CHAPTER 2
BASIN SETTING

2.1 INTRODUCTION TO BASIN SETTING

Physical Setting and Characteristics

The Oxnard Subbasin of the Santa Clara River Valley Groundwater Basin is located near the western edge of the Transverse Ranges Geomorphic Province, which extends from the San Bernardino Mountains in the east to the San Miguel, Santa Rosa, and Santa Cruz Islands in the west (Figure 2-1; CGS 2002). The Transverse Ranges Geomorphic Province is characterized by a series of east-to-west-trending mountain ranges and valleys that are formed by north–south compression across a restraining bend in the San Andreas Fault (Hadley and Kanamori 1977; Bohannon and Howell 1982; Zoback et al. 1987; Eberhart-Philips et al. 1990; Nicholson et al. 1994). Compression across this restraining bend is responsible for rapid, ongoing uplift of the mountain ranges (Yeats 1988; Feigl et al. 1993; Marshall et al. 2008) and extensive folding and faulting of the Pleistocene and older geologic formations in the province (Rockwell et al. 1988; Huftile and Yeats 1995).

The Oxnard Subbasin underlies the Oxnard Plain, an approximately 58,000-acre coastal plain formed by deposition of sediments from the Santa Clara River and Calleguas Creek, in southwestern Ventura County (DWR 1965, 2003). The northern boundary of the Oxnard Subbasin is the Oak Ridge Fault, and the southern boundary is the contact between permeable alluvium and semipermeable rocks of the Santa Monica Mountains (SWRCB 1956; DWR 2003). The eastern boundary of the Oxnard Subbasin lies against the Las Posas Valley and Pleasant Valley Basins. The western boundary of the Oxnard Subbasin is the Pacific Ocean (SWRCB 1956; DWR 2003).

The stratigraphic sequence underlying the Oxnard Plain comprises an upper unit of active and older alluvial deposits that unconformably overlies the San Pedro and Santa Barbara Formations (Table 2-1). The San Pedro Formation is a lower to middle Pleistocene shallow marine deposit that grades upward from a white gray sand and gravel basal layer into an overlying series of interbedded silts, clays, and gravels. The Santa Barbara Formation is a lower Pleistocene marine sand and clay deposit (SWRCB 1956; Weber and Kiessling 1976; Turner 1975). The primary water-bearing units in the Oxnard Subbasin are the alluvial deposits that compose the Oxnard and Mugu Aquifers and the white gray sand and gravel layer of the San Pedro Formation that composes the Fox Canyon Aquifer (FCA; Table 2-1). In addition to these primary aquifers, wells in the Oxnard Subbasin also produce water from the Hueneme Aquifer in the upper San Pedro Formation and the Grimes Canyon Aquifer in the Santa Barbara Formation.

Table 2-1
Oxnard Subbasin Stratigraphic and Hydrostratigraphic Nomenclature

Geologic Period	Geologic Epoch	Mukae and Turner (1975)	Kew (1924); Bailey (1951)	Weber et al. (1976)	Dibblee (1992a, 1992b)	Mukae and Turner (1975); DWR (2003)		
		Lithologic Units and Formations				*Hydrostratigraphy*		
Quaternary	**Holocene**	**Alluvium:** Active stream deposits, sand, and gravel; stream, swamp, and lagunal deposits of clay, sand, and gravel	**Recent Alluvium**: Active lagoonal, beach, river, and floodplain and alluvial deposits			**Oxnard**	**Semi-Perched**	**Upper Aquifer System**
	Upper Pleistocene		**Terrace deposits**: Deformed river deposits	**Older Alluvium**: Deformed beach, river, floodplain, and terrace deposits			**Oxnard**	
		Older Alluvium: Clays silts, sands, and gravels from the Santa Clara River				**Mugu**		
			Saugus Formation: Terrestrial and marine sand and gravel	**Saugus Formation**: Terrestrial fluvial	**Saugus Formation**: Terrestrial			
				San Pedro Formation: Marine clays and sand and terrestrial sediment		**Hueneme**		**Lower Aquifer System**
	Lower Pleistocene	**San Pedro Formation**: Marine and nonmarine clay, sand, and gravel			**Las Posas Sand**: Shallow marine sand			
						Fox Canyon		
		Santa Barbara Formation: Marine clay, sand, and gravel		**Santa Barbara Formation**: Shallow marine sand		**Grimes Canyon**		
Tertiary	**Pliocene**	**Pico Formation**: Shale, sandstone, and conglomerate	**Fernando Group**			**Non-Water Bearing**		
	Miocene	**Santa Margarita and Modelo Formations**	**Modelo Formation**: Marine mudstones		**Monterey Formation**			
		Topanga Formation and Volcanics	**Conejo Volcanics**: Terrestrial and marine extrusive and intrusive igneous rocks					
	Oligocene/ Eocene	**Older Rocks**	**Sespe Formation**: Sandstone and cobble conglomerate					

The shallowest aquifer in the Oxnard Subbasin is a semi-perched aquifer comprising sands and gravels deposited by the Santa Clara River. This unit is underlain by a clay layer, commonly referred to as the "clay cap," that is nearly continuous throughout the subbasin, with the notable exception of an approximately10-square-mile area in the eastern part of the subbasin, adjacent to and south of the Santa Clara River, referred to as the “forebay area” (Figure 2-1; Mukae and Turner 1975). In this region, the Oxnard and underlying Mugu Aquifers are unconfined. In the areas where the clay cap separates the semi-perched aquifer from the underlying Oxnard Aquifer, the Oxnard Aquifer is confined. The area in which the Oxnard Aquifer is confined is referred to as the “pressure plain area” of the Oxnard Subbasin (Figure 2-1; Mukae and Turner 1975).

The majority of the Oxnard Subbasin lies within the jurisdiction of the Fox Canyon Groundwater Management Agency (FCGMA), with two exceptions (Figure 2-1). These exceptions are the northeastern area of the Oxnard Subbsin, at the western end of South Mountain, and the southeastern area of the Oxnard Subbasin adjacent to the foothills of the Santa Monica Mountains. The reason for the discrepancy is that the FCGMA boundary was established based on a vertical projection of the FCA as defined by the Fox Canyon Groundwater Management Agency Act in 1982, whereas the Oxnard Subbasin boundary is based on the surface extent of the alluvium in the Oxnard Plain, the location of both geologic structures and facies changes that impede flow between the Oxnard Subbasin and neighboring groundwater basins (DWR 2003). The geologic and hydrologic descriptions of the Oxnard Subbasin in this Groundwater Sustainability Plan are based on the boundaries of the Oxnard Subbasin, including the areas to the northeast and southeast of the FCGMA jurisdictional boundaries.

Current Conditions

Water Budget

2.2 HYDROGEOLOGIC CONCEPT MODEL

The five commonly recognized water-bearing formations in the Oxnard Subbasin are the Oxnard, Mugu, Hueneme, Fox Canyon, and Grimes Canyon Aquifers (DWR 1965, 2003; Turner 1975). These aquifers are grouped into an upper and lower aquifer system, with the Oxnard and Mugu Aquifers composing the upper aquifer system (UAS) and the Hueneme, Fox Canyon, and Grimes Canyon Aquifers composing the lower aquifer system (LAS). The UAS primarily comprises recent to upper Pleistocene-age alluvial deposits of the Santa Clara River system.

The forebay area is the primary recharge area for all the aquifers in the Oxnard Subbasin. In this area, the UAS rests directly on the folded and eroded upper surface of the FCA and Hueneme Aquifer. Water that recharges the UAS in the forebay area is able to migrate throughout the subbasin. Both the lithologic units and geologic structures present in the Oxnard Subbasin affect the hydrology of the subbasin. These features are discussed in more detail in the following text.

2.2.1 Geology

Geologic Units and Variation

Tertiary Sedimentary and Igneous Formations

Tertiary sedimentary and igneous rocks that underlie the Oxnard Subbasin are generally considered semipermeable or non-water-bearing (Turner and Mukae 1975). These tertiary formations include the Oligocene/Eocene-age Sespe Formation, the lower Miocene Conejo Volcanics, the upper Miocene Modelo and Monterey Formations, and the Pliocene Pico Formation (Table 2-1;Weber and Kiessling 1976; Diblee 1992a, Diblee 1992b). These formations have been sampled in deep wells drilled in the Oxnard Subbasin (Figure 2-2; Turner 1975; Weber and Kiessling 1976). Because these formations typically contain poor-quality water, they are not considered an important source of groundwater in the Oxnard Subbasin (Turner 1975).

Quaternary Sedimentary Formations

Santa Barbara Formation (Lower Pleistocene; Marine)

The Santa Barbara Formation typically comprises laminated, poorly indurated blue-gray marine mud- and siltstone with sand and gravel (Table 2-1; Turner and Mukae 1975). The upper clay-rich sediments act as an aquitard between the Santa Barbara Formation and the overlying San Pedro Formation (Weber and Kiessling 1976). The localized basal conglomerate within the upper member of the Santa Barbara Formation hosts the Grimes Canyon Aquifer (Weber and Kiessling 1976).

San Pedro Formation (Lower to Middle Pleistocene; Marine and Nonmarine)

The San Pedro Formation is an interbedded, poorly lithified fine marine, silty sandstone, shale, and mudstone with local pebble conglomerate and an extensive basal sand unit that unconformably overlies the Santa Barbara Formation in the Oxnard Subbasin (Mukae and Turner 1975; Weber and Kiessling 1976). The pebbles are plutonic, metamorphic, and metavolcanic clasts.

The upper and lower parts of the San Pedro Formation are separated by a laterally extensive clay marker bed (Turner 1975). Overlying the clay marker bed are lenticular layers of sand, gravel, and silt (Mukae and Turner 1975). The lenticular deposits of sand and gravel in the upper San Pedro Formation are known as the Hueneme Aquifer in the Oxnard Subbasin. The sediments of the upper San Pedro Formation coarsen to the west, with a larger percentage of sand and gravel in the western part of the subbasin and a larger percentage of fines in the eastern part of the subbasin, particularly in the area adjacent to the boundary with the Las Posas Valley Basin.

In contrast, the basal unit of the San Pedro Formation fines to the west. This unit comprises a 100- to 600-foot-thick continuous white or gray fine to medium marine sand with stringers of gravel and local silt and clay lenses (Turner 1975).[1] The lower part of the San Pedro Formation hosts the FCA, which is an important source of groundwater supply in the Oxnard Subbasin (Turner 1975).

Older Alluvium (Upper Pleistocene; Terrestrial)

The older alluvium, which comprises gravel, sand, silt, and clay, unconformably overlies the upper San Pedro Formation. The older alluvium was deposited in river, floodplain, and beach environments. The older alluvium has been gently folded (Mukae and Turner 1975). The older alluvium can be divided into two units: an upper clay zone and a lower sand and gravel zone (Mukae and Turner 1975). The Mugu Aquifer occurs in the sand and gravel zone at the base of the older alluvium (Mukae and Turner 1975).

Recent Alluvium (Holocene; Terrestrial)

The recent alluvium in the Oxnard Subbasin comprises sands and gravels interbedded with silt and clay (DWR 1965). These sediments, which unconformably overlay the older alluvium, reach a thickness of up to 300 feet. The basal unit includes coarse sands and gravels intercalated with clay layers (Mukae and Turner 1975). Overlying the basal unit throughout much of the subbasin is a laterally continuous clay layer that reaches a thickness of up to 160 feet locally. The Oxnard aquifer occurs in the sand and gravel layer below the clay. Above the clay is the "semi-perched" aquifer.

Geologic Structure

Wright Road Fault

The Wright Road Fault is an active oblique right reverse fault that generally parallels the eastern jurisdictional boundary of the Oxnard Subbasin, separating the Las Posas Valley Basin to the east from the Oxnard Subbasin to the west (Figure 2-2; DeVecchio et al. 2007). The fault trace is characterized by a 20-meter-high topographic scarp with up to the east displacement along the north/northwest-trending fault (DeVecchio et al. 2007). There is no evidence that the Wright Road Fault impacts groundwater flow between the Oxnard Subbasin and the Las Posas Valley Basin.

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[1] This marine sand has been identified as both the Saugus Formation (Kew 1924; Jakes 1979) and the Las Posas Sand (Pressler 1929; Dibblee 1992a; Dibblee 1992b; DeVecchio et al. 2012). The term "San Pedro Formation" is used here for consistency with California Department of Water Resources nomenclature (DWR 2003).

Oak Ridge and McGrath Faults

The Oak Ridge Fault is a high-angle, south-dipping, left-lateral reverse fault that juxtaposes water-bearing alluvium and older, semipermeable formations in the subsurface (Figure 2-2; SWRCB 1956). To the east of the Oxnard Subbasin, anticlinal folding in the hanging wall of the Oak Ridge Fault resulted in the Oak Ridge and South Mountain uplift (Yeats 1988). In the Oxnard Subbasin, the western extent of the Oak Ridge Fault is concealed beneath the recent alluvium (Mukae and Turner 1975).

The McGrath Fault, located approximately 2 miles south of the Oak Ridge Fault along the coast in the Oxnard Subbasin, is a branch of the Oak Ridge Fault system with the same sense of motion (Mukae and Turner 1975). The McGrath Fault defines the northerly limit of the forebay area (Turner 1975). Together, the McGrath and Oak Ridge Faults limit hydraulic communication between the Oxnard Subbasin to the south and the Mound and Santa Paula Subbasins of the Santa Clara River Valley Groundwater Basin to the north.

Bailey Fault

Along the northern edge of the Santa Monica Mountains, the Bailey Fault Zone trends northeast–southwest through the Oxnard Subbasin (Figure 2-2; Turner 1975). The Bailey Fault is a near-vertical fault with up to the south displacement in the subsurface that offsets quaternary sedimentary formations to the north with non-water-bearing older formations to the south (Turner 1975). Groundwater elevation differences and chloride ion concentration differences across the fault suggest that it is a barrier to groundwater movement (Turner 1975).

Las Posas Syncline

The Las Posas syncline causes thickening and downwarping of the San Pedro Formation and older formations in the central part of the Oxnard Subbasin (Figure 2-2). The axis of the Las Posas syncline trends northeast from its western mapped extent at the intersection of West 5th Avenue and Harbor Boulevard, through El Rio, and into the Las Posas Valley (Turner 1975). At the deepest part of the Las Posas syncline, the upper San Pedro Formation reaches a thickness of approximately 1,150 feet (Mukae and Turner 1975).

Montalvo Anticline

Deformation in the hanging wall of the Oak Ridge and McGrath Faults has resulted in anticlinal structures on the northern boundary of the Oxnard Subbasin, including the Montalvo anticline (Figure 2-2). The upper San Pedro Formation has been eroded away in the forebay area of the Oxnard Subbasin along the axis of the anticline (Turner 1975). Erosion of the upper San Pedro

Formation results in direct communication between the alluvium and the white and gray marine sands of the lower San Pedro Formation that compose the FCA.

2.2.2 Boundaries

The western boundary of the Oxnard Subbasin is the Pacific Ocean. The northern boundary is the Oak Ridge Fault and associated McGrath Fault, which are high-angle reverse faults that juxtapose the San Pedro Formation to the north and older, semipermeable formations to the south (SWRCB 1956; Turner 1975). The southern boundary of the Oxnard Subbasin is the contact between permeable alluvium and semipermeable rocks of the Santa Monica Mountains (SWRCB 1956; DWR 2003). The eastern boundary of the subbasin lies against the Las Posas Valley and Pleasant Valley Basins (SWRCB 1956; DWR 2003).

2.2.3 Basin Bottom

The bottom of the Oxnard Subbasin generally corresponds to the base of the San Pedro Formation and the base of the FCA in the northern and western parts of the subbasin, where the Santa Barbara Formation is absent (Figures 2-2 and 2-3; Turner 1975). In the southern and eastern parts of the subbasin, where the Santa Barbara Formation is present, the bottom of the subbasin is defined by the contact between the upper member of the Santa Barbara Formation, the Grimes Canyon Aquifer, and the underlying strata that have poor water quality (Figure 2-4).

In general the bottom of the Oxnard Subbasin is shallower in the east and deeper in the west. Along the eastern margin of the subbasin, the basin bottom has been mapped at depths between 0 and 1,200 feet below mean sea level (Turner 1975). Along the western edge of the basin, the depth to the basin bottom ranges from 400 to over 1,800 feet below mean sea level (Turner 1975). The deepest part of the subbasin occurs along the axis of the Las Posas syncline in the north-central part of the subbasin.

2.2.4 Principal Aquifers and Aquitards

Semi-Perched Aquifer

River-deposited sands and gravels interbedded with minor silt and clay compose the "semi-perched" aquifer in the Oxnard Subbasin (DWR 1965; Turner 1975). The term "semi-perched" aquifer is used in this Groundwater Sustainability Plan as the name for the aquifer that overlies the extensive clay cap in the pressure plain area of the Oxnard Subbasin (Figure 2-2 and Table 2-1). This name was used in Bulletin 12 of the State Water Resources Control Board (SWRCB 1956) to distinguish the water-bearing sedimentary units in the pressure plain area from those in the forebay area, and this terminology has been adopted by subsequent investigators (Mukae and Turner 1975; Turner 1975; Hanson et al. 2003; DWR 2003). Water-level data indicate that the sediments underlying the semi-perched aquifer are saturated. Therefore, the term “semi-perched aquifer” is used in this Groundwater Sustainability Plan to denote the limited migration of water from the uppermost aquifer to the underlying confined aquifer in the pressure plain area. It is not used to denote a discontinuity in saturation.

The semi-perched aquifer is part of the recent alluvium described in Section 2.2.1. This aquifer extends from the base of developed soil horizons to a depth of approximately 75 feet throughout most of the subbasin (Turner 1975). Notably, this aquifer is absent in the forebay area of the Oxnard Subbasin adjacent to and south of the present course of the Santa Clara River. The permeable sand and gravel deposits of the semi-perched aquifer tend to be continuous in a northeast–southwest orientation, which is similar to the present orientation of the Santa Clara River and lenticular to the northwest and southeast (Turner 1975).

The lenticular shape of the semi-perched aquifer deposits limits flow in the northwest–southeast direction and facilitates flow in the northeast–southwest direction. These deposits have not been affected by faulting or folding in the basin, and there are no structural restrictions to flow through the semi-perched aquifer.

Agricultural return flows, saline connate water and coastal flooding affect both groundwater quality and groundwater elevation in the semi-perched aquifer (Mukae and Turner 1975). The highest water levels in the aquifer, which are typically within a few feet of land surface, are found in heavily irrigated areas (Turner 1975). Tile drains are used throughout the Oxnard Subbasin to alleviate the high groundwater conditions. Agricultural return flows that cause the high water conditions, combined with seawater intrusion, have resulted in high concentrations of total dissolved solids and chloride in the semi-perched aquifer (Turner 1975). Chloride concentrations have been as high as 23,000 milligrams per liter in samples from this aquifer (USGS 1996). Because of the poor water quality, few wells are screened solely in the semi-perched aquifer.

Clay Cap

Underlying the semi-perched aquifer is a clay layer that separates the semi-perched aquifer from the Oxnard Aquifer below (Turner 1975). The thickness of the clay cap is approximately 160 feet adjacent to the Pacific Ocean. The clay cap is absent in the forebay area (DWR 1968; Mukae and Turner 1975). Although the clay cap functions as an aquitard, water can migrate vertically through the clay cap under conditions of differential head (Turner 1975).

Oxnard Aquifer

The Oxnard Aquifer is a laterally continuous layer of upper Plesitocene and Holocene nonmarine gravel and cobbles (up to 6 inches in diameter); coarse to fine sand; and interbedded clay, silty clay, and silt lenses (Turner 1975). The deposits that compose this aquifer are part of the recent alluvium and are found beneath the entire Oxnard Subbasin and extend offshore, where they are exposed in the walls of the Hueneme and Mugu submarine canyons (DWR 1965, 1968). The deposits tend to be finer near the coast and coarsen to the east (Turner 1975; DWR 2003). The local silty clay and silt lenses restrict both horizontal and vertical movement of water through the aquifer, and distinct permeable horizons have been identified in logs (DWR 1963).

The top of the Oxnard Aquifer has been shaped by differential erosion and sedimentation of the Santa Clara River (Turner 1975). Throughout much of the Oxnard Subbasin, a clay-rich aquitard that ranges in thickness from 10 to 100 feet separates the Oxnard Aquifer system from the underlying Mugu Aquifer (Mukae and Turner 1975). The basal surface of the clay is more uniform than the upper surface and generally deepens to the west–southwest (DWR 1968). The thickness of the Oxnard Aquifer also generally increases to the west–southwest, with a minimum thickness of less than 50 feet in the vicinity of the forebay area and reaching a maximum thickness of greater than 150 feet in the vicinity of Point Mugu (DWR 1968; Turner 1975).

Flow of groundwater through the Oxnard Aquifer is controlled by lithologic variability. There are no documented structural features that restrict flow in this aquifer (Turner 1975; DWR 2003). The Oxnard Aquifer crops out offshore in the Hueneme and Mugu canyons, making it susceptible to seawater intrusion. The chloride concentration of native water in the Oxnard Aquifer is approximately 40 milligrams per liter (USGS 1996). In the vicinity of the Hueneme and Mugu canyons, however, chloride concentrations were as high as 17,000 milligrams per liter when last measured (Izbicki et al. 2005).

The specific yield of the gravels of the Oxnard Aquifer is about 16% in the forebay area where there are few clay deposits and the aquifer is unconfined (SWRCB 1956; DWR 2003). Wells screened in the Oxnard Aquifer are typically screened in multiple aquifers, including the underlying Mugu Aquifer. The California Department of Water Resources reports that the average well yield in the Oxnard Aquifer is about 900 gallons per minute (DWR 2003). Aquifer test results for two wells screened solely within the Oxnard Aquifer, however, have a higher average well yield of approximately 1,500 gallons per minute, with an average specific capacity of 47 gallons per minute per foot (Hopkins, pers. comm. 2016). Storage coefficients of $6.18\text{x}10^{-4}$ and $3\text{x}10^{-4}$ were estimated from pumping test data at these two wells, and the transmissivity was estimated to be approximately 20,400 feet squared per day (Hopkins, pers. comm. 2016). The well yield and specific capacity were measured at three additional wells screened solely in the Oxnard Aquifer, although aquifer tests were not performed at these wells. The average well yield and specific capacity for these wells is 2,450 gallons per minute and 108 gallons per minute per foot. Based on these measurements, the average transmissivity is approximately 32,000 feet squared per day (Hopkins, pers. comm. 2016).

Water quality in the Oxnard Aquifer has been degraded by seawater intrusion and leakage of agricultural return flows through the clay cap separating the Oxnard Aquifer from the overlying semi-perched aquifer. Seawater intrusion has been documented in both the Port Hueneme and Port Mugu areas (Turner 1975; UWCD 2016). Water produced from this aquifer is used for agricultural, municipal, and industrial purposes.

Mugu Aquifer

The sediments that compose the Mugu Aquifer are upper Pleistocene-age fine to coarse sands and gravels (DWR 1965; Turner 1975). These sand and gravel deposits are laterally extensive throughout the subbasin and represent the basal deposits of the older alluvium. In general, the sediments of the Mugu Aquifer are finer near the coast and coarsen to the east (Turner 1975). A low-permeability clay deposit that ranges in thickness from 10 to 100 feet separates the Mugu Aquifer from the overlying Oxnard Aquifer throughout much of the Oxnard Subbasin. However, the clay layer is absent in the forebay area of the subbasin near the Santa Clara River (DWR 1965; SWRCB 1979; Turner 1975). The Mugu Aquifer ranges in thickness from approximately 30 feet in the forebay to approximately 270 feet in the vicinity of Point Mugu (DWR 1965; Turner 1975).

The Mugu Aquifer crops out offshore in the Hueneme and Mugu canyons, making it susceptible to seawater intrusion. The chloride concentration of native water in the Mugu Aquifer is approximately 40 milligrams per liter (USGS 1996).

The base of the Mugu Aquifer was deposited over an irregular surface that has been affected by both folding and erosion (Turner 1975). The extensive folding of the aquifers underlying the Mugu Aquifer, however, has not been documented within the sediments of the Mugu Aquifer. There are no known structural boundaries to flow within the aquifer.

Wells screened in the Mugu Aquifer are typically screened in multiple aquifers, including the overlying Oxnard Aquifer. The California Department of Water Resources does not reports aquifer properties specifically for the Mugu Aquifer (DWR 2003). In the Forebay, well 02N22W36E04S, screened solely within the Mugu Aquifer has a well yield of 1,500 gallons per minute, a specific capacity of 17.8 gallons per minute per foot, and an estimated transmissivity of 7,900 feet squared per day (Hopkins, pers. comm. 2016). For wells screened in both the Oxnard and Mugu Aquifers, the average yield is 2,300 gallons per minute, the average specific capacity is 110 gallons per minute per foot, and the average estimated transmissivity is 29,000 feet squared per day (Hopkins, pers. comm. 2016). Water produced from this aquifer is used for agricultural, municipal, and industrial purposes.

Hueneme Aquifer

The Hueneme Aquifer comprises a series of lenticular silts, sands, and gravels in the upper San Pedro Formation. This aquifer is present in the northern part of the Oxnard Subbasin but is absent to the south of Etting and Hueneme Roads (Mukae and Turner 1975). The Hueneme Aquifer is up to 1,150 feet thick along the axis of the Las Posas syncline (Turner 1975).

Changes in lithologic composition, with the aquifer generally containing a higher percentage of fine materials adjacent to the Las Posas and Pleasant Valley Basins, affect flow through the aquifer. The change in composition is accompanied by an increase in the lenticular nature of the deposits that compose the Hueneme Aquifer along the eastern boundary of the Oxnard Subbasin. These changes limit subsurface flow between the Oxnard Subbasin and the Las Posas Valley and Pleasant Valley Basins to the east.

In addition to changes in lithology, structural folding of the Hueneme Aquifer also affects subsurface flow (Turner 1975). Folding, subsequent erosion, and recent deposition have resulted in a direct hydraulic connection between the Hueneme Aquifer and the overlying Mugu Aquifer throughout much of the Oxnard Subbasin (Turner 1975). However, in the southwestern portion of the basin, where seawater intrusion has affected the Mugu Aquifer, the Mugu and Hueneme Aquifers are not in direct hydraulic communication. As a result, water quality in the Hueneme Aquifer has not been affected by seawater intrusion (Turner 1975; USGS 2003). The chloride concentration of native water in the Hueneme Aquifer is approximately 40 milligrams per liter (USGS 1996).

Wells screened solely within the Hueneme Aquifer have an average capacity of approximately 2,500 gallons per minute and an average specific capacity of 38 gallons per minute per foot (Hopkins, pers. comm. 2016). Storage coefficients of $2x10^{-4}$ and $3x10^{-4}$ were estimated from pumping test data at two wells and the transmissivity was estimated to be approximately 13,400 feet squared per day (Hopkins, pers. comm. 2016). Water produced from this aquifer is used for agricultural, municipal, and industrial purposes.

Fox Canyon Aquifer

The FCA is a 100- to 600-foot-thick marine sand and gravel deposit in the lower San Pedro Formation (Mukae and Turner 1975). The water-bearing deposits of the FCA fine toward the west (Turner 1975). This unit is laterally continuous throughout the Oxnard Subbasin, except at the western tip of South Mountain, where the Santa Barbara Formation is in direct contact with the Mugu Aquifer, and in the southwestern part of the basin, where uplift and erosion have removed the FCA (Turner 1975). In the northern and western parts of the subbasin, the FCA defines the base of the fresh water zone.

In the Oxnard Subbasin, the FCA is thickest along the axis of the Las Posas syncline. In this area, the FCA reaches thickness in excess of 500 feet, and the base of the aquifer is below 2,000 feet below sea level (Turner and Mukae 1975; Turner 1975). The primary source of recharge to the FCA is infiltration through the Oxnard and Mugu Aquifer systems in the forebay area (Turner 1975; FCGMA 2007).

Water quality in the FCA is generally good, with the native water having a chloride concentration of 40 milligrams per liter (USGS 1996). Chloride concentration measured in 2002 from a well in the southeastern part of the subbasin ranged from 183 to 367 milligrams per liter (Izbicki et al. 2005). The concentration of chloride in wells in the FCA has remained relatively constant with time, indicating that water quality in this aquifer has not been degraded by seawater intrusion (Izbicki et al. 2005).

Well 02N22W18H14S in the northern Oxnard Subbasin, isscreened solely within the FCA. The well yield from this well is 1,300 gallons per minute, the specific capacity is 6.5 gallons per minute per foot, and the estimated transmissivity is approximately 2,100 feet squared per day (Hopkins, pers. comm. 2016). Well 02N22W20J02S, also in the northern Oxnard Subbasin, is screened in both the FCA and overlying Hueneme Aquifer. This well has a yield of 3,030 gallons per minute, a specific capacity of 95.3 gallons per minute per foot, and a transmissivity of 40,100 feet squared per day (Hopkins, pers. comm. 2016). Water produced from this aquifer is used for agricultural, municipal, and industrial purposes.

Grimes Canyon Aquifer

The Grimes Canyon Aquifer comprises lower Pleistocene-age sand with minor amounts of gravel. This aquifer corresponds with the basal conglomerate within the upper member of the Santa Barbara Formation and is only found underlying the southern and eastern parts of the Oxnard Subbasin (Turner 1975). In the southern part of the subbasin, the Grimes Canyon Aquifer is found in a band approximately 5 miles wide along the base of the Santa Monica Mountains from the Pacific Ocean to the boundary with the Pleasant Valley Basin to the east (Turner 1975). Throughout the rest of the subbasin, the Grimes Canyon member of the Santa Barbara Formation is absent.

The Grimes Canyon Aquifer, where present in the Oxnard Subbasin, is in hydraulic communication with the overlying FCA, and there are no wells perforated solely in the Grimes Canyon Aquifer (Turner 1975; VCWPD 2013). As a result, there is little information on the water quality or aquifer properties of the Grimes Canyon Aquifer. In general, in the Oxnard Subbasin, the Grimes Canyon Aquifer has water of poor quality, and some basal portions of the aquifer have brackish water that is likely a result of limited flushing since deposition and upward migration of oilfield brines from underlying formations (Mukae and Turner 1975; Turner 1975;

Hanson et al. 2003). Aquifer properties data specific to the Grimes Canyon Aquifer are not currently available.

2.2.5 Data Gaps and Uncertainty

2.2.6 Maps and Cross-Sections

A geologic map is provided in Figure 2-2, and cross-sections are provided in Figures 2-3 and 2-4.

2.3 GROUNDWATER CONDITIONS

2.3.1 Groundwater Elevation Data

Groundwater elevations in the Oxnard Subbasin were first measured in agricultural wells in the 1930s and an annual groundwater monitoring program was initiated in the subbasin by the FCGMA, United Water Conservation District (UWCD), and the U.S. Geological Survey in the 1990s (FCGMA 2007). The FCGMA annual groundwater monitoring program includes both production wells and multiple-completion nested monitoring wells. Many of the production wells included in the monitoring program are screened across multiple aquifers. Historically, the FCGMA annual reports have included potentiometric surface maps for wells screened in the UAS and wells screened in the LAS (FCGMA 2015).

In order to conform with 23 CCR Section 354.14, the following discussion of groundwater elevation is limited to production and monitoring wells screened in a single aquifer. Water level measurements collected between March 2 and March 29, 2015, are used to represent groundwater elevations in the spring of 2015. Water level measurements collected between October 2 and 29, 2015, are used to represent groundwater elevations in the fall of 2015.

Because many production wells within the Subbasin are screened across multiple aquifers, a discussion of water elevations only in wells that are screened in a single aquifer may not be representative of regional pumping patterns. Self-reported groundwater extraction data for the year 2015 are shown in Figures 2-5 and 2-6 for wells screened in the UAS and the LAS, respectively. In the UAS, the location of the greatest amount of extraction is within the forebay, with additional extraction areas both west and south of the City of Oxnard (Figure 2-5). The majority of the production from the LAS is in the area south of the Spanish Hills, near the boundary between the Pleasant Valley Basin and the Subbasin (Figure 2-6). The volume of groundwater extracted from the LAS is greater than that extracted from the LAS.

Current and historical groundwater elevations are discussed below by aquifer. Full hydrographs for all Oxnard Subbasin wells are included in Appendix A.

2.3.1.1 Oxnard Aquifer

Spring and Fall 2015 Groundwater Elevations

In the spring of 2015, groundwater elevations in the Oxnard aquifer ranged from -27.2 to 46.3 feet above mean sea level (amsl; Figure 2-7). In the fall of 2015, groundwater elevations ranged from 37.9 to -30.7 feet amsl (Figure 2-8).

Groundwater flows from areas of high groundwater elevation to areas of low groundwater elevation. The highest groundwater elevations in the Oxnard aquifer are found in the forebay in both the fall and spring of 2015, despite the groundwater production from this area (Figures 2-7 and 2-10). The hydraulic gradient in the forebay in the spring of 2015 was approximately 0.005 feet/feet with groundwater flowing to the south and southwest, toward the pumping centers west and south of the City of Oxnard. In the fall of 2015 the hydraulic gradient was approximately 0.005 feet/feet with groundwater flowing to the west-southwest and south. Away from the forebay, groundwater elevations in the Oxnard aquifer are higher on the western and eastern boundaries of the Subbasin than they are in the center of the Subbasin. In this central area, groundwater elevations are over 20 feet below sea level in both the spring and fall of 2015 (Figures 2-7 and 2-8). This reflects the groundwater production from wells south of the City of Oxnard in the central Oxnard Subbasin (Figure 2-7). The hydraulic gradient, directed toward the production wells, was less than approximately 0.001 feet/feet in both the spring and fall of 2015.

There is uncertainty associated with the groundwater elevation contours, hydraulic gradient, and groundwater flow direction in the Oxnard aquifer in the spring and fall of 2015. Fewer wells are screened solely within the Oxnard aquifer than are producing groundwater from the Oxnard aquifer. The majority of the wells that produce groundwater in the Oxnard aquifer are screened across multiple aquifers. These wells were not used to create the contour maps in order to conform with 23 CCR Section 354.14. The uncertainty in hydraulic gradient, flow direction, and groundwater elevation within the Oxnard aquifer is particularly pronounced in the southern Oxnard Subbasin where there are few wells screened solely within the Oxnard aquifer but several production wells screened in multiple aquifers (Figure 2-7 and 2-8).

Vertical Gradients

Groundwater elevations in the Oxnard Aquifer are higher than those in the underlying Mugu aquifer, resulting in a downward vertical gradient from the Oxnard to the Mugu Aquifer throughout the Oxnard Subbasin (Table 2-2). The magnitude of the vertical gradient varies with distance from the coast. The downward vertical gradient between the Oxnard and Mugu Aquifers was calculated for five wells in the fall of 2015 (Table 2-2). The wells in Table 2-2 were selected from a larger group of nested groundwater monitoring wells to represent the vertical gradient at different geographic locations in the Subbasin.

In the spring of 2015, the vertical gradient from the Oxnard aquifer to the underlying Mugu aquifer ranged from 0.004 feet/feet at the coast near Port Hueneme to 0.278 feet/feet inland of Point Mugu (Table 2-2). In the fall of 2015, the vertical gradient from the Oxnard aquifer to the underlying Mugu aquifer ranged from 0.002 feet/feet at the coast near Port Hueneme to 0.468 feet/feet inland of Point Mugu (Table 2-2). The vertical gradients along the coast are lower than they are inland, reflecting the influence of seawater in the aquifer, moderating water levels at the coast.

The vertical gradient between the Oxnard and Mugu aquifers was higher in the fall than in the spring, except at the coast where it was the same in the spring and fall (wells 01N22W20M02S and -03S), and in the forebay where the gradient was higher in the spring than in the fall (wells 02N22W23B07S and -08S). The vertical gradient in the forebay was higher in the spring because of surface water spreading grounds in the forebay that are primarily utilized during periods of higher flow in the Santa Clara River.

Vertical gradients within the Oxnard aquifer were determined from monitoring well clusters 01N21W19L, 02N22W23B, and 01N22W28G, which have two screen intervals within the Oxnard aquifer (Table 2-2). For each of these locations, the vertical hydraulic gradient within the Oxnard aquifer was directed downward. The downward vertical hydraulic gradient ranged from 0.009 to 0.278 feet/feet in the spring of 2015. In the fall of 2015, the downward vertical gradient ranged from 0.016 to 0.643 feet/feet. The downward vertical hydraulic gradient was larger in the fall than in the spring, and the largest downward vertical hydraulic gradient was in the forebay. The smallest downward vertical hydraulic gradient within the Oxnard aquifer was adjacent to the coast (Table 2-2; Figure 2-8).

Table 2-2
Vertical Gradient

Location	SWN	Well	Screen Interval		Spring 2015 Elevation (feet MSL)	Gradient (feet/ feet)[1]	Fall 2015 Elevation (feet MSL)	Gradient (feet/ feet)[1]	Aquifer[2]
			Top	Bottom					
Forebay	02N22 W23B	09	75	95	NA	-	10.41	-0.643	Oxnard
		08	135	155	-13.06	-0.057	-28.19	-0.019	Oxnard
		07	260	300	-20.72	-0.012	-30.81	-0.028	Mugu
		06	460	500	-23.2	-0.114	-36.43	-0.107	Hueneme
		05	830	870	-65.53	-0.036	-75.84	-0.039	Hueneme
		04	1110	1150	-75.59	-0.014	-86.77	0.032	Huene

								me
		03	1210	1250	-77	-	-83.55	-	Fox
Forebay	02N21 W07L	06	135	155	8.2	-0.012	-12.07	-0.042	Fox
		04	500	540	3.88	-0.014	-27.9	0.022	Fox
		03	640	700	1.84	-	-24.59	-	
North - Coastal	01N23 W01C	05	120	145	1.18	-0.040	-0.92	-0.048	Oxnard
		04	630	695	-20.03	-0.009	-26.52	-0.010	Hueneme
		03	965	1065	-23.24	-0.014	-29.95	-0.010	Hueneme
		02	1390	1490	-29.31		-34.34		Fox
Port Hueneme	01N22 W20M	06	50	70	1.27	-0.071	1.8	-0.131	Semi-perched
		05	150	170	-5.78	-0.004	-11.27	-0.002	Oxnard
		04	280	300	-6.26	-0.033	-11.55	-0.039	Mugu
		03	520	560	-14.6	-0.017	-21.3	-0.019	Hueneme
		02	700	740	-17.57	-0.040	-24.8	-0.048	Hueneme
		01	900	940	-25.65		-34.47		Fox
Port Hueneme	01N22 W28G	5	180	200	-7.4	-0.009	-12.4	-0.016	Oxnard
		4	255	275	-8.1	-0.030	-13.6	-0.032	Oxnard
		3	720	760	-22.3	-0.039	-28.8	-0.051	Hueneme
		2	995	1095	-34.2	0.010	-44.2	0.019	Fox
		1	1295	1395	-31.3	-	-38.6	-	Grimes
Point Mugu	01N22 W36K	09	175	195	-13.07	-0.110	-24.14	-0.156	Oxnard
		08	310	330	-27.89	-0.220	-45.17	-0.561	Mugu
		07	410	450	-52.06	-0.005	-106.82	-0.019	Fox
		06	540	580	-52.71	-0.025	-109.32	-0.014	Fox
		05	680	720	-56.26	-	-111.34	-	Grimes
South/ Central	01N21 W19L	14	18	38	11.97	-0.278	10.1	-0.331	Semi-perched
		13	110	130	-13.63	-0.048	-20.33	-0.096	Oxnard
		12	200	220	-17.93	-0.109	-28.96	-0.119	Oxnard
		11	300	320	-28.85	-0.390	-40.87	-0.620	Mugu
		10	394	414	-65.55	-	-99.19	-	Fox
South	01N21 W32Q	06	275	285	-41.21	-0.278	-65	-0.468	Oxnard
		07	180	220	-12.7	-0.356	-20.24	-0.560	Mugu
		05	330	370	-60.7	-0.021	-97.74	-0.028	Mugu

		04	600	640	-66.3	-0.047	-105.38	-0.044	Fox Canyon
		03	800	840	-75.6	0.084	-114.17	0.084	Grimes
		02	930	970	-64.7	-	-103.2	-	Grimes

1) Negative gradients are directed downward.

2) The Oxnard and Mugu aquifers compose the UAS and the Hueneme, Fox and Grimes aquifers compose the LAS. Aquifer designations were provided by UWCD.

Historical Groundwater Elevation Trends

Groundwater elevations in the Oxnard Aquifer have declined and recovered over climatic cycles since the 1930s (Figure 2-9a). Groundwater elevation trends in well 01N21W07H01S, the well with the longest historical groundwater elevation record in the Oxnard Subbasin, match the trends observed in the record of cumulative departure from the mean precipitation on the Oxnard Plain (Figure 2-9a). Declines in groundwater elevation occur between 1941 and 1966, 1970 and 1977, 1984 and 1990, and 2011 and 2016, coincident with periods of drought shown in the declining limb of the cumulative departure from the mean precipitation curve (Figure 2-9a). Groundwater elevations recover after each drought period. The amount of recovery depended on the length of time between droughts and the amount of precipitation received in each of the water years between the droughts. By 1980, the groundwater elevation recovered to within 10 feet of the previous maximum measured in 1941 and by 1999, water levels exceeded the 1941 maximum (Figure 2-9a). Since 2011, groundwater elevations in this well have declined approximately 40 feet.

The patterns of water level decline and recovery observed in well 01N21W07H01S are observed in Oxnard Aquifer wells throughout the Oxnard Subbasin although absolute changes in water level vary geographically within the Oxnard Subbasin (Figure 2-9a and 2-9b). Wells in the forebay area and northeastern Oxnard Subbasin have experienced water level declines of approximately 90 feet since 2011 (Figure 2-9b) while water levels in wells adjacent to the coast and in wells farther south have declined between 18 and 40 feet over the same time period (Figure 2-9a). The larger water level changes observed in the northeastern Oxnard Subbasin reflect the influence of groundwater recharge from spreading basins in the forebay area.

2.3.1.2 Mugu Aquifer

Spring and Fall 2015 Groundwater Elevations

In the spring of 2015, groundwater elevations in the Mugu aquifer in the Oxnard Subbasin ranged from -60.7 to 8.2 feet amsl (Figure 2-10). In the fall of 2015, groundwater elevations ranged from -97.7 to -12.1 feet amsl (Figure 2-11).

The highest groundwater elevations in the Mugu aquifer are found in the forebay in both the fall and spring of 2015 (Figures 2-10 and 2-11). The hydraulic gradient in the forebay in the spring of 2015 was approximately 0.003 feet/feet with groundwater flowing to the south and southwest. In the fall of 2015 the hydraulic gradient was approximately 0.002 feet/feet with groundwater flowing to the south and southwest. Groundwater elevations in the Mugu aquifer are lowest in the southern area of the Subbasin. In this area, groundwater elevations are 60 to 100 feet below sea level in 2015 (Figures 2-10 and 2-11). The hydraulic gradient, directed toward the area of low groundwater elevations, was approximately 0.002 feet/feet to the southeast in the spring of 2015. In the fall of 2015 the hydraulic gradient directed toward the area of low groundwater elevations ranged from approximately 0.004 to 0.009 feet/feet to the east-southeast.

There is uncertainty associated with the groundwater elevation contours, hydraulic gradient, and groundwater flow direction in the Mugu aquifer in the spring and fall of 2015. Fewer wells are screened solely within the Mugu aquifer than are producing groundwater from the Mugu aquifer. The majority of the wells that produce groundwater in the Mugu aquifer are screened across multiple aquifers. These wells were not used to create the contour maps in order to conform with 23 CCR Section 354.14. The uncertainty in hydraulic gradient, flow direction, and groundwater elevation within the Mugu aquifer is particularly pronounced in the southern and eastern Oxnard Subbasin where groundwater appears to flow to the south-southeast from the Oxnard Subbasin to the Pleasant Valley Basin (Figure 2-10 and 2-11). This apparent flow direction is likely an artifact of contouring wells that are solely screened in the Mugu aquifer, and may not reflect actual flow directions within the aquifer.

Vertical Gradients

Groundwater elevations in the Mugu Aquifer are lower than those in the overlying Oxnard Aquifer, resulting in a downward vertical gradient from the Oxnard to the Mugu Aquifer throughout the Oxnard Subbasin (Table 2-2; Section 2.3.1.1). Groundwater elevations in the Mugu Aquifer are higher than those in the underlying Hueneme aquifer, resulting in a downward vertical gradient from the Mugu to the Hueneme aquifer in the forebay and adjacent to Point Hueneme (Table 2-2). At monitoring well cluster 01N22W20M, adjacent to Point Hueneme, the downward vertical hydraulic gradient was 0.033 feet/feet in the spring of 2015 and 0.039 feet/feet in the fall of 2015. At monitoring well cluster 02N22W23B, in the forebay, the downward vertical hydraulic gradient was 0.012 feet/feet in the spring of 2015 and 0.028 feet/feet in the fall of 2015.

Within the Mugu Aquifer, a downward vertical gradient of 0.365 feet/feet was calculated in the spring of 2015 wells 01N21W32Q07S and 01N21W32Q05S (Figure 2-10). In the fall of 2015, the downward vertical gradient was 0.560 feet/feet (Table 2-2; Figure 2-11).

Historical Groundwater Elevation Trends

Groundwater elevations in the Mugu aquifer have declined and recovered over climatic cycles since the 1930s (Figure 2-12). Groundwater elevation trends in well 02N22W24P01S, the well with the longest historical groundwater elevation record in the Mugu aquifer, match the trends observed in the record of cumulative departure from the mean precipitation on the Oxnard Plain (Figure 2-12). Declines in groundwater elevation occur between 1974 and 1977, 1984 and 1990, and 2011 and 2016, coincident with periods of drought shown in the declining limb of the cumulative departure from the mean precipitation curve (Figure 2-12). Groundwater elevations recover after each drought period. The amount of recovery depends on the length of time between droughts and the amount of precipitation received in each of the water years between the droughts. In 1996, water levels exceeded the previous maximum in 1980 (Figure 2-12). Since 2011, groundwater elevations in this well have declined approximately 100 feet.

The patterns of water level decline and recovery observed in well 02N22W24P01S are observed in Mugu aquifer wells throughout the Oxnard Subbasin although absolute changes in water level vary geographically within the subbasin (Figure 2-12). Well 02N22W24P01S is located in the forebay area. Other wells in the forebay area experienced similar water level declines and recoveries to those observed in well 02N22W24P01S (Figure 2-12). Water levels in wells adjacent to the coast and in wells farther south, however, tend to have larger intra-annual variation in water level, but a smaller inter-annual drought response (e.g. Wells 01N21W32Q05S and 01N21W19L11S; Figure 2-12). The groundwater elevation in these wells declined between 20 and 80 feet between 2011 and 2015, whereas the groundwater elevation in wells in the forebay area declined approximately 100 feet over the same time period. The larger water level changes observed in the northeastern Oxnard Subbasin reflect the influence of groundwater recharge from spreading basins in the forebay area.

2.3.1.3 Hueneme Aquifer

Spring and Fall 2015 Groundwater Elevations

In the spring of 2015, groundwater elevations in the Hueneme aquifer in the Oxnard Subbasin ranged from -89.4 to 10.2 feet amsl (Figure 2-13). In the fall of 2015, groundwater elevations ranged from -115.5 to 2.1 feet amsl (Figure 2-14). There are fewer wells screened solely in the Hueneme aquifer than are screened in the Oxnard, Mugu or Fox Canyon aquifers in the Oxnard Subbasin. The small number of wells screened solely within the Hueneme aquifer, creates uncertainty in the groundwater elevation contours, hydraulic gradient, and groundwater flow direction, particularly south of 5th Street (Figures 2-13 and 2-14).

The highest groundwater elevations in the Hueneme aquifer are found in the forebay in both the fall and spring of 2015 (Figures 2-13 and 2-14). The hydraulic gradient in the forebay in the spring of 2015 was approximately 0.008 feet/feet with groundwater flowing to the southwest. In the fall of 2015 the hydraulic gradient was approximately 0.007 feet/feet with groundwater flowing to the south-southwest.

Groundwater elevations in the Hueneme aquifer are lowest south of the Forebay and west of Central Avenue (Figures 2-13 and 2-14). In this area, groundwater elevations are 80 to 100 feet below sea level in 2015 (Figures 2-13 and 2-14). This area of lower groundwater elevations coincides with the location of several production wells that are screened solely within the Hueneme aquifer (Figure 2-6). The hydraulic gradient, directed toward the area of low groundwater elevations, ranged from approximately 0.003 feet/feet to the southeast in the spring of 2015 to approximately 0.008 feet/feet to the east-southeast in the fall of 2015.

Vertical Gradients

Groundwater elevations in the Hueneme Aquifer are lower than those in the overlying Mugu Aquifer, resulting in a downward vertical gradient from the Mugu to the Hueneme aquifer (Table 2-2; Section 2.3.1.2). Groundwater elevations in the Hueneme aquifer are higher than those in the underlying Fox Canyon aquifer, in both the spring and fall of 2015, except in the forebay. In the forebay, the groundwater elevation in the Hueneme aquifer is higher than it is in the Fox Canyon aquifer in the spring of 2015, and lower than that in the Fox Canyon aquifer in the fall of 2015 (Table 2-2). In the spring of 2015, the downward vertical hydraulic gradient between the Hueneme and Fox Canyon aquifers ranged from 0.014 feet/ feet to 0.040 feet/feet. In the fall of 2015, the vertical hydraulic gradient between the Hueneme and Fox Canyon aquifers ranged from 0.050 feet/ feet downward adjacent to the coast, to 0.032 upward in the forebay (Table 2-2). The switch between the downward and upward directed vertical gradient in the forebay from spring to fall likely represents the combined effects of surface water spreading in the spring and groundwater production from the Fox Canyon aquifer in the fall.

Within the Hueneme Aquifer, a downward vertical gradient of 0.017 feet/feet was calculated for wells 01N22W20M03S and 01N22W20M02S, in the spring of 2015 (Figure 2-13). In the fall of 2015, the gradient in these wells is 0.019 feet, which is the same as in the spring. Farther north, in wells 01N23W01C03S and 01N23W01C04S, the vertical gradient within the Hueneme Aquifer is similar to that calculated for wells 01N22W20M03S and 01N22W20M02S. In the spring of 2015, the downward vertical hydraulic gradient was 0.009 feet/feet in wells 01N23W01C03S and 01N23W01C04S. In the fall, the downward vertical hydraulic gradient was 0.010 feet/feet between wells 01N23W01C03S and 01N23W01C04S (Table 2-2).

In wells 02N22W23B07S and 02N22W23B08S, in the forebay, the downward vertical gradient is higher, in the upper Hueneme aquifer than in the lower Hueneme aquifer (Table 2-2). The gradients within the Hueneme aquifer in the forebay are similar to those within the Hueneme aquifer along the coast.

Historical Groundwater Elevation Trends

Groundwater elevations in the Hueneme aquifer have declined and recovered over climatic cycles (Figure 2-15). Groundwater elevation trends in well 02N21W31P03S, the well with the longest historical groundwater elevation record in the Hueneme aquifer, match the trends observed in the record of cumulative departure from the mean precipitation on the Oxnard Plain (Figure 2-15). Declines in groundwater elevation occur between 1974 and 1977, 1984 and 1990, and 2011 and 2016, coincident with periods of drought shown in the declining limb of the cumulative departure from the mean precipitation curve (Figure 2-15). Groundwater elevations recover after each drought period. The amount of recovery depends on the length of time between droughts and the amount of precipitation received in each of the water years between the droughts. Since 2011, groundwater elevations in this well have declined approximately 40 to 60 feet (Figure 2-15).

The patterns of water level decline and recovery observed in well 02N21W31P03S are also observed in Hueneme Aquifer wells 01N22W03F05S and 01N22W26M03S, although the magnitude of the change water levels varies between the wells (Figure 2-15). Between 1996 and 2010, groundwater elevations were relatively stable in well 01N22W26M03S and declined by approximately 32 feet in well 01N22W03F05S. Between 2011 and 2015, during a period of drought, groundwater elevations declined approximately 47 feet in well 01N22W26M03S and approximately 55 feet in well 01N22W03F05S (Figure 2-15).

2.3.1.4 Fox Canyon Aquifer

Spring and Fall 2015 Groundwater Elevations

In the spring of 2015, groundwater elevations in the Fox Canyon aquifer in the Oxnard Subbasin ranged from -107.3 to 3.9 feet amsl (Figure 2-16). In the fall of 2015, groundwater elevations ranged from -156.3 to -24.6 feet amsl (Figure 2-17).

The highest groundwater elevations in the Fox Canyon aquifer are found in the northeastern Oxnard Subbasin, in both the fall and spring of 2015 (Figures 2-16 and 2-17). The lowest groundwater elevations are found at well 01N21W06J05S, south of 5th Street, west of Pleasant Valley Road (Figures 2-16 and 2-17). The low groundwater elevations in this well reflects the production from the Fox Canyon aquifer in this location (Figure 2-6). However, there are several wells in the surrounding areas that produced more groundwater in 2015, but are screened across multiple aquifers in the LAS. The hydraulic gradient in the Fox Canyon aquifer is directed toward well 01N21W06J05S in both the spring and fall of 2015. In the spring of 2015, the hydraulic gradient was approximately 0.001 to 0.002 feet/feet. In the fall of 2015 the hydraulic gradient ranged from approximately 0.002 to approximately 0.005 feet/feet. These gradients may not fully depict the direction and magnitude of flow within the Fox Canyon aquifer because more production wells are screened across multiple aquifers in the LAS than are screened solely within the Fox Canyon aquifer.

Vertical Gradients

Groundwater elevations in the Fox Canyon Aquifer are, generally, lower than those in the overlying aquifers (Figures 2-16 and 2-17; Table 2-2). In the spring of 2015, the downward vertical gradient from the Mugu to the Fox Canyon aquifer ranged from 0.012 feet/feet in the forebay to 0.390 feet/feet adjacent to Highway 1 (Figure 2-16 and Table 2-2). In the fall of 2015, the downward vertical gradient from the Mugu aquifer to the Fox Canyon aquifer ranged from 0.620 feet/feet in the forebay to 0.028 feet/feet south of Hueneme Road.

In the spring of 2015, the downward vertical gradient from the Hueneme aquifer to the Fox Canyon aquifer was similar geographically, ranging from 0.014 feet/ feet in the forebay and along the coast north of Port Hueneme to 0.040 feet/feet adjacent to the coast at Port Hueneme (Table 2-2). In the fall of 2015, the vertical hydraulic gradient between the Hueneme and Fox Canyon aquifers ranged from 0.050 feet/feet downward along the coast near Port Hueneme to 0.032 feet/feet upward in the forebay (Table 2-2).

Within the Fox Canyon Aquifer, a downward vertical gradient of 0.005 feet/feet was calculated for wells 01N22W36K06S and 01N22W36K07S in the spring of 2015. The vertical hydraulic gradient in these wells, near Point Mugu, was 0.019 feet/feet downward in the fall of 2015. In the forebay area, the vertical hydraulic gradient within the Fox Canyon aquifer is 0.014 feet/feet downward in the spring of 2015 and 0.022 feet/feet upward in the fall of 2015 (Table 2-2; wells 02N21W07L04S and 02N21W07L06S). The reversal in the direction of the gradient is likely a reflection of the combined influence of surface water spreading in the spring, and groundwater production from the lower Fox Canyon aquifer in the fall.

Groundwater elevations in the Fox Canyon Aquifer are higher than those in the underlying Grimes Canyon Aquifer, except adjacent to Port Hueneme in wells 01N22W28G04S and 01N22W28G05S (Table 2-2).

Historical Groundwater Elevation Trends

Groundwater elevations in the Fox Canyon aquifer have declined and recovered over climatic cycles (Figure 2-18). Groundwater elevation trends in well 01N22W26K04S, the well with the longest historical groundwater elevation record in the Fox Canyon aquifer, match the trends observed in the record of cumulative departure from the mean precipitation on the Oxnard Plain

(Figure 2-18). Declines in groundwater elevation occur between 1974 and 1977, 1984 and 1990, and 2011 and 2016, coincident with periods of drought shown in the declining limb of the cumulative departure from the mean precipitation curve (Figure 2-18). Groundwater elevations recover after each drought period. The amount of recovery depends on the length of time between droughts and the amount of precipitation received in each of the water years between the droughts. In 1999, water levels exceeded the previous maximum in 1983 (Figure 2-18). Since 2011, groundwater elevations in this well have declined approximately 50 feet.

The patterns of water level decline and recovery observed in well 01N22W26K04S are observed in Fox Canyon aquifer wells throughout the Oxnard Subbasin although absolute changes in water level vary geographically within the Oxnard Subbasin (Figure 2-18). Well 01N22W26K04S is located south of Hueneme Road. Other wells this area experienced similar water level declines and recoveries to those observed in well 01N22W26K04S (Figure 2-18). Water levels in wells farther inland tend to have larger intra-annual variations in water level (e.g. Wells 01N21W06J05S and 01N21W09C04S; Figure 2-18). The groundwater elevation in these wells declines by 40 to 50 feet each year between the spring high and fall low water levels. In contrast, well 01N23W01C02S, adjacent to the coast decline approximately 5 feet between the spring high and fall low water level (Figures 2-16, 2-17, and 2-18).

2.3.1.5 Grimes Canyon Aquifer

Spring and Fall 2015 Groundwater Elevations

Only six wells in the Oxnard Subbasin are screened solely within the Grimes Canyon aquifer. These wells are located in the southern part of the Subbasin, west of Revolon Slough (Figure 2-19). In the spring of 2015, groundwater elevations in the Grimes Canyon Aquifer ranged from -31.3 feet to -75.6 feet amsl (Figure 2-19). In the fall of 2015, groundwater elevations ranged from -38.6 feet amsl to -114.2 feet amsl (Figure 2-20).

Where measured, groundwater in the Grimes Canyon Aquifer flows to the east - northeast from the coast toward the Revolon Slough (Figures 2-19 and 2-20). In the spring of 2015, the hydraulic gradient in the vicinity of Point Mugu was approximately 0.003 feet/feet (Figure 2-19). In the fall of 2015, the hydraulic gradient was approximately 0.008 feet/feet (Figure 2-20).

There is a large degree of uncertainty associated with the groundwater elevation contours, hydraulic gradient, and groundwater flow direction in the Grimes Canyon aquifer in the spring and fall of 2015 because so few wells are screened solely within the Grimes Canyon aquifer. The direction of flow, as contoured by the wells that are screened within the Grimes Canyon aquifer likely reflects the LAS groundwater production south of Hueneme Rd (Figure 2-6). However, no wells are screened solely within the Grimes Canyon aquifer north of Hueneme

Road and, therefore, the groundwater elevation, hydraulic gradient and direction of flow in the Grimes Canyon aquifer is unknown for much of the Oxnard Subbasin.

Vertical Gradients

Groundwater elevations in the Grimes Canyon Aquifer are, generally, lower than those in the overlying Fox Canyon aquifer, except adjacent to Port Hueneme in wells 01N22W28G04S and 01N22W28G05S (Table 2-2). The downward vertical hydraulic gradient in the spring of 2015 ranged from 0.047 feet/feet downward at wells 01N21W32Q04S and 01N21W32Q05S to 0.01 feet/feet upward wells 01N22W28G04S and 01N22W28G05S (Table 2-2). Vertical hydraulic gradients were similar in the fall of 2015, ranging from 0.044 feet/feet downward to 0.019 feet/feet upward, in the same wells.

Only well cluster 01N21W32Q has two wells screened within the Grimes Canyon aquifer (Figure 2-119). Within the Grimes Canyon Aquifer, the vertical hydraulic gradient was 0.084 feet/feet upward in both the spring and fall of 2015 (Table 2-2).

Historical Groundwater Elevation Trends

Groundwater elevations in the Grimes Canyon Aquifer have been measured since 1989. Similar to the water levels in the overlying Fox Canyon Aquifer, the water levels in the Grimes Canyon Aquifer recovered between 1990 and 1996 (Figure 2-21). Between 1996 and 2010, groundwater elevations were relatively stable, with intra-annual variation of up to 80 feet per year, but inter-annual variation of 10 feet or less. Between 2011 and 2015 groundwater elevations in the Grimes Canyon aquifer declined, coincident with a period of drought. Groundwater elevations in wells 01N22W28G01S and 01N22W35E01S vary less than groundwater elevations in other Grimes Canyon aquifer wells because they are adjacent to the coast (Figure 2-19 and 2-21).

2.3.2 Estimated Change in Storage

Estimated monthly change in storage values for the Oxnard Subbasin were generated by the numerical groundwater flow model prepared by UWCD (UWCD pers com. D. Ritter). Monthly data reported from the model was summed to get the annual change in storage for the period from water year 1986 to water year 2015. The average annual change in storage in the Oxnard Subbasin was a decrease in storage of approximately 2,000 acre-feet per year. The maximum annual increase in storage was 91,390 acre-feet in water year 1993, and the maximum annual decrease in storage was 47,178 acre-feet in water year 1987 (Figure 2-22). The cumulative change in storage in the model over the period of record was a loss of 59,808 acre-feet (Figure 2-23). Pumping in FCGMA is reported on a calendar year basis, so pumping and spreading in figures is per calendar year, while change in storage is per water year. Change in storage does not appear to be strongly correlated to groundwater pumping in the Oxnard plain. Spreading at the UWCD spreading grounds appears to have a much larger effect on change in storage (Figures 2-24 and 2-25).

Model change in storage is dependent on several input parameters to the model, which include groundwater pumping, artificial aquifer recharge, interbasin flows, recharge from precipitation and irrigation returns, stream leakage and groundwater discharge to streams, and inflows from the ocean. Numbers may also initially be biased due to assumptions about the head of water in the aquifer at the start of the model. These inputs were estimated using the best available data and calibrated to water levels in the model to the greatest extent possible. Changes in calculations for these input values, along with continued model calibration, will result in changes in the model estimate of change in storage in the future.

2.3.3 Seawater Intrusion

Seawater intrusion in the Oxnard Subbasin was originally discovered in the 1930s adjacent to the Hueneme and Mugu submarine Canyons. Under high seaward groundwater gradients, groundwater flows southwest from the Oxnard Forebay Area toward the Pacific Ocean and out to sea. When groundwater heads near the coast fall below sea level, the gradient reverses, drawing seawater into the groundwater aquifers. Seawater intrusion is most prevalent in the vicinity of Port Hueneme and Point Mugu due to the near shore presence of the groundwater - seawater contact in the deeply incised submarine canyons (UWCD 2016). The general extent of the Oxnard Subbasin seawater intrusion is shown on Figure 2-26. The location of Figure 2-26 is shown on Figure 2-2.

In addition to seawater intrusion, saline intrusion from brine migration can also degrade water quality in the Oxnard Subbasin. Groundwater level declines can cause compaction of aquitards, which can expel connate brines and, in the deeper aquifers create low pressure conditions that promote both the migration of brines along faults and the upwelling of brines from deeper formations (UWCD 2016).

As described in Section 2.2, the aquifers of the Oxnard Subbasin are designated as belonging to the Semi-Perched Aquifer, the UAS (the Oxnard and Mugu Aquifers), or the LAS (the Hueneme, Fox Canyon, and Grimes Canyon Aquifers). Each aquifer system is composed of different geological units with different aquifer characteristics. Both of the main groundwater production aquifer systems (UAS and LAS) have been subject to historic seawater intrusion. Although relatively little water quality data exist for the Semi-Perched Aquifer, groundwater quality is generally believed to be of poorer quality and is rarely used for supply purposes (UWCD 2016). Groundwater from the UAS and LAS is produced for several beneficial uses.

Historical Progression of Seawater Intrusion

Both seawater and saline water intrusion have occurred in the Oxnard Subbasin since the 1930s, particularly during periods of prolonged drought. Seawater intrusion can be controlled, or prevented during wet or even average climatic periods. Because seawater intrusion is related to pressure gradients, seawater intrusion is also related to groundwater recharge, groundwater extractions, and groundwater management projects and policies. The combination of these factors has resulted in variable ingress and regress of seawater intrusion over time.

Early aquifer development was primarily focused in the UAS due to the availability of groundwater and the relative ease of extracting it. As groundwater levels dropped, seawater intrusion began. Increased LAS pumping, combined with natural recharge and artificial recharge projects in the Oxnard Forebay, have increased groundwater levels in the UAS resulting in less seawater intrusion. However, seawater intrusion became more significant in the LAS than in the UAS. In order to 1998 FCGMA ordinance prohibited new wells in the LAS in the Oxnard plain area and requires that new wells extract water from the UAS in order to take advantage of the more easily recharged UAS.

Although the major aquifer units in the Oxnard Subbasin are separated by low-permeability units, vertical gradients between aquifers can result in vertical groundwater movement between most of the major aquifers (UWCD 2016). This groundwater movement can occur through the aquitards that separate the various aquifer units and through wells that are screened across both the UAS and LAS. In particular, a downward gradient is created when LAS groundwater levels are substantially lower than UAS groundwater levels (UWCD 2016). This gradient can result in leakage of UAS groundwater into the LAS. Similarly, when heads in the UAS are lower than heads in the Semi-Perched Aquifer, a downward pressure gradient can exist. Heads are lowered in the UAS either regionally by drought conditions or locally by pumping wells (UWCD 2016).

Historical documentation of seawater intrusion in the Oxnard Subbasin started in 1965 with the California Department of Water Resources and County of Ventura Public Works Agency documenting chloride concentrations in water from wells in the UAS. Table 2-3 lists historical seawater intrusion reports and studies for the Oxnard Subbasin.

Table 2-3
Seawater/Saline Water Historical Reports and Studies

Title	Author/Agency	Date
Sea Water Intrusion, Oxnard Plain Ventura County	California Department of Water Resources	October, 1965
Sea-Water Intrusion: Aquitards in the Coastal Ground Water Basin of Oxnard Plain, Ventura County	California Department of Water Resources, Bulletin No. 63-4	September, 1971
Oxnard Plain Groundwater Study	State Water Resources Control	March, 1979

	Board	
Chloride Sources in a California Aquifer	John A. Izbicki	July, 1991
A Study of Seawater Intrusion Using Direct-Current Soundings in the Southeastern Part of the Oxnard Plain, California	United States Geological Survey, Open File Report 93-524	1993
Seawater Intrusion in a Coastal California Aquifer	USGS	July, 1996
Mugu Seawater/Saline Water Intrusion Monitoring Program, AB303 Grant, Agreement No. 4600004100	UWCD	April 2007
Saline Intrusion Update, Oxnard Plain and Pleasant Valley Basins	UWCD	October, 2016

Current Seawater/Saline Intrusion Status

In the fall of 2015, known seawater and saline intrusion in the UAS and LAS generally occurs near and southeast of Port Hueneme and in the area surrounding Mugu Lagoon. The extent of the fall 2015 seawater and saline intrusion in the Semi-Perched Aquifer and in the Oxnard and Mugu Aquifers (UAS), and the Hueneme, Fox Canyon, and Grimes Canyon Aquifers (LAS) are shown on Figures 2-27 to 2-32 as the 2016 interpreted saline water intrusion inland extent line. The exact extent of saline impacts to the various confined aquifers of the Oxnard Plain is difficult to determine from the existing network of coastal monitoring wells (UWCD 2016).

2.3.4 Groundwater Quality

FCGMA has adopted Basin Management Objectives (BMOs) for nitrate (mg/L as nitrate, or NO_3), chloride (Cl) and total dissolved solids (TDS) in the Oxnard Subbasin (FCGMA 2007). Additionally, the Water Quality Control Plan: Los Angeles Region (“Basin Plan”) specifies Water Quality Objectives (WQOs) for sulfate (SO_4), and boron (B) (LARWQCB 2013). The current and historical distribution of these five constituents are discussed below, based on aquifer system, rather than individual aquifer. There are too few measurements of water quality in wells screened solely within a single aquifer to allow for meaningful discussion of water quality by aquifer. Additionally, as discussed in Section 2.3.1, the majority of the groundwater production in the Oxnard Subbasin occurs in wells that are screened across multiple aquifers. This production has the potential to impact water quality in multiple aquifers simultaneously. Therefore, impacts to groundwater quality in the Subbasin should be considered based on aquifer system, rather than by individual aquifer.

Groundwater quality monitoring within the Oxnard Subbasin occurs at different intervals for different wells. In order to assess the current groundwater quality conditions within the Subbasin, the most recent concentration of each of the five constituents listed above was plotted for samples collected between 2011 and 2015. Historical groundwater quality hydrographs are presented in Appendix B. Statistics on the most recent sample date, the maximum and minimum concentrations measured, the number of times sampled, and the number of samples whose concentration exceeded two standard deviations from the mean are presented in Appendix C.

2.3.4.1 Total Dissolved Solids

Upper Aquifer System

The water quality objective for total dissolved solids (TDS) is 1,200 milligrams per liter (mg/L) in the forebay and confined aquifers, and 3,000 mg/L in the unconfined aquifers (LARWQCB 2013). The basin management objective for TDS is 1,200 mg/L for the forebay (FCGMA 2007). Concentration of TDS in groundwater in the UAS ranged from 652 to 49,600 mg/L between 2011 and 2015 (Figures 2-33A and 2-33B). Both the highest and lowest concentrations of TDS were measured adjacent to the coast in wells 01N22W27R05S and 01N22W27C02S, respectively (Figure 2-33A). There is no clear pattern of TDS distribution within the UAS. The majority of the wells in the UAS had concentrations of TDS below 1,500 mg/L, however wells with concentrations of TDS greater than 1,500 mg/L are found throughout the Oxnard Subbasin.

Lower Aquifer System

Concentration of total dissolved solids (TDS) in groundwater in the LAS ranged from 392 to 37,200 mg/L between 2011 and 2015 (Figure 2-34). The highest concentration was measured in well 01N21W32Q03S, which is in the southern Subbasin, inland from the coast, and is screened within the Grimes Canyon aquifer (Figure 2-34). The higher concentration of TDS in this area likely resulted from upward migration of brines in deeper formations, induced by lowered groundwater elevations from groundwater production in the LAS (Izbicki 2005; UWCD 2016). The lowest concentration was measured in well 01N22W35E03S, screened in the Fox Canyon aquifer south of Point Hueneme (Figure 2-34). In general, TDS concentrations in the LAS are higher in the southern Oxnard Subbasin than in the northern part of the subbasin (Figure 2-34).

2.3.4.2 Chloride

Upper Aquifer System

The water quality objective for chloride is 150 mg/L in the forebay and confined aquifers, and 500 mg/L in the unconfined aquifers (LARWQCB 2013). The basin management objective for chloride is 150 mg/L for the UAS.

Concentration of chloride in groundwater in the UAS ranged from 23 to 20,700 mg/L between 2011 and 2015 (Figures 2-35A and 2-35B). The highest concentration of chloride was measured in well 01N22W27R05S, adjacent to the coast south of Point Hueneme (Figure 2-35A). Groundwater from this well also had the highest concentration of TDS. The lowest concentration of chloride was measured in well 01N22W11C02S in the central Oxnard Subbasin (Figure 2-35A). Chloride concentrations in the UAS are higher near the coast, from Point Hueneme south to Point Mugu, than they are inland or north of Point Hueneme (Figure 2-35A). In the forebay, the concentration of chloride is less than 150 mg/L (Figure 2-35B).

The UAS has a long history of seawater intrusion, with groundwater elevations below sea level measured as early as the 1930s (see Section 2.3.3; UWCD 2016). Flow from the ocean into the aquifer is the cause of the high chloride concentrations in the UAS.

Lower Aquifer System

The water quality objective for total chloride is 150 mg/L in the forebay and confined aquifers, and 500 mg/L in the unconfined aquifers (LARWQCB 2013). The basin management objective for chloride is 150 mg/L for the LAS.

Concentration of chloride in groundwater in the LAS ranged from 33 to 14,300 mg/L between 2011 and 2015 (Figures 2-36). The lowest concentration of chloride was measured in well 01N23W01C02S on the coast, north of Point Hueneme (Figure 2-36). The highest concentration of chloride was measured in well 01N21W32Q03S, in the southern Oxnard Subbasin (Figure 2-36). Groundwater quality in this well is likely impacted from upward migration of brines, induced by groundwater production in the LAS.

In general, chloride concentrations in the LAS are higher in the southern Oxnard Subbasin than they are elsewhere in the Oxnard Subbasin (Figure 2-36). In the forebay, the concentration of chloride in groundwater is less than 100 mg/L, while concentrations of chloride south of Point Hueneme exceed 500 mg/L (Figure 2-36). Seawater intrusion affects a smaller area of the LAS than the UAS, and is more pronounced near Point Mugu than near Point Hueneme (UWCD 2016).

2.3.4.3 Nitrate

Upper Aquifer System

The basin management objective for nitrate is 22.5 mg/L in the forebay (FCGMA 2007). The water quality objective for nitrate as NO_3 is 45 mg/L for the entire Oxnard Subbasin (LARWQCB 2013). Concentration of nitrate as NO_3 in groundwater in the UAS ranged from below the detection limit (ND) to 240 mg/L between 2011 and 2015 (Figures 2-37A and 2-37B).

The highest concentration was measured in well 02N22W26C01S in the forebay (Figure 2-37B). In general, nitrate as NO_3 concentrations are highest in the southern forebay and northeastern Oxnard Subbasin. The lowest concentrations are found in the southern Oxnard Subbasin, with the concentration of nitrate below the detection limit in the majority of the wells in the southern Subbasin (Figure 2-37A).

Lower Aquifer System

Concentration of nitrate as NO_3 in groundwater in the LAS ranged from below the detection limit to 57 mg/L between 2011 and 2015 (Figure 2-38). The highest concentration was measured in well 02N21W19A03S, in the northeastern Oxnard Subbasin. The majority of the wells in the LAS have nitrate as NO_3, concentrations below the detection limit. In the forebay, the concentration of nitrate as NO_3, is lower in the LAS than it is in the UAS (Figures 2-37B and 2-38).

2.3.4.4 Sulfate

Upper Aquifer System

The water quality objective for sulfate is 600 mg/L in the forebay and confined aquifers, and 1,000 mg/L in the unconfined aquifers (LARWQCB 2013). Concentrations of sulfate in the UAS ranged from 100 to 5,740 mg/L between 2011 and 2015 (Figures 2-39A and 2-39B). The highest concentration was measured in well 01N22W27R05S, which also had the highest concentration of chloride and TDS. The lowest concentration was measured in well 01N22W36K09S, in the southern Oxnard Subbasin. The majority of the wells in the Oxnard Subbasin have sulfate concentrations below 600 mg/L. Similar to nitrate, wells in the forebay tend to have higher concentrations of sulfate than wells farther south, with the notable exception of wells 01N22W27R05S and 01S21W08L04S (Figure 2-39A).

Lower Aquifer System

Concentrations of sulfate in the LAS ranged from below the detection limit to 2,030 mg/L between 2011 and 2015 (Figure 2-40). The highest concentration was measured in well 01N21W32Q03S, which also had the highest concentration of chloride and TDS. Only four wells in the LAS had concentrations of sulfate that exceeded 600 mg/L. These wells are distributed throughout the Oxnard Subbasin and do not follow a clear geographic pattern. Similar to nitrate, LAS wells in the forebay have lower concentrations of sulfate than UAS wells in the forebay (Figures 2-40).

2.3.4.5 Boron

Upper Aquifer System

The water quality objective for boron in the Oxnard Subbasin is 1 mg/L (LARWQCB 2013). Concentrations of boron in the UAS ranged from 0.05 to 5.9 mg/L between 2011 and 2015 (Figures 2-41A and 2-41B). The highest concentration was measured in well 01N22W27R05S, which also had the highest concentrations of sulfate, chloride and TDS. The lowest concentration was measured in well 02N22W24A01S, in the northeastern Oxnard Subbasin (Figure 2-41A). Only seven wells in the UAS had boron concentrations greater than 1 mg/L between 2011 and 2015.

Lower Aquifer System

Concentrations of boron in the LAS ranged from 0.3 to 2.2 mg/L between 2011 and 2015 (Figure 2-42). The highest concentration was measured in well 01N21W32Q03S, which also had the highest concentrations of sulfate, chloride, and TDS. Only five wells in the LAS had boron concentrations greater than 1 mg/L between 2011 and 2015.

2.3.4.6 Map of Oil and Gas Deposits

In the database maintained by the County of Ventura, four oil fields entirely or partially fall within the Oxnard Subbasin: Montalvo, W.; Oxnard; El Rio; Santa Clara Avenue; and Saticoy (Figure 2-43).

2.3.4.7 Maps of Locations of Impacted Surface Water, Soil, and Groundwater

Impaired surface waters (i.e., 303[d] Listed Reaches) that overlie the Oxnard Subbasin include approximately 3 miles of the Santa Clara River, the Revolon Slough, Calleguas Creek, and a number of lined drains serving agricultural areas south of the City of Oxnard (Figure 2-44; SWRCB 2004).

Locations of impacted soil and groundwater were assessed on a basin-wide scale by reviewing information available on the California SWRCB Geotracker website and the California Department of Toxic Substances Control (DTSC) EnviroStor website. Cases that were closed by the supervisory agency were not considered.

Of the 290 open cases located within the boundaries of the Oxnard Subbasin and Pleasant Valley, groundwater was impacted in 77. Dudek reviewed and catalogued the Constituents of

Concern (COCs) present on site in these 77 cases (Figure 2-45). Case details are included in Table 2-4 in Appendix D.

Of the 71 open cases in the Oxnard Plain in which groundwater is or is potentially impacted, the following COCs were identified as present at the following number of sites (Figure 45, Appendix D):

- Chlorinated VOCs, including COCs marked as “solvents,” “VOCs,” “chlorinated hydrocarbons,” and “chlordane,” were present at 34 sites
- Gasoline and diesel, including COCs marked “TPH” and “petroleum,” were present at 32 sites
- Metals were present at 27 sites
- PCBs were present at 23 sites
- Benzene, Toluene, Ethylbenzene and/or Xylenes (BTEX) were present at 18 sites
- Pesticides were present at 12 sites
- Methyl tert-butyl ethylene (MTBE) and/or tert-butyl alcohol (TBA) were present at seven sites
- Two sites listed other COCs

Many of these sites are located on land administered by the U.S. military (Figure X). Outside of military bases, these sites tend to occur within the city limits of the Cities of Oxnard, Port Hueneme, and Camarillo.

The risk that contamination in the shallow groundwater of the Oxnard Subbasin would reach the UAS is mitigated by the presence of a confining layer that separates the semi-perched zone from the water-bearing units of the UAS throughout much of the Oxnard Plain (Turner and Mukae 1975).

Based on a review of open Geotracker and EnviroStor cases with impacted groundwater, it does not appear that existing groundwater contamination in the perched aquifer poses a substantial threat to beneficial use of groundwater in the UAS and LAS.

2.3.5 Subsidence

Inelastic, or irrecoverable, land subsidence (subsidence) is a concern in areas of active groundwater extraction, including the Oxnard Subbasin. Active causes of land subsidence in the Oxnard Subbasin include tectonic forces, petroleum reservoir compaction, and aquifer compaction (Hanson et al. 2003). Significant water level declines in the FCGMA groundwater basins since the early 1900s suggest that fluid extraction, rather than tectonic activity, is the major cause of land subsidence (Hanson et al. 2003). Subsidence resulting from any of these sources can cause increased flood risk, well casing collapse, and a permanent reduction in the specific storage of the aquifer.

Direct measurement of subsidence within the Oxnard Subbasin is limited. Elevation data from U.S. Geological Survey (USGS) bench mark (BM) E548 in the southern part of the Oxnard Plain indicate subsidence of about 1.6 feet (0.49 meter) during the period from 1939 to 1960, and an additional 1 foot (0.31 meters of subsidence from 1960 to 1978 (Hanson et al. 2003). The average rate of subsidence for these two time periods was similar, averaging approximately 0.07 feet (0.02 meter) per year from 1939 to 1960, and approximately 0.06 feet (0.02 meter) per year from 1960 to 1978 (Hanson et al. 2003). In contrast elevation data from USGS BM Z901, located approximately 2.6 miles southeast of BM E548, indicate subsidence of approximately 0.3 feet (0.10 meters) between 1960 and 1978. The average rate of subsidence at BM E548 was 0.02 feet (0.01 meters) per year for this time period. The rate of subsidence at BM Z901 decreased to approximately 0.01 feet per year from 1978 to 1992. Data are not available for BM E548 after 1978.

In addition to direct measurement of subsidence in the southern part of the Oxnard Plain, potential subsidence was modeled for the entire Oxnard Plain for different future water production scenarios (Hanson et al. 2003). The scenarios included consideration of proposed water projects and ordinances for the FCGMA Basins. The model results suggest that areas within the Oxnard Plain may experience an additional 0.1 to 1 feet of subsidence by 2040 (Hanson et al. 2003). This estimate agrees with the DWR, which designated the Oxnard Plain as an area that has a medium to high potential for future subsidence. The amount of future subsidence will depend on whether future water levels decline below previous maximum declines or remain above these previous low levels (Hanson et al. 2003). Maintaining water levels above the previous low water levels will limit future subsidence.

2.3.6 Groundwater–Surface Water Connections

The Santa Clara River, Calleguas Creek, Revolon Slough, Mugu Lagoon, Ormond Beach, and McGrath Lake have all been identified as surface water bodies that may have a connection to shallow groundwater in the Oxnard Subbasin. However, shallow groundwater elevation data for the Oxnard Subbasin are extremely limited, with no monitoring sites near enough to surface water bodies to establish the extent of the connection between these surface water bodies and underlying groundwater. The best available data for groundwater-surface water connections comes from the UWCD numerical model, which simulates the leakage from major surface water bodies in the Oxnard Subbasin using data from streamgages and estimated aquifer properties. The UWCD model reports stream leakage from the Santa Clara River and Calleguas Creek into the underlying shallow aquifer. Numbers from the model represent net stream leakage, and do not necessarily indicate direct connection between surface water bodies and groundwater in the shallow aquifer system. Model boundaries do not necessarily coincide with the boundaries of FCGMA. As a result, stream leakage numbers include leakage to portions of the shallow aquifer that lie outside of the jurisdiction of the FCGMA.

The UWCD model calculated stream percolation for water years from 1986 to 2015 (Table 2-5). The Santa Clara River had net recharge to groundwater in 25 of 30 water years, with an average net recharge to groundwater of ~13,000 acre-feet per year. The 5 years of groundwater discharge to the Santa Clara River were 1987, 1999, 2002, 2007, and 2013. Conejo Creek exhibited net recharge to groundwater in all years modeled, with an average net recharge to groundwater of ~4,700 acre-feet per year.

Table 2-5
Modeled Surface Water Percolation from Streams in the Oxnard Subbasin

Water Year	Santa Clara River Percolation*	Calleguas Creek Percolation
1986	23105	4418
1987	-391	1366
1988	16296	3616
1989	306	2124
1990	305	1373
1991	10639	1972
1992	26553	5945
1993	51163	7191
1994	12024	3166
1995	25402	6497
1996	5711	3829
1997	12734	4145
1998	15647	8661
1999	-685	5057
2000	13072	5126
2001	14574	6783
2002	-1307	5274
2003	24181	5741
2004	6811	3641
2005	38176	9018
2006	3344	6103
2007	-825	4323
2008	18075	6099
2009	8833	5119
2010	26855	5367

2011	26176	7015
2012	7052	4848
2013	-880	2541
2014	5789	1568
2015	1312	2223
AVERAGE	13002	4672

*Negative numbers represent discharge of groundwater to the stream.

2.3.7 Groundwater Dependent Ecosystems

Six groundwater dependent ecosystem (GDEs) units were identified in the Oxnard Groundwater Subbasin (TNC 2017a). They are defined by dominant hydrologic features and identified as the lower Santa Clara River downstream of the Oxnard Forebay and upstream of the estuary, McGrath Lake, Ormond Beach wetlands, Mugu Lagoon, lower Calleguas Creek, and Revolon Slough GDEs (Figure 2-46). The GDE units were identified using the statewide potential GDE map (pGDE v0.3.1, TNC 2017b) and groundtruthed using local information to confirm the potential hydrologic connection to groundwater, as described in The Nature Conservancy's GDE Guidance Framework (Rohde et al. 2017). The statewide map of potential GDEs is based on best available statewide data on phreatophytic vegetation (i.e., vegetation known to use groundwater) (US NBVC 2013; US FS 2014) and wetlands identified in the National Wetland Inventory Inventory (US FWS 2016). The statewide potential GDE map was groundtruthed using aerial photos, local knowledge, and field verification and an assessment of the hydrologic connection to groundwater (TNC 2017a).

Lower Santa Clara River GDE

The lower Santa Clara River GDE (located downstream of Highway 101 and upstream of the estuary) is comprised of approximately 1,300 acres of aquatic habitat, in-channel wetland, and a range of willow-cottonwood riparian forest patches with mulefat and willow scrub, and invasive Arundo donax within the 1,000 to 1,500 foot-wide leveed lower Santa Clara River corridor. Arroyo willow and black cottonwood are focal phreatophytic species for the riparian forests of the Santa Clara River and preferentially occur in reaches with shallow groundwater, which provide a reliable summer source of water (Ventura 2016). The GDE is located in the floodplain of the lower Santa Clara River, which undergoes substantial transformations in vegetation composition and distribution due to the dynamic nature of the river flows during winter. For example, the January and February 2005 winter floods scoured the active channel and floodplain terraces down to bare riverwash. By 2009, recolonization by herbaceous vegetation transformed to willow and cottonwood alliances and arundo, (Ventura 2011). This successional pattern is typical of southern California rivers.

The lower Santa Clara River GDE supports a rich community of species including habitat for the state and federally listed endangered least Bell's vireo and salt marsh bird's beak; critical habitat for the state and federally- listed southwestern willow flycatcher and federally listed threatened western snowy plover. The river is also critical habitat for the federally listed endangered Southern California steelhead and federally- listed endangered tidewater goby. The area is listed as an Audubon California Important Bird Area, 1,200 acres of wetlands are listed in the National Wetland Inventory, and the RWQCB listed beneficial uses include: Wildlife Habitat (WILD), Rare, Threatened, or Endangered Species (RARE), Migration of Aquatic Organisms (MIGR), Spawning, Reproduction, and/or Early Development (SPWN), and Wetlands (WET). An inventory of ecological assets is listed in Table 2-6.

The lower Santa Clara River downstream of Highway 101 has historically been a perennial stretch of the Santa Clara River with extensive historical riparian willow-cottonwood forest and freshwater wetland complex, both of which were supported during the dry summer with groundwater (Beller et al., 2011). Based on studies over the past 20 years, groundwater flow direction between the semi-perched aquifer and the lower Santa Clara River, its estuary and nearby McGrath Lake, depends on tidal conditions, river stage and recharge rates due to agricultural irrigation (Stillwater Sciences, 2016a). Groundwater levels from wells in the vicinity of the lower Santa Clara River GDE generally range between 7 and 11 feet below ground surface (bgs) (Figure 2-47). The years 2006 to 2015 generally represent a dry period of record, with the latter 5 representing drought climatic conditions. The levels have been relatively constant across the 10 years of available monitoring in well 02N22W30A03S. A typical seasonal variation of 2 feet is shown in the groundwater depth data from well GW-04. The groundwater depths are within the range considered necessary for juvenile establishment (< 10 feet) and mature vegetation growth (<20 feet) (Stillwater Sciences 2016a).

This reach of the Santa Clara River is generally considered a gaining reach (Stillwater Science 2016a). Streamflow records from Station 723 at Victoria Avenue (2008-2015) indicate summer dry season flows less than 0.5 cfs (for 2008, 2009, 2011) to no flow. Low flow conditions may occur more often than recorded, as Station 723 was designed and calibrated as a peak-flow flood-control gage. A water balance assessment conducted by Stillwater Sciences (2011) for the Santa Clara River Estuary for water year 2010 provides some quantification of current hydrologic conditions, although it should be noted the estuary itself is located in the Mound Groundwater Basin and includes components such as the VWRF effluent. For the fall/winter period, groundwater was estimated to contribute approximately 15 percent of the inflow volume, which itself was dominated by Santa Clara River inflow (45% of the total volume) and Ventura Water Reclamation Facility (RFWF) effluent (35% including groundwater flow via the VFWF Wildlife Ponds). Stillwater Sciences (2011) found that for summer/spring 2010 period, the groundwater contribution was estimated at 10 percent, with majority from the VWRF. For this reach of the

Santa Clara River upstream of the estuary, groundwater provides the dry summer baseflow, if it exists, and a quarter of the winter flow based on the 2010 water year assessment.

Table 2-6 Ecological Assets

Ecological Assets	Lower Santa Clara River	McGrath Lake	Ormond Beach Wetlands	Mugu Lagoon and Wetlands	Lower Calleguas Creek	Revolon Slough
List any locally important, special status, rare, threatened, or endangered plants or animals supported by the GDE	Santa Ana sucker; western pond turtle; tidewater goby; coast horned lizard; white rabbit-tobacco; Southern Riparian Scrub; least Bell's vireo (CNDDB, 2016) steelhead	Belding's savannah sparrow; burrowing owl; California least tern; least Bell's vireo; salt marsh bird's-beak; sandy beach tiger beetle; silvery legless lizard; Ventura Marsh milk-vetch (CNDDB, 2016). Sandy beach tiger beetle, brown pelican, Western least bittern, white-faced ibis, osprey, white-tailed kite, Northern harrier, sharp-shinned hawk, Cooper's hawk, Light-footed clapper rail, Western snowy plover, long-billed curlew, California least tern, Western yellow-billed cuckoo, burrowing owl, Southwestern willow flycatcher, loggerhead shrike, Least Bell's Vireo, yellow warbler, yellow-breasted chat, Belding's Savannah sparrow, Calfironia red-legged frog, Southwestern pond turtle, silvery legless lizard, San Diego horned lizard, two-striped garter snake, South coast garter snake, Townsend's big-eared bat (Table 3-2, ESA, 2003)	Belding's savannah sparrow; California least tern; Coulter's goldfields; California brackishwater snail; salt marsh bird's-beak; tidewater goby; western snowy plover (CNDDB, 2016). Western Snowy Plover, California Least Tern, California Brown Pelican, Light-footed Clapper Rail, Least Bell's Vireo. Southern California saltmarsh shrew, San Diego black-tailed jackrabbit, Double-crested Cormorant, American Bittern, Great Blue Heron, Great Egret, Snowy Egret, Black-crowned Night Heron, White-faced Ibis, White-tailed Kite, Northern Harrier, Cooper's Hawk, Sharp-shinned Hawk, Merlin, Mountain Plover, Long-billed Curlew, Western Burrowing Owl, Loggerhead Shrike, Yellow warbler, California Horned Lark, Tricolored Blackbird, South Coast garter snake, tiger beetle, sandy beach tiger beetle, wandering skipper, globose dune beetle, red sand-verbena, spiny rush, , and woolly seablite. (WRA, 2007)	arroyo chub; Belding's savannah sparrow; burrowing owl; California brown pelican; California least tern; Coulter's goldfields; estuary seablite; ferruginous hawk; globose dune beetle; least Bell's vireo; light-footed clapper rail; salt marsh bird's-beak; sandy beach tiger beetle; senile tiger beetle; Southern Coastal Salt Marsh; tidewater goby; wandering (=saltmarsh) skipper; western snowy plover (CNDDB, 2016). peregrine falcon	arroyo chub; two-striped gartersnake; least Bell's vireo (CNDDB, 2016).	Arroyo chub (CNDDB, 2016); least Bell's vireo (Dellith, 2017)

Describe whether the GDE provides important or critical habitat for native species (Source- CH, 2016)	Southwestern willow flycatcher critical habitat (569 acres); Tidewater goby critical habitat (22 acres);-Western snowy plover critical habitat (35 acres); Steelhead critical habitat; Audubon California Important Bird Area	Southwestern willow flycatcher critical habitat (32 acres); Tidewater goby critical habitat (18 acres); Ventura Marsh Milk-vetch critical habitat (78 acres); Audubon California Important Bird Area	Tidewater goby critical habitat (88 acres); Western snowy plover critical habitat (26 acres); Audubon California Important Bird Area	Western snowy plover critical habitat (51 acres); Wetland of Regional Importance in the Western Hemisphere Shorebird Reserve Network; Essential Fish Habitat (EFH) and Habitat Areas of Particular Concern (HAPC) are designated for Pacific Coast Groundfish and Coastal Pelagic Species in the nearshore marine and estuarine habitats; Laguna Point to Latigo Point Area of Special Biological Significance. Audubon California Important Bird Area	no	no
Describe whether any portion of the GDE is a recognized wetland (Sources- NWI, 2016; pGDE, 2016)	1,180 acres (93%)	197 acres (71%)	207 acres (96%)	5,943 acres (93%)	6 acres (4%)	2 acres (8%)
Describe whether any portion of the GDE part of a protected area, locally-important conservation or wildlife corridor plan (Source: CPAD, 2016)	The Nature Conservancy (160 acres); City of Ventura (1.2 acres)	McGrath State Beach (56 acres); Mandalay State Beach (29 acres); Mandalay County Park (0.7 acres)	The Nature Conservancy (129 acres); Port Hueneme Beach Park (1.3 acres)	Point Mugu State Park (0.1 acres)	no	no

List any environmental beneficial uses designated in the RWQCB Basin Plan for the surface water found in the groundwater basin	• Wildlife Habitat (WILD) • Rare, Threatened, or Endangered Species (RARE) • Migration of Aquatic Organisms (MIGR) • Spawning, Reproduction, and/or Early Development (SPWN) • Wetlands (WET) Also, REC1, REC2	• Estuarine Habitat (EST) • Wildlife Habitat (WILD) • Rare, Threatened, or Endangered Species (RARE) • Wetlands (WET) Also, REC1, REC2	• Estuarine Habitat (EST) • Wildlife Habitat (WILD) • Rare, Threatened, or Endangered Species (RARE) • Wetlands (WET) Also, REC1, REC2	• Estuarine Habitat (EST) • Marine Habitat (MAR) • Wildlife Habitat (WILD) • Preservation of Biological Habitats of Special Significance (BIOL) • Rare, Threatened, or Endangered Species (RARE) • Migration of Aquatic Organisms (MIGR) • Spawning, Reproduction, and/or Early Development (SPWN) • Shellfish Harvesting (SHELL) • Wetlands (WET) ALso, REC1 (potential), REC2	Reach 2: • WARM • COLD • Wildlife Habitat (WILD) • Rare, Threatened, or Endangered Species (RARE) • Wetlands (WET) Also, REC1, REC2	Reach 4 (Revolon Slough): • WARM • Wildlife Habitat (WILD) • Wetlands (WET) Also, REC1, REC2
Is the GDE area comprised of > 30% native vegetation? (Source- pGDE, 2016)	yes	yes	yes	yes	yes	yes

Sources:
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McGrath Lake GDE

The McGrath Lake GDE includes a wide range of hydrologically dependent ecosystems: a coastal freshwater back-dune lake, arroyo willow riparian forest, freshwater emergent marsh, saline emergent marsh covering approximately 280 acres extending southward from the Santa Clara River estuary through McGrath and Mandalay State Beach Parks to Wooley Road (note the estuary itself is not included as it is not in the Oxnard Groundwater Subbasin). The McGrath Lake GDE supports a wide range of habitats for many species, including critical habitat for the endangered plant species Ventura marsh milk-vetch, Southwestern willow flycatcher, and tidewater goby. Many special status bird species, including the federally listed threatened western snowy plover and the state and federally listed endangered California least tern, are known or have the potential to occur in the McGrath Lake GDE (Table 2-6). The GDE is partially protected as McGrath and Mandalay State Beaches (85 acres), 197 acres are delineated as wetlands in the National Wetland Inventory. In addition, the RWQCB lists beneficial uses as WILD, RARE, WET, and estuarine habitat (EST).

As noted above, the McGrath Lake GDE is hydrologically connected to freshwater, estuarine, and groundwater sources. Locally, a clay layer ranging between 3 and 8 feet msl in the semi-perched aquifer causes surface sources to remain perched near the surface (ESA 2003). This shallow groundwater is expressed at the surface at McGrath Lake, with lake recharge rates supplied by agricultural irrigation. McGrath Lake is pumped to reduce the flooding of agricultural fields adjacent to the lake (due to agricultural irrigation and naturally-high groundwater levels), with normal operational water surface elevations maintained between 2.7 and 3.6 feet above mean sea level (Ventura 2011). Groundwater flows toward the Santa Clara River during open-mouth conditions and towards McGrath Lake when the Santa Clara River estuary fills following mouth closure (Ventura 2011). As measured since 2009, depths to groundwater around the McGrath Lake GDE range between ground surface and 10 feet bgs, depending on the well (Figure 2-48). Given management of McGrath Lake, interannual variations are relatively constant, with seasonal variations around 5 feet.

Ormond Beach GDE

The Ormond Beach GDE is comprised of approximately 210 acres of southern coastal salt marsh and coastal freshwater/brackish marsh that are currently in isolated patches of low quality condition (WRA 2007). These remnant wetlands have been drained, filled, and degraded by past industrial and agricultural use. The Nature Conservancy owns 129 acres of these wetlands. The Ormond Beach GDE is part of a larger 1,500 acre coastal dune – marsh system of dunes, lakes, lagoons, salt and freshwater marshes, and is considered to be the most important wetlands restoration project in southern California (CCC 2010). The area hosts over 200 migratory bird species; more shorebird species are known to use Ormond Beach than any other site in Ventura

County. Ormond Beach is located on the Pacific Flyway, is an e-Bird International Hot Spot and is listed as critical habitat for tidewater goby and Western snowy plover. Twenty-seven (27) special status plant species and 42 special status wildlife species have documented presence or a moderate or high potential to occur within the Ormond Beach wetlands GDE including Endangered Belding's Savannah Sparrow, Salt Marsh Bird's-Beak, Least Bell's Vireo, Light-Footed Clapper Rail, Western snowy plover and California least tern (WRA 2007) (Table 2-6). The biological significance of the area is recognized by all 14 federal and state resource agencies participating in the Southern California Wetlands Recovery Project and the County of Ventura and the City of Oxnard (CCC 2017). RWQCB beneficial uses listed for WILD, RARE, WET, and EST.

The Ormond Beach GDE is hydrologically connected to the semi-perched aquifer. Shallow groundwater elevations are influenced by rainfall, tidal events and the surface water elevations of the surface water features such as the agricultural drains and flood control channels Tšumaš (Chumash) Creek (formerly, J Street Drain), Ormond Lagoon Waterway (formerly, the Oxnard Industrial Drain) and Hueneme Drain. Depth to groundwater ranges between 2 and 15 feet bgs in well 01N22W27C04S over the 25 year well record. Levels vary seasonally but are relatively constant across the wetter period (pre-2006); more variation and lower groundwater levels are observed during the drier climatic period (2006-2015). Three other wells located near the Ormond Beach GDE indicate groundwater levels across the Ormond Beach GDE are even shallower, ranging between ground surface and 4 feet bgs, with seasonal variations between 2 to 4 feet (Figure 2-49).

Mugu Lagoon GDE

Mugu Lagoon GDE is comprised of approximately 5,900 acres of wetlands, representing the largest salt marsh estuary in Southern California as delineated in the National Wetland Inventory. The GDE provides habitat for hundreds of thousands of seasonal waterfowl and shorebirds (American Bird Conservancy 2003). Endangered species dependent on this habitat include Belding's Savannah Sparrow, Salt Marsh Bird's-Beak, Least Bell's Vireo, Light-Footed Clapper Rail, Western snowy plover, California least tern, amongst others. Mugu Lagoon has many designated habitats, including Wetland of Regional Importance in the Western Hemisphere Shorebird Reserve Network; Essential Fish Habitat (EFH) and Habitat Areas of Particular Concern (HAPC) for Pacific Coast Groundfish and Coastal Pelagic Species in the nearshore marine and estuarine habitats, and is part of the Laguna Point to Latigo Point Area of Special Biological Significance (Table 2-6). The Regional Water Quality Control Board (RWQCB) beneficial uses listed for WILD, RARE, WET, EST, MIGR, SPWN, Marine Habitat (MAR), Preservation of Biological Habitats of Special Significance (BIOL), and Shellfish Harvesting (SHELL).

The water table of the semi-perched aquifer varies between ground surface and 6 feet below ground surface across Mugu Lagoon GDE (see Figure 2-50). The figures present the estimated depths to groundwater in the GDE, based on interpolation of water elevation data from representative wells at Naval Base Ventura County Point Mugu to reference point locations within the Mugu Lagoon GDE. Based on data from well MW6-6A, groundwater levels have varied over a narrow range of less than three feet across the 20 year record; the trend is relatively flat. Data from well S35MW8 does have a decreasing trend; the data record starts in 2010 through 2016, which corresponds to the recent drought period. Hydrogeologic investigations across Naval Base Ventura County Point Mugu indicate the semi-perched aquifer is still separated in this area from the Oxnard aquifer by discontinuous clay layers (TtEMI 2003). Mugu Lagoon receives groundwater discharge from the semi-perched aquifer along with freshwater from Calleguas Creek, the drainage ditches, primarily Oxnard Drainage Ditch No. 2, and salt water from tidal fluctuations. The semi-perched aquifer is also affected by natural seawater degradation and tidal influence (TtEMI 2003). The upper 20 feet of the semi-perched aquifer overlies a saltwater wedge (TtEMI 2003). Aquatic life and bird species, including the light-footed clapper rail, in Mugu Lagoon has been impacted by pollutants (primarily pesticides) from nonpoint sources (RWQCB 2016). The high TDS and chloride levels are attributed to sea water intrusion in this area (TtEMI 2003).

Lower Calleguas Creek GDE

The lower Calleguas Creek GDE is comprised of approximately 150 acres of aquatic habitat and surrounding mulefat and willow riparian forest within a narrow 350 to 400 foot-wide leveed lower Calleguas Creek corridor. Riparian and wetland plant communities represent less than 3 percent of the watershed, which is below the statewide average of 10 percent. In the Calleguas Creek GDE, only 6 acres are delineated as wetlands in the National Wetland Inventory. Three native special status species, arroyo chub, two-striped gartersnake and least Bell’s vireo, has been found in the lower Callegaus Creek GDE. The RWQCB listed beneficial uses for Reach 2 (Potrero Road to the estuary) include: WILD, RARE, WET, WARM and COLD habitat. An inventory of ecological assets is listed in Table 2-6.

The GDE overlies the semi-perched aquifer. Historically, Calleguas Creek was an intermittent creek on the Oxnard Plain without a defined channel (Beller et al. 2011). Currently, the channel invert (i.e., channel bottom) of Calleguas Creek is approximately 4 to 5 feet above the surrounding grade, (Tony Chen 2017). The channel has been separated from the adjacent floodplain since the 1960s by a riprap and earthen levee countersunk about 3 feet below the surrounding grade. Thus, Calleguas Creek is a losing reach in the Oxnard Plain. Lower Calleguas Creek maintains a perennial streamflow due to a combination of wastewater effluent and pumped tile drain discharge from adjacent agricultural fields, with the addition of natural precipitation and stormwater runoff during winter months. The pumped tile drain discharge from adjacent agricultural fields. The tile drain source is typically a combination of perched groundwater, irrigation return flow, local precipitation, and water that has seeped through the levees driven by the head differential between the Calleguas Creek and the adjacent grade. Groundwater elevations at semi-perched aquifer monitoring wells (located approximately one mile to the southwest at Naval Base Ventura County Point Mugu) indicate typical groundwater elevations range from -1 to 6 ft MSL. Extrapolated depths to groundwater at the downstream end of the Calleguas Creek GDE, at approximately 12 ft MSL, are between 6 to 13 feet bgs. The extrapolated groundwater depths indicate the potential for the riparian vegetation to access shallow groundwater.

Revolon Slough GDE

The Revolon Slough GDE is comprised of around 25 acres of aquatic habitat and surrounding willow riparian forest within a narrow 100 to 200 foot-wide corridor between Wood Road and Calleguas Creek. This section of Revolon Slough is soft-bottom, rip-rap lined waterway that flows through agricultural fields (RWQCB 2007). The lower mile to mile and a half of the slough above Las Posas Road appears to be tidally influenced by inflows from Mugu Lagoon. Revolon Slough flows into Mugu Lagoon in a channel that runs parallel to Calleguas Creek near Pacific Coast Highway. In the Revolon Slough GDE, only 2 acres are delineated as wetlands in the National Wetland Inventory. Two native special status species, arroyo chub and least Bell's vireo, has been found in Revolon Slough. The RWQCB listed beneficial uses include: WILD, WET, and WARM habitat. The riparian habitat is considered "de minimis" given the limited extent adjacent to the waterway and poor quality. An inventory of ecological assets is listed in Table 2-6. Streamflow in lower Revolon Slough is considered to be a combination of agricultural return flow, and precipitation and stormwater runoff; the degree of groundwater recharge and/or discharge has not been studied. Groundwater elevation (depth-to-groundwater) data is not available for this area. Groundwater elevations at semi-perched aquifer monitoring wells located approximately one mile to the southwest at Naval Base Ventura County Point Mugu indicate typical groundwater elevations range from -1 to 6 ft MSL. Extrapolated depths to groundwater at the downstream end of the Revolon Slough GDE would be between 9 to 16 feet bgs. The extrapolated groundwater depths indicate the potential for the riparian vegetation to access shallow groundwater.

2.4 WATER BUDGET

2.4.1 Current Water Budget

(most recent as of January 2015)

- Surface water flows
  - Map of surface water/groundwater interactions (RFP Task 7)
- Inflow to groundwater system by source type (see RFP Task 7 for list of sources)
- Outflows from groundwater system by use sector (see RFP Task 7 for list of sources)
- Change in annual volume of groundwater in storage
- Overdraft
- Water year type
- Sustainable yield estimate
- Identify uncertainties in the groundwater budget (RFP Task 7) and recommend studies to reduce uncertainties (RFP Task 13)

2.4.2 Historical Water Budget

(minimum of 10 years base period, likely to extend through 2014)

- Quantify, and display in graphics, maps and tables (RFP Task 7)
  - Surface water flows
  - Inflow to groundwater system by source type
  - Outflows from groundwater system by use sector
  - Change in annual volume of groundwater in storage
  - Overdraft
  - Water year type
  - Sustainable yield estimate
- Historical water source reliability
- Impact of historical reliability on Agency operations
- Magnitude of diurnal/seasonal/inter-annual fluctuations in water budget components (RFP Task 7)

2.4.3 Projected Water Budget

(using minimum of 50 years of precip, ET, streamflow; see additional details in RFP Task 7)

Quantify and display in graphics, maps and tables (RFP Task 7)

- Surface water flows
- Inflow to groundwater system by source type
- Outflows from groundwater system by use sector
- Change in annual volume of groundwater in storage
- Overdraft
- Water year type
- Sustainable yield estimate

Future scenarios: climate change and sea level rise

Future scenarios: local land use planning, population growth, climate change

2.5 MANAGEMENT AREAS

[Number of Management Areas to be filled in based on future discussions] For each management area:

- Reason for management area
- Minimum thresholds and measurable objectives
- Monitoring and analysis
- Avoiding undesirable results outside the management area

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