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 lithologic 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 Lithology

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 Pleistocene	**San Pedro Formation**: Marine and nonmarine clay, sand, and gravel			**Las Posas Sand**: Shallow marine sand			**Lower Aquifer System**
						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 exceptions 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,” and an approximately 4-square-mile area in the southwestern-most area of the subbasin in the vicinity of Point Mugu (Figure 2-1; Mukae and Turner 1975). In these regions, 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. 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. Migration of recharge to the lower aquifer system from the forebay region, however, may be limited by a subsurface fault that extends southwest from the western end of the Camarillo Hills to the Pacific coast. 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 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

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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.

Geologic Structure

Wright Road Fault

The Wright Road Fault is an active oblique right reverse fault that forms the eastern 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 throughout 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

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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 non-water-bearing strata (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

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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 and seawater intrusion 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, and the hydrologic properties of this aquifer have not been documented.

Clay Cap

Underlying the semi-perched aquifer is a continuous clay layer that separates the semi-perched aquifer from the Oxnard Aquifer below (Turner 1975). The thickness of the clay cap ranges from approximately 160 feet adjacent to the Pacific Ocean to 0 feet in the forebay area and in the vicinity of Mugu Lagoon (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).

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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 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 6.18×10^{-4} and 3×10^{-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

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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). 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 deposited in shallow marine and nonmarine conditions (DWR 1965; Turner 1975). These 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 and in the vicinity of Point Hueneme and Point Mugu in the southwestern corner of the subbasin (DWR 1965; 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). In the vicinity of the Hueneme and Mugu canyons, however, chloride concentrations were as high as 6,300 milligrams per liter when last measured (Izbicki et al. 2005).

The base of the Mugu Aquifer is 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 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 Oxnard Subbasin, one well 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

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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 anticline (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). A fault or similar structural barrier to flow within the FCA is likely responsible for the abrupt change in groundwater elevations observed to the south of the Las Posas syncline and west of the Camarillo Hills (FCGMA 2007). Groundwater elevations are higher to the north of this northeast-to-southwest-trending feature and lower to the south. The primary source of recharge to the FCA is infiltration through the Oxnard and Mugu Aquifer systems in the forebay area to the north of this structural feature (Turner 1975; FCGMA 2007). The steep gradient across this feature may indicate that only a portion of the water recharging the aquifer in the forebay area is able to migrate south in the Oxnard Subbasin.

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).

Few wells in the Oxnard Subbasin are screened solely in the FCA. Data from one well screened solely within the FCA indicate a well yield of 1,300 gallons per minute, a specific capacity of 6.5 gallons per minute per foot, and an estimated transmissivity of approximately 2,100 feet squared per day (Hopkins, pers. comm. 2016). A well screened in the FCA and overlying Hueneme Aquifer 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). The average yield of four wells screened in both the FCA and Oxnard Aquifer was 1,050 gallons per minute, and the average specific capacity was 59 gallons per minute per foot (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 uppermost unit of the Santa Barbara Formation and is only found underlying the southern and eastern parts of the Oxnard Subbasin (Turner 1975). In

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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

(as detailed in Section 354.16.(a))

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2.3.1.1 Elevation Contour Maps

2.3.1.2 Hydrographs and Hydraulic Gradients

2.3.2 Estimated Change in Storage

2.3.3 Seawater Intrusion

2.3.4 Groundwater Quality

2.3.4.1 Map of Oil and Gas Deposits

2.3.4.2 Map of Locations of Impacted Surface Water, Soil and Groundwater

2.3.5 Subsidence

2.3.6 Groundwater–Surface Water Connections

2.3.7 Groundwater Dependent Ecosystems

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)

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- 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:

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

2.6 REFERENCES CITED

Bailey, T.L. 1951. “Geology of a Portion of Ventura Basin: Los Angeles and Ventura Counties, California” [map]. 1:24,000.

Bohannon, R.G., and D.G. Howell. 1982. “Kinematic Evolution of the Junction of the San Andreas, Garlock, and Big Pine Faults, California.” *Geology*: 10:358–363. doi: 10.1130/0091-7613(1982)10<358:KEOTJO>2.0.CO.

CGS (California Geological Survey). 2002. *Note 36: California Geomorphic Provinces*. Revised December 2002.

DeVecchio, D.E., E.A. Keller, L.A. Owen, and M. Fuchs. 2007. “Earthquake Hazard of the Camarillo Fold Belt: An Analysis of the Unstudied Fold Belt in Southern California Hot Zone.” Final. U.S. Geological Survey/National Earthquake Hazards Reduction Program (NEHRP) Award Number 07HQGR0040.

DeVecchio, D.E., R.V. Heermance, M. Fuchs, and L.A. Owen. 2012. “Climate-Controlled Landscape Evolution in the Western Transverse Ranges, California: Insights from Quaternary Geochronology of the Saugus Formation and Strath Terrace Flights.” *Lithosphere* 4(2):110–130. doi: 10.1130/L176.1.

Dibblee, T.W. Jr. 1992a. “Geologic Map of the Moorpark Quadrangle, Ventura County: Santa Barbara California, Dibblee Geological Foundation” [map]. 1:24,000.

Dibblee, T.W. Jr. 1992b. “Geologic Map of the Simi Quadrangle, Ventura County: Santa Barbara California, Dibblee Geological Foundation” [map]. 1:24,000.

DWR (California Department of Water Resources). 1965. *Bulletin No. 62-1: Seawater Intrusion Oxnard Plain of Ventura County*. October 1965.

DWR. 1968. *Bulletin No. 74-9: Well Water Standards, Ventura County*. August 1968.

DWR. 2003. *California’s Groundwater Bulletin 118: Santa Clara River Valley Groundwater Basin, Oxnard Subbasin*. Last updated January 20, 2006. Accessed October 2016. http://www.water.ca.gov/pubs/groundwater/bulletin_118/basindescriptions/4-4.02.pdf.

Eberhart-Phillips, D., M. Lisowski, and M.D. Zoback. 1990. "Crustal Strain Near the Big Bend of the San Andreas Fault: Analysis of the Los Padres-Tehachapi Trilateration Networks, California." *Journal of Geophysical Research* 95(B2):1,139–1,153.

FCGMA (Fox Canyon Groundwater Management Agency). 2007. *2007 Update to the Fox Canyon Groundwater Management Agency Groundwater Management Plan*. Prepared by FCGMA, United Water Conservation District, and Calleguas Municipal Water District. May 2007.

Feigl, K.L., D.C. Agnew, Y. Bock, D. Dong, A. Donnellan, B.H. Hager, T.A. Herring, and D.D. Jackson. 1993. "Space Geodetic Measurement of Crustal Deformation in Central and Southern California, 1984–1992." *Journal of Geophysical Research* 98(B12): 21,677–21,712.

Hadley, D., and H. Kanamori. 1977. "Seismic Structure of the Transverse Ranges, California." *Geological Society of America Bulletin* 88:1,469–1,478.

Hanson, R.T., P. Martin, and K. Koczot. 2003. *Simulation of Ground-Water/ Surface-Water Flow in the Santa Clara-Calleguas Ground-Water Basin, Ventura County, California*. U.S. Geological Survey Water Resources Investigation Report 2002-4136.

Hopkins, C. 2016. Oxnard Plain and Vicinity Aquifer Properties Data Request. Email from C. Hopkins (Hopkins Groundwater) to Claire Kouba and Jill Weinberger (Dudek). October 2016.

Huftile, G.J., and R.S. Yeats. 1995. "Convergence Rates Across a Displacement Transfer Zone in Western Transverse Ranges, Ventura Basin, California." *Journal of Geophysical Research* 100(B2):2,043–2,067.

Izbicki, J.A., A.H. Christensen, M.W. Newhouse, G.A. Smith, and R.T. Hanson. 2005. "Temporal Changes in the Vertical Distribution of Flow and Chloride in Deep Wells." *Groundwater* 43(4): 531–544.

Jakes, M.C. 1979. "Surface and Subsurface Geology of the Camarillo and Las Posas Hills Area: Ventura County, California." Master's thesis; Oregon State University.

Kew, W.S., 1924. "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties California." In *United States Geological Survey (USGS) Bulletin 753*.

Marshall, S.T., M.L. Cooke, and A.E. Owen. 2008. "Effects of Nonplanar Fault Topology and Mechanical Interaction on Fault-Slip Distributions in the Ventura Basin, California."

PRELIMINARY DRAFT – NOT FOR PUBLIC CITATION

Bulletin of the Seismological Society of America 98(3):1,113–1,127. doi:10.1785/0120070159.

Mukae, M.M., and J.M. Turner. 1975. "Geologic Formations, Structures and History in the Santa Clara-Calleguas Area." In *Compilation of Technical Information Records for the Ventura County Cooperative Investigation: Volume I*. Prepared by the Ventura County Public Works Agency Flood Control and Drainage Department for the California Department of Water Resources. 1-28.

Nicholson, C., C.C. Sorlien, T. Atwater, J.C. Crowell, and B.P. Luyendyk. 1994. "Microplate Capture, Rotation of the Western Transverse Ranges, and Initiation of the San Andreas Transform as a Low-Angle Fault System." *Geology* 22:491–495.

Pressler, E. 1929. "The Fernando Group in the Las Posas-South Mountain District, Ventura County, California." *University of California, Department of Geological Science, Publication* 18(13):325–345.

Rockwell, T.K., E.A. Keller, and G.R. Dembroff. 1988. "Quaternary Rate of Folding of the Ventura Avenue Anticline, Western Transverse Ranges, Southern California." *Geological Society of America Bulletin* 100: 850–858.

SWRCB (State Water Resources Control Board). 1956. *Bulletin No. 12: Ventura County Investigation Volume I*. October 1953. Revised April 1956.

Turner, J.M. 1975. "Aquifer Delineation in the Oxnard-Calleguas Area, Ventura County." In *Compilation of Technical Information Records for the Ventura County Cooperative Investigation: Volume I*. Prepared by the Ventura County Public Works Agency Flood Control and Drainage Department for the California Department of Water Resources. 1-45.

Turner, J.M., and M.M. Mukae. 1975. "Effective Base of Fresh Water Reservoir in the Oxnard-Calleguas Area." In *Compilation of Technical Information Records for the Ventura County Cooperative Investigation: Volume I*. Prepared by the Ventura County Public Works Agency Flood Control and Drainage Department for the California Department of Water Resources. 1-15.

USGS (U.S. Geological Survey) 1996. *Seawater Intrusion in a Coastal California Aquifer*. U.S. Geological Survey Fact Sheet 125-96.

VCWPD (Ventura County Watershed Protection District). 2013. *2013 Groundwater Section Annual Report*. VCWPD: Water and Environmental Resources Division.

PRELIMINARY DRAFT – NOT FOR PUBLIC CITATION

Weber, F.H., and E.W. Kiessling. 1976. "General Features of Seismic Hazards of Ventura County, California." In *Seismic Hazards Study of Ventura County, California.* Prepared by the California Division of Mines and Geology in cooperation with the County of Ventura. Adopted 1975. Revised July 1976.

Yeats, R.S. 1988. "Late Quaternary Slip Rate on the Oak Ridge Fault, Transverse Ranges, California: Implications for Seismic Risk." *Journal of Geophysical Research* 93(B10):12,137–12,149.

Zoback, M.D., M.L. Zoback, V.S. Mount, J. Suppe, J.P. Eaton, J.H. Healy, D. Oppenheimer, P. Reasenberg, L. Jones, C.B. Raleigh, I.G. Wong, O. Scotti, and C. Wentworth. 1987. "New Evidence of the State of Stress of the San Andreas Fault System." *Science* 238(4830): 1,105–1,111.

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