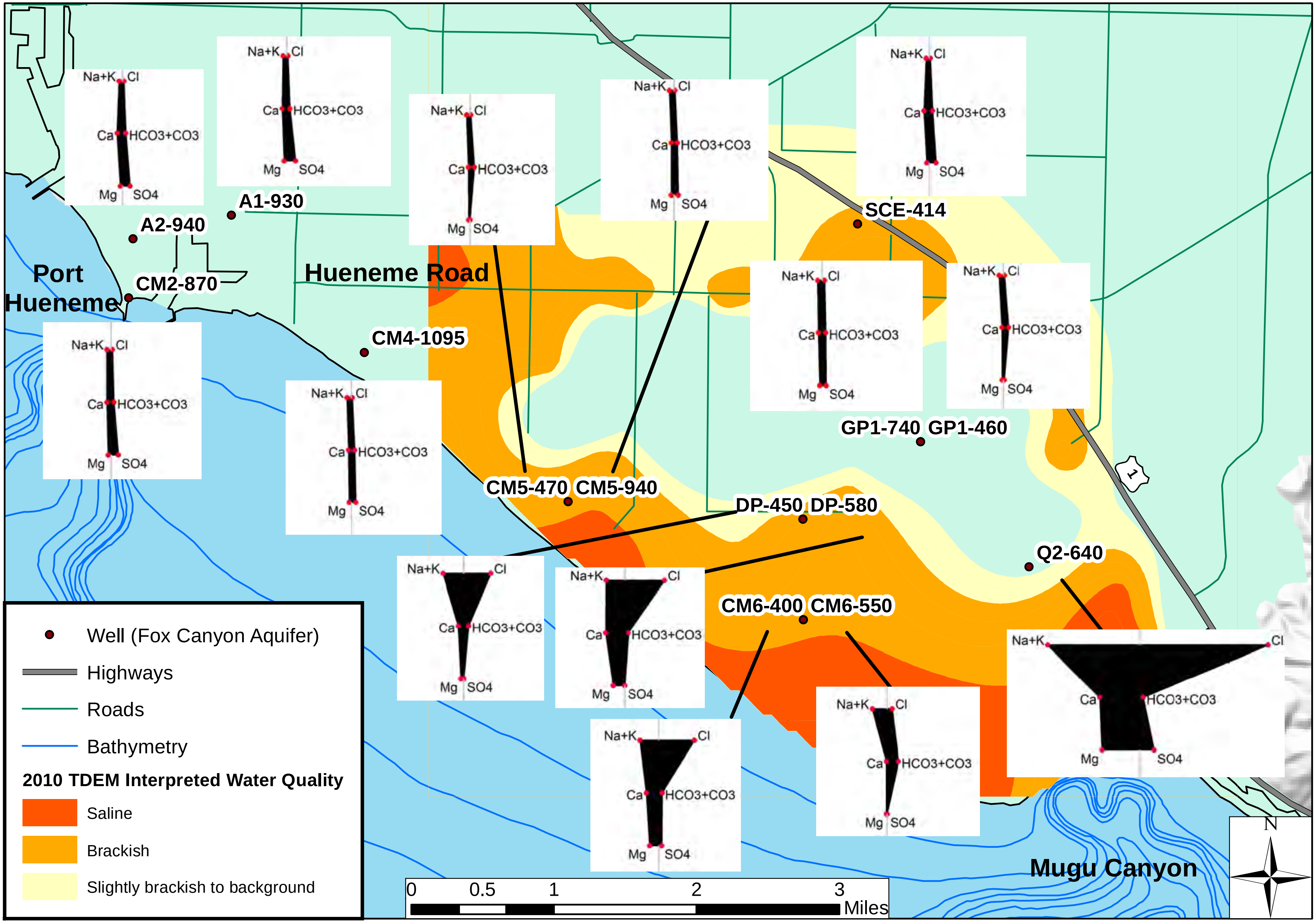


Figure B-14. Stiff diagrams for Fox Canyon aquifer coastal monitoring wells; data 2014 and 2015.

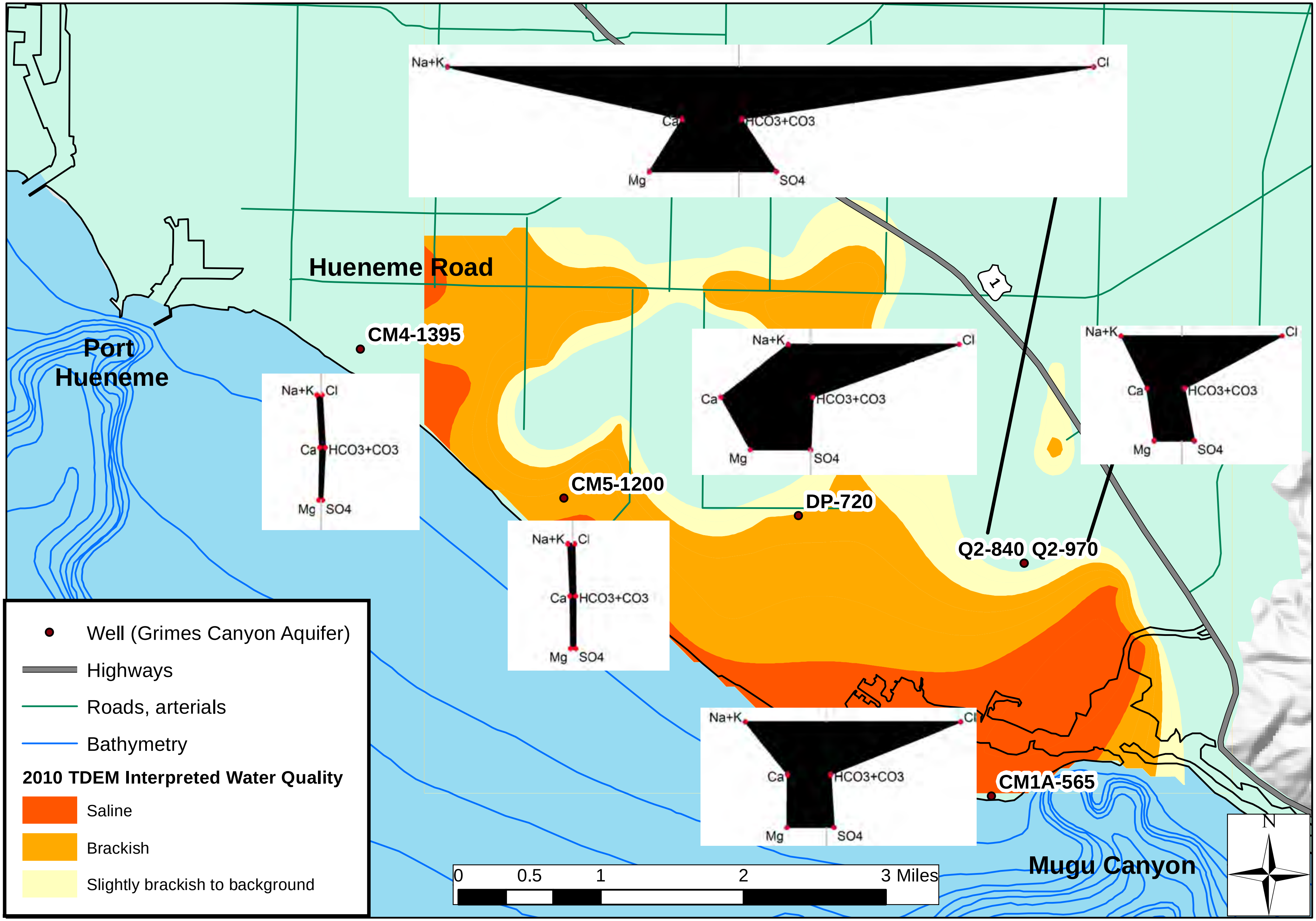


Figure B-15. Stiff diagrams for Grimes Canyon aquifer coastal monitoring wells; data 2014 and 2015.