# Groundwater Sustainability Plan

## Monterey Subbasin

Marina Coast Water District Groundwater Sustainability Agency
Salinas Valley Basin Groundwater Sustainability Agency

DRAFT Chapter 4

Hydrogeologic Conceptual Model

September 2021

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# 4 HYDROGEOLOGIC CONCEPTUAL MODEL

This section presents the hydrogeologic conceptual model (HCM) for the Subbasin. As described in the Hydrogeological Conceptual Model Best Management Practices (BMP) document (DWR, 2016), an HCM provides, through descriptive and graphical means, and understanding of the physical characteristics of an area that affect the occurrence and movement of groundwater, including geology, hydrology, land use, aquifers and aquitards, and water quality. This HCM serves as a foundation for subsequent Basin Setting analysis including water budgets (Section 6), numerical models, monitoring network development (Section 7), and the development of sustainable management criteria (Section 8).

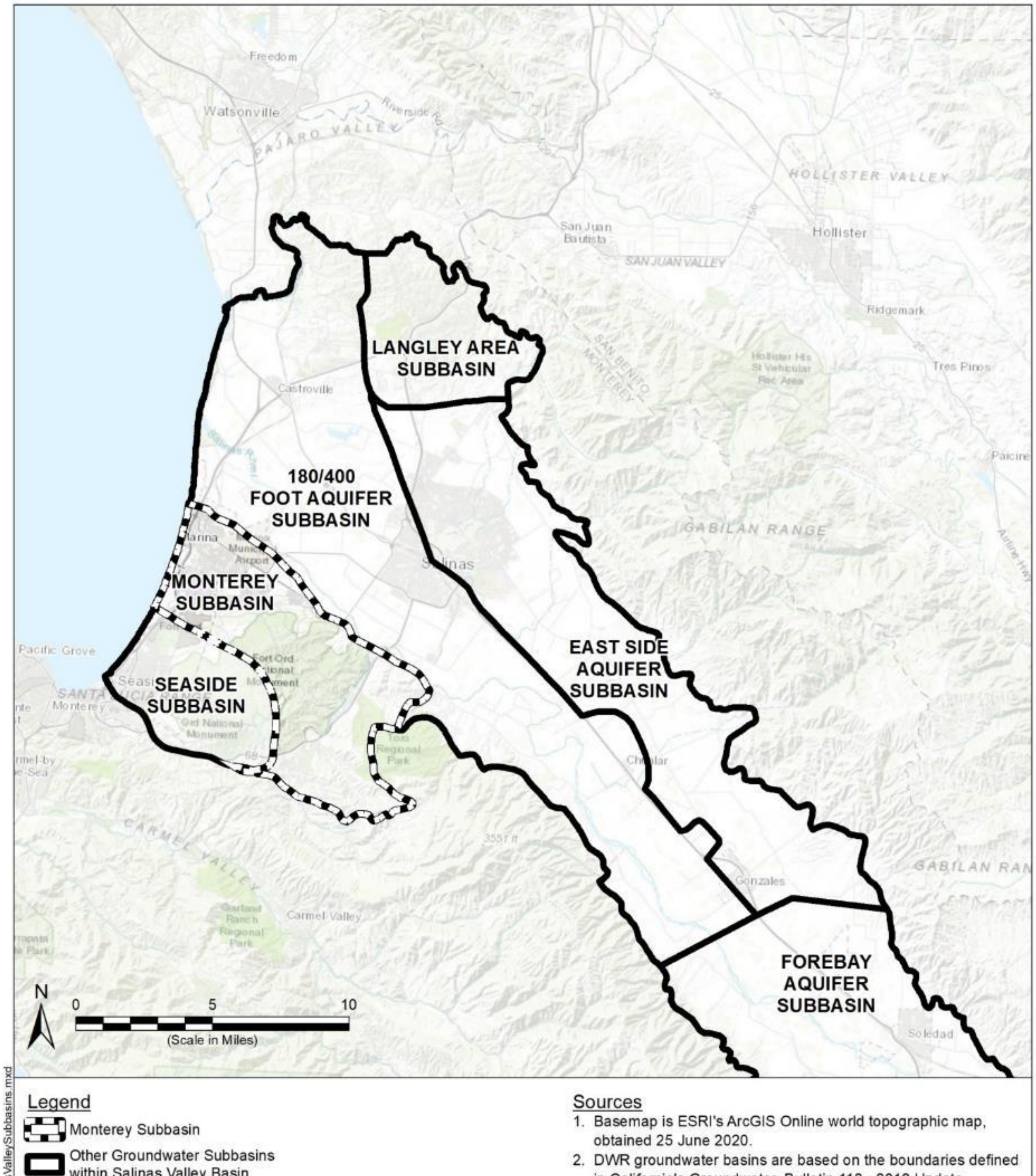
## 4.1 General Description

The Monterey Subbasin (Subbasin; DWR Basin No. 3-004.10) is located at the northwestern end of the Salinas Valley Groundwater Basin, an approximately 90-mile long alluvial basin underlying the elongated, intermountain valley of the Salinas River. The Subbasin includes the portions of the Monterey Bay coastal plain, south of the approximate location of the Reliz Fault, as well as upland areas to the southeast of the coastal plain. The Subbasin is bordered by the 180/400-Foot Aquifer Subbasin to the northeast and by the adjudicated Seaside Subbasin to the southwest (Figure 4-1 and Figure 4-2).

### 4.1.1 Geological and Structural Setting

The Subbasin geology forms the physical framework in which groundwater occurs and moves. The geology described here is based on previously published scientific reports from investigations conducted by the USGS, State of California, other consulting firms, and academic institutions.

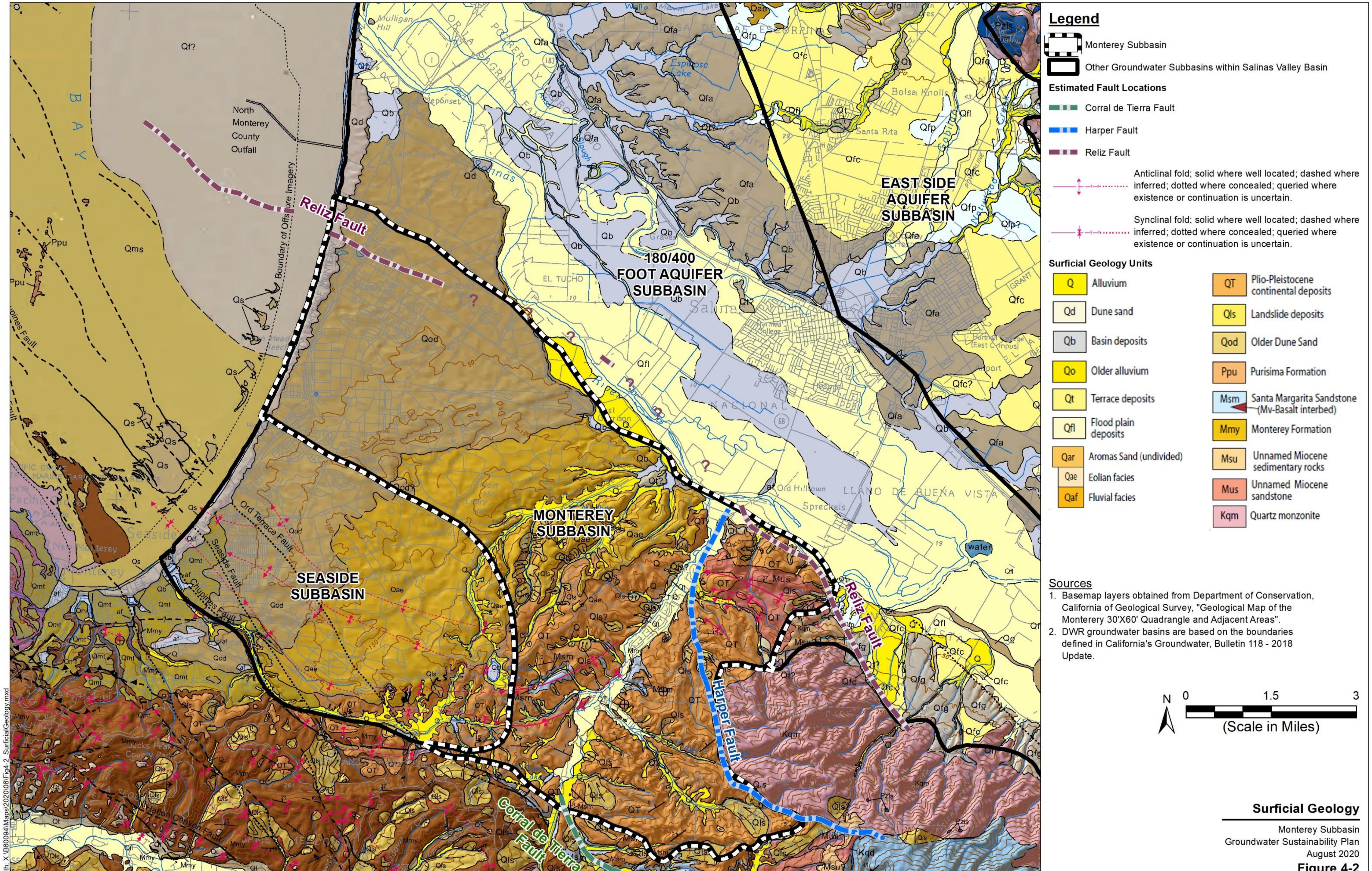
The Salinas Valley was formed through periods of structural deformation and periods of marine and terrestrial sedimentation in a tectonically active area on the eastern edge of the Pacific Plate. The water bearing sediments of the Salinas Valley are over 2,000 feet thick in places and are composed of unconsolidated marine and alluvial sediments of Pliocene and younger age (Brown & Caldwell, 2015). Within the Monterey Subbasin, the water-bearing strata include river and sand dune deposits of Holocene and Pleistocene age, the Aromas Sand and Paso Robles Formation of Plio-Pleistocene age, the Purisima Formation of Pliocene age, and the Santa Margarita Formation of Miocene age (Greene, 1970; Harding ESE, 2001; Geosyntec, 2007). The Monterey Formation of Miocene age represents the relatively non-water-bearing bedrock that underlies the Subbasin (see Section 4.1.2.2, Bottom of the Basin).




**Salinas Valley Subbasins**

Monterey Subbasin
Groundwater Sustainability Plan
June 2020

**Figure 4-1**


Legend
Monterey Subbasin
Other Groundwater Subbasins within Salinas Valley Basin
Estimated Fault Locations
Corral de Tierra Fault
Harper Fault
Reliz Fault
Anticlinal fold; solid where well located; dashed where inferred; dotted where concealed; queried where existence or continuation is uncertain.
Synclinal fold; solid where well located; dashed where inferred; dotted where concealed; queried where existence or continuation is uncertain.
Surficial Geology Units
Q Alluvium
Qd Dune sand
Qb Basin deposits
Qo Older alluvium
Qt Terrace deposits
Qfl Flood plain deposits
Qar Aromas Sand (undivided)
Qae Eolian facies
Qaf Fluvial facies
QT Plio-Pleistocene continental deposits
Qls Landslide deposits
Qod Older Dune Sand
Ppu Purisima Formation
Msm Santa Margarita Sandstone (Mv-Basalt interbed)
Mmy Monterey Formation
Msu Unnamed Miocene sedimentary rocks
Mus Unnamed Miocene sandstone
Kqm Quartz monzonite
Sources
1. Basemap layers obtained from Department of Conservation, California of Geological Survey, "Geological Map of the Monterrey 30'X60' Quadrangle and Adjacent Areas".
2. DWR groundwater basins are based on the boundaries defined in California's Groundwater, Bulletin 118 - 2018 Update.
N
0 1.5 3
(Scale in Miles)
EAST SIDE AQUIFER SUBBASIN
180/400 FOOT AQUIFER SUBBASIN
MONTEREY SUBBASIN
SEASIDE SUBBASIN
Reliz Fault
Harper Fault
Corral de Tierra Fault
North Monterey County Outfall
Boundary of Offshore Imagery
Salinas
Spreckels
LLANO DE BUENA VISTA
Surficial Geology
Monterey Subbasin
Groundwater Sustainability Plan
August 2020
Figure 4-2
Path: X:\B60094\Maps\2020\08\Fig4-2_SurficialGeology.mxd

#### 4.1.1.1 *Geologic Formations*

Major geologic units of the Monterey Subbasin are described below, starting at the ground surface and moving downwards through the strata from youngest to oldest. The corresponding designation on Figure 4-2 Surficial Geology are provided in parenthesis.

- *Alluvium, Flood Plain Deposits, Landslide Deposits (Q, Qfl, Qls)* – Holocene Alluvium consists of unconsolidated stream and basin deposits occur at the base of eastern Subbasin hillslopes. These deposits have gradational contacts the Floodplain Deposits (Qfl) that occur along El Toro Creek and its tributaries. The Floodplain Deposits consist predominately of unconsolidated layers of mixed sand, gravel, silt, and clay that were deposited in a fluvial environment by the Salinas River and its tributaries. Numerous landslides are present in upland portions of the subbasin such as San Benancio, Harper, and Corral de Tierra Canyons.
- *Older Dune Sand (Qod)* – This Pleistocene unit blankets most of the northwestern portions of the Subbasin and is the predominant surface deposit present in approximately one third of the Subbasin. This unit only exists southwest of the Salinas River and is up to 250 feet thick. This sand is predominately fine- to medium-grained, with thin, gentle to moderate cross-bedding (Harding ESE, 2001).
- *Older Alluvium (Qo)* – This Pleistocene unit comprises alternating, interconnected beds of fine-grained and coarse-grained deposits, predominately associated with alluvial fan depositional environments. The Older Alluvium underlies coastal Marina-Ord Area but is not exposed at the ground surface. This unit underlies the Older Dune Sand, and in the Marina-Ord Area has been referred to in some reports as Valley Fill Deposits, which is described as including an estuarine clay layer (Salinas Valley Aquitard) and an underlying sand and gravel fluvial sequence (Harding ESE, 2001).
- *Aromas Sand (Qae)* – This Pleistocene unit is composed of cross-bedded sands containing some clayey layers (Harding ESE, 2001). This unit was deposited in predominately in an eolian, high-energy alluvial, alluvial fan, and shoreline environments, with the predominant deposition environment being eolian (Harding ESE, 2001; Greene, 1970; Dupre, 1990). The Aromas Sand likely extends into the northern portion of the 180/400 Foot Aquifer Subbasin (MCWRA, 2017). The Aromas Sand is exposed throughout the ridge and hilltops in the southeastern portion of the Subbasin, while the unit is buried beneath Older Dune Sand and Alluvium in the vicinity of the City of Marina. Thickness of the Aromas Sand varies within the Subbasin and is up to 300 feet thick (Harding ESE, 2001; Muir, 1982). Although a clayey or hard red bed is often observed at the basal contact with the underlying Paso Robles Formation, the stratigraphic relationship between the Aromas Sand and the Paso Robles Formation is difficult to discern due to lithologic similarities and the complex interface between them (Harding ESE, 2001; Dupre, 1990)
- *Paso Robles Formation (QT)* – This Pliocene to lower Pleistocene unit is composed of lenticular beds of sand, gravel, silt, and clay from terrestrial deposition (Thorup, 1976; Durbin *et al*, 1978). The depositional environment is largely fluvial but also includes alluvial fan, lake and floodplain deposition (Durbin, 1974; Harding ESE, 2001; Thorup, 1976; Greene, 1970). The individual beds of fine and coarse materials typically have thicknesses of 20 to 60 feet (Durbin *et al*, 1978).

Durham (1974) reports that the thickness of the Paso Robles Formation is variable due to erosion of the upper part of the unit. Varying thicknesses ranging from 500 feet to 1,000 feet are found within the Subbasin. Outcrops of the Paso Robles Formation occur in the central and southern portions of the Subbasin.

- *Purisima Formation (Ppu)* – This Pliocene unit consists of interbedded siltstone, sandstone, conglomerate, clay and shale deposited in a shallow marine environment (Greene, 1977; Harding ESE, 2001). The Purisima Formation has been found in boreholes near the cities of Marina and Seaside; however, the unit is missing from the more inland portions of the Monterey and Seaside Subbasins (Harding ESE, 2001; HydroMetrics, 2009; Geosyntec, 2007). The Purisima Formation ranges in thickness from 500 to 1,000 feet (Feeney and Rosenberg, 2003).
- *Santa Margarita Sandstone (Msm)* –The Miocene Santa Margarita Sandstone is a friable, arkosic sandstone. In the northern portion of the Subbasin, the Paso Robles Formation conformably overlays the Purisima Formation, which interfingers with the Santa Margarita Sandstone (Durbin, 2007; Hydrometrics, 2009). Towards the boundaries with the Seaside Subbasin and the Corral de Tierra Area, the Paso Robles unconformably overlays over the Santa Margarita Sandstone. Outcrops of the Santa Margarita Sandstone are found in the Corral de Tierra Area.
- *Monterey Formation (Mmy)* – The Monterey Formation (Miocene) is a shale or mudstone deposited in a shallow marine environment (Harding ESE, 2001; Greene, 1977). As discussed below, the Monterey Formation is relatively impervious. The top of the Monterey Formation is defined as the bottom of the Subbasin (Section 4.1.2.2).
- *Unnamed Miocene Sandstone (Mus)* – An unnamed Miocene sandstone unit (Mus) underlies the Monterey Formation. The Mus unit consists of an upper part of marine arkosic sandstone and conglomerate; and a lower part of continental sandstone and conglomerate (Wagner, et al. 2002). This unit is exposed in the Corral de Tierra Area near the eastern and southern Subbasin boundaries. This unit is sometimes referred to as the Basal Sandstone in other reports (GeoSyntec, 2007).
- *Unnamed Miocene Sedimentary Rocks (Msu)* – Miocene metamorphic sedimentary rocks (Msu) are deposited on granitic rocks of the Galiban Range (Kqm). The Msu unit is comprised of granitic conglomerate and arkosic sandstone of marine and non-marine sources (Wagner, et al. 2002). This unit is exposed in the Corral de Tierra Area near the eastern Subbasin boundary. These unnamed Miocene units (i.e. Mus and Msu) are approximately 250 feet thick (Geosyntec, 2007).

#### 4.1.1.2 *Surface Geology*

As shown on Figure 4-2, the predominant surficial geologic unit covering the coastal plain portion of the Subbasin is "Qod" (i.e., Older Dune Sand [Pleistocene]). South of the coastal plain area, the Eolian facies of Aroma Sand “Qae” (Pleistocene) comprises the hills of the Fort Ord area. Further south near Highway 68 and in the Corral de Tierra area, the predominant surficial geologic unit is “QT” (Paso Robles Formation

[Plio-Pleistocene]). Other minor units in the area include "Q" (Alluvium [Holocene]), and "Qls" (Landslide Deposits [Pleisto-Holocene]), found in thin strips along the intermittent tributaries to El Toro Creek, which is a tributary to the Salinas River (as discussed above); and "Qls" (landslide deposits) that exist in pockets in the upland areas.

### 4.1.2 **Subbasin Extent**

#### 4.1.2.1 *Lateral Basin Boundaries*

The Monterey Subbasin is bounded by the following combination of Subbasin boundaries and physical boundaries of the Salinas Valley Basin:

Two subbasins are adjacent to the Monterey Subbasin.

1. The 180/400-Foot Aquifer Subbasin. The northeastern boundary with the 180/400-Foot Aquifer Subbasin is divided into two parts: the northern part coincides with a buried trace of the Reliz Fault (DWR, 2016); the southern part follows the contact between Aromas Sand / Paso Robles Formations (Qae/QT) and alluvium (Q). The Reliz Fault does not appear to be a barrier to groundwater flow between these subbasins (see Section 4.2.3).
2. The Seaside Subbasin. The southwestern boundary with the Seaside Subbasin is based on an inferred groundwater divide. The boundary with the Seaside Subbasin was formally established in the Seaside Basin Adjudication Amended Decision (Superior Court of California, 2007).

Two additional physical features bound the Monterey Subbasin.

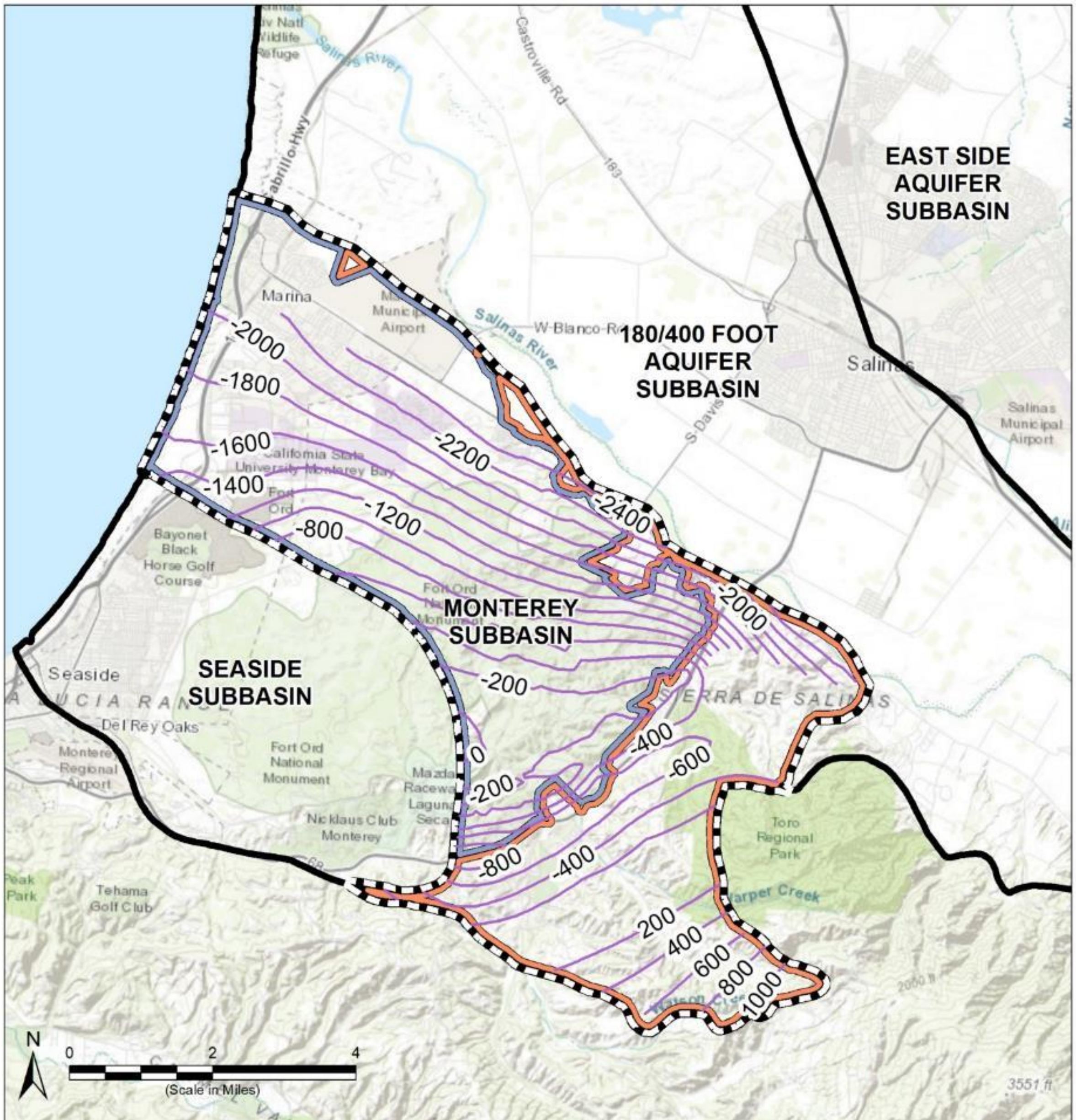
1. The Monterey Bay shoreline bounds the northwestern edge of the Subbasin.
2. The Sierra de Salinas bound the eastern and southern edge of the Subbasin. One part of this boundary follows the contact between Pleistocene units and the Cretaceous quartz monzonite, and another part of this boundary generally follows the contact between Pleistocene units and Miocene rocks as shown on Figure 4-2.

#### 4.1.2.2 *Bottom of the Basin*

The bottom of the Monterey Subbasin is defined herein as the top of Monterey Formation. The Monterey Formation has low hydraulic conductivity as it is comprised of shale and diatomite (Yates, 2002) and yields water that is generally of low water quality (Geosyntec, 2007). Figure 4-3 shows contours that define the top elevation of the Monterey Formation for most of the Monterey Subbasin.

The deepest groundwater production wells in the Subbasin generally extend to depths within the Purisima or Santa Margarita Formations above the Monterey Formation, and are found closer to the coast. Along the northeastern boundary of the Subbasin, where the Monterey Formation is overlain by the Purisima Formation (Durbin 2007, Yates and others 2005, Greene 1970, Greene 1977), the deepest groundwater extractions are from MCWD wells MCWD-10, -11, and -12, which are screened across Paso Robles and Purisima Formations from 780 ft bgs to 1,840 ft bgs. In the Corral de Tierra Area, many wells are screened in the Aromas Sand and Paso Robles Formation continental deposits as well as the Santa Margarita Sandstone. Slightly south of the Corral de Tierra Area, outside of the Subbasin, a number of wells tap both the Monterey Formation and the unnamed sandstone and conglomerate unit (GeoSyntec, 2007; Feeney, 2003).

The top of the Monterey Formation ranges from an elevation of 1,000 feet in the Corral de Tierra area to -2,400 feet near the coast, or from approximately 700 feet below land surface in the Corral de Tierra area to over 2,000 feet below land surface near the coast. As shown on Figure 4-3 and Figure 4-4, there is a set of an east/northeast trending highs and lows on the surface of the Monterey Formation near the Ord-Corral de Tierra boundary. This reflects the mapped structural deformation of the unit in this area illustrated by the pink anticline and synclines in Figure 4-2. Additionally, the depth to the Monterey Formation can illustrate the structural, depositional, and erosional complexity which defines this hydrostratigraphic setting (Figure 4-6).




Path: X:\B60094\Maps\2020\06\Fig4-3_Top_of_Monterey.mxd

Legend

Monterey Subbasin

Other Groundwater Subbasins within Salinas Valley Basin

Top of Monterey Fm. ft MSL

**Management Areas**

Marina-Ord Area

Corral de Tierra Area

Abbreviations

Fm. = formation

Ft MSL = feet mean sea level

Notes

1. All locations are approximate.

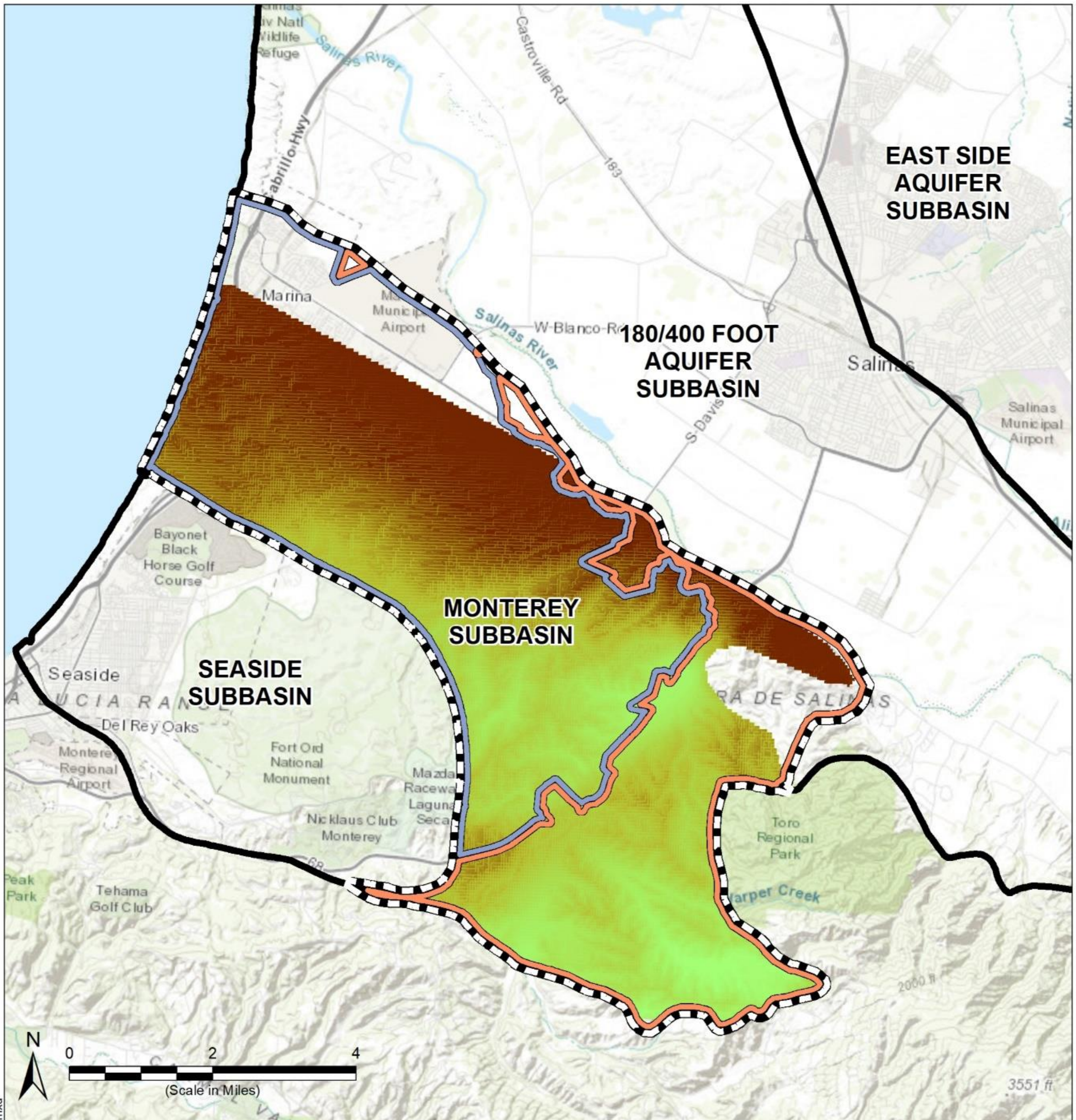
Sources

1. Basemap is ESRI's ArcGIS Online world topographic map, obtained 25 June 2020.
2. The elevations of the top of Monterey Fm. are obtained from the sources below:
   - Rosenberg (2001, 2009)
   - Staal. Gardner and Dunne (1987)
   - Feeney and Rosenberg (2003)

**Bottom of the Basin – Top of the Monterey Formation**

Monterey Subbasin
Groundwater Sustainability Plan
June 2020

**Figure 4-3**




Legend

Monterey Subbasin

Other Groundwater Subbasins within Salinas Valley Basin

**Management**

Marina-Ord

Corral de Tierra

**Depth to Top of Monterey Formation (ft bgs)**

133

2735

Abbreviations

DEM = digital elevation model

Fm. = formation

Ft bgs = feet below ground surface

Notes

1. All locations are approximate.

Sources

1. Basemap is ESRI's ArcGIS Online world topographic map, obtained 18 August 2020.
2. The depth to the top of the Monterey Formation are obtained from subracting the elevation of the top of the Monterey Formation (Figure 4-3) from ground surface elevation.

**Depth to Top of the Monterey Formation**

Monterey Subbasin
Groundwater Sustainability Plan
August 2020

**Figure 4-4**

### 4.1.3 **Physical Characteristics**

#### 4.1.3.1 *Topographic Information*

Figure 4-5 shows the topography within the Monterey Subbasin. Topography generally slopes down to the northwest towards Monterey Bay, ranging from sea level at the shoreline to 1,900 ft msl in the southeastern corner of the Subbasin.

In the coastal area of the Subbasin, the topography is shaped by active coastal sand dunes, followed by a coastal plain and older stabilized sand dunes. Coastal sand dunes are present along a narrow quarter-mile-wide stretch of land where the Subbasin meets the bay. These coastal dunes rise to approximately 100 feet in elevation and grade eastward into a narrow coastal plain varying in width from one to two miles. Older sand dunes dominate the topography in the northwestern portion of the Subbasin and the majority of the Marina-Ord Area (CH2M, 2004).

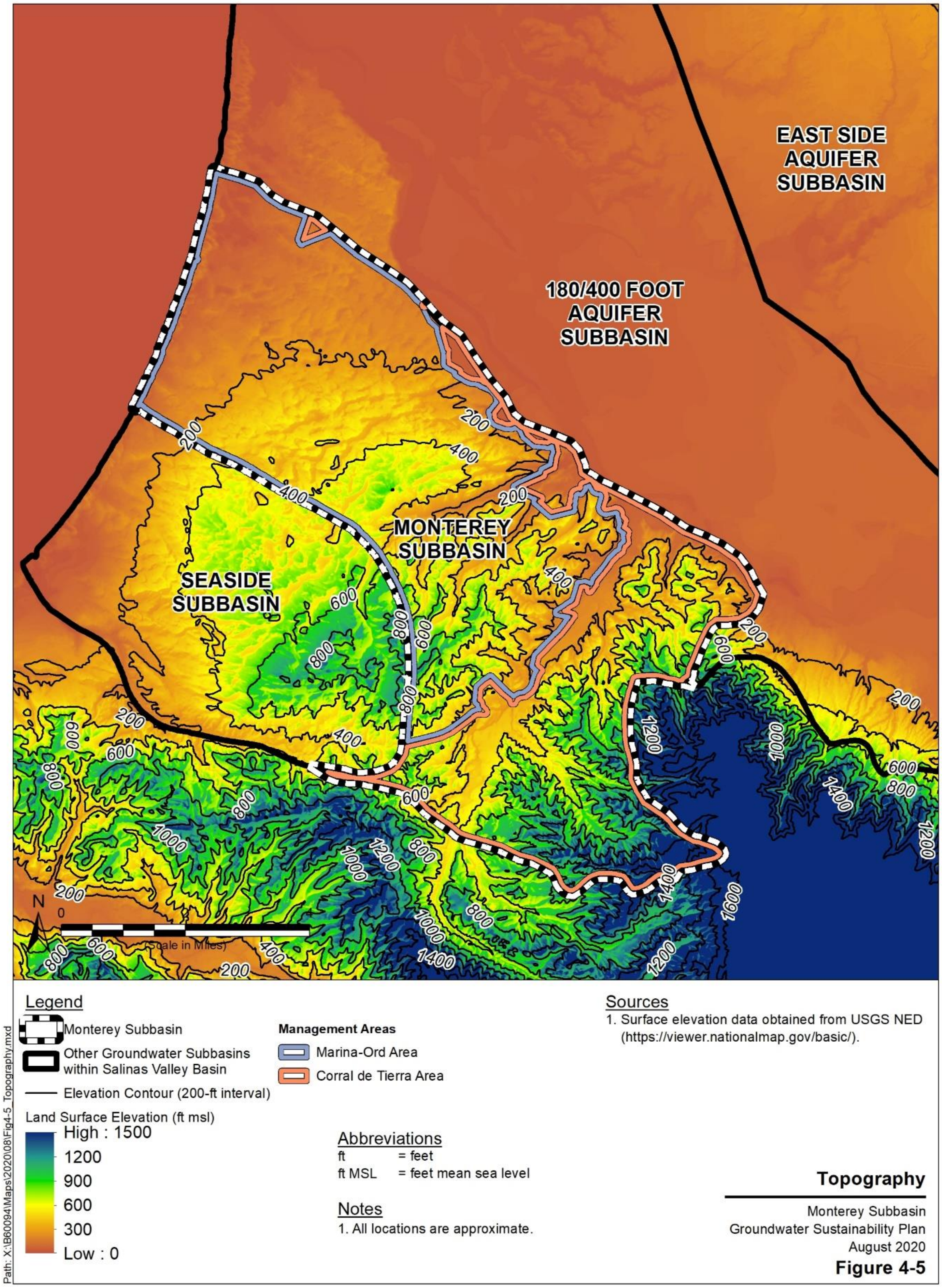
The topography of the southeastern uplands area is characterized by low hills and small sub-watersheds with well-defined drainages. Runoff from these areas is northeastward towards the Salinas River Valley by way of El Toro Creek or other smaller tributaries.

#### 4.1.3.2 *Soil Characteristics*

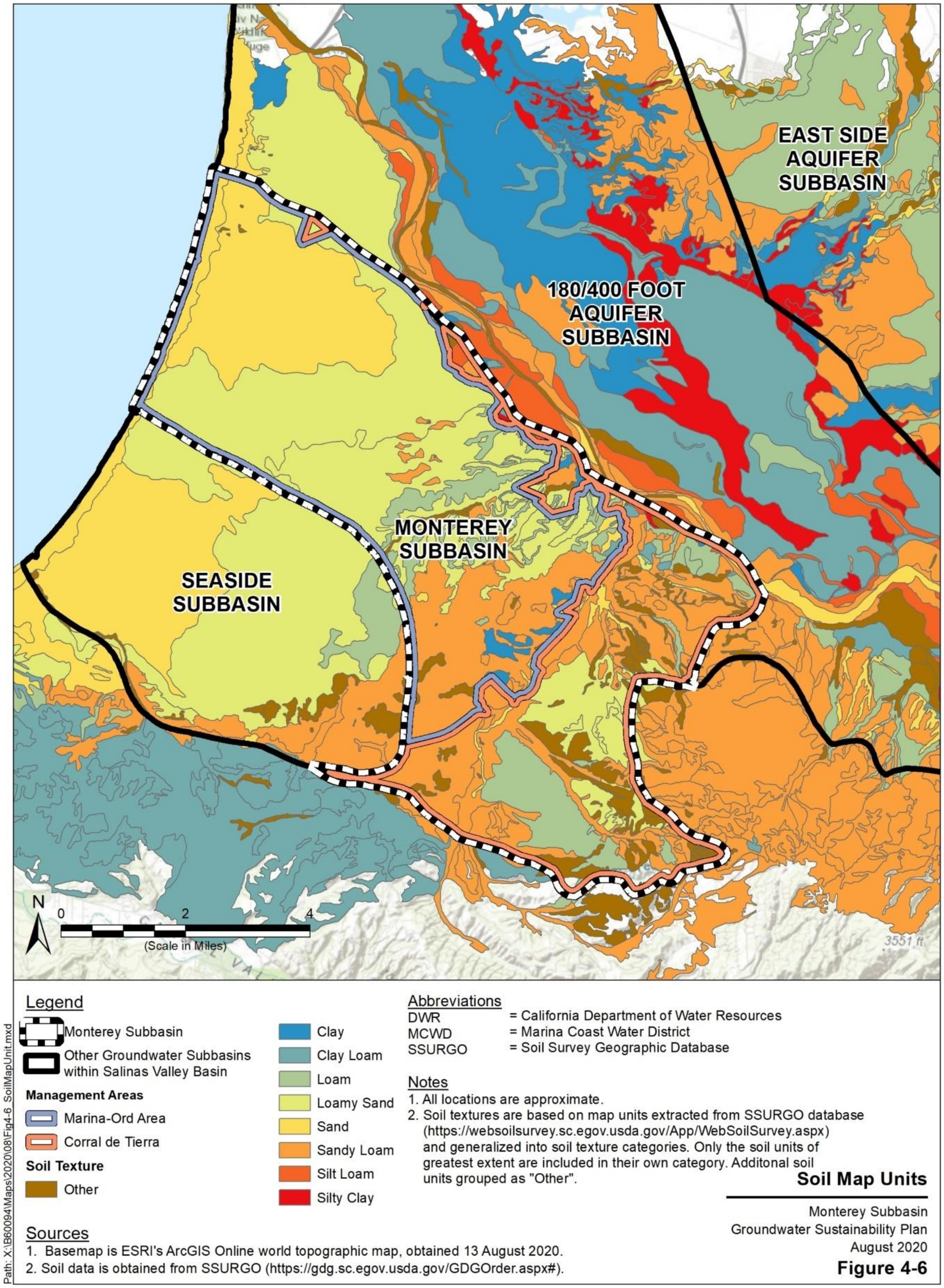
The soils of the Subbasin are derived from the underlying geologic formations and influenced by the historical and current patterns of climate and hydrology. Soil types can influence groundwater recharge and are an important consideration for the siting of potential artificial recharge projects.

Soils within the Subbasin are shown on Figure 4-6, and are based on the U.S Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) Soil Survey Geographic Database (SSURGO). Soils within the Subbasin are relatively coarse in texture, with the predominant types being sand, loamy sand, and fine sandy loam. Textures are generally coarser near the coast and finer to the south.

Figure 4-7 shows the infiltration potential of soils based on SSURGO’s Hydrologic Soil Group designations. Soils within the subbasin are predominantly of Hydrologic Soil Group A in the coastal plain area, indicating high infiltration rates and low runoff potential. In the Fort Ord hills area, soils predominately belong to Hydrologic Soil Groups C and D, with below average and low infiltration rates, respectively, and moderately high and high runoff potential, respectively. A mix of Hydrologic Soil Groups A through D exist in the Corral de Tierra area east of El Toro Creek.



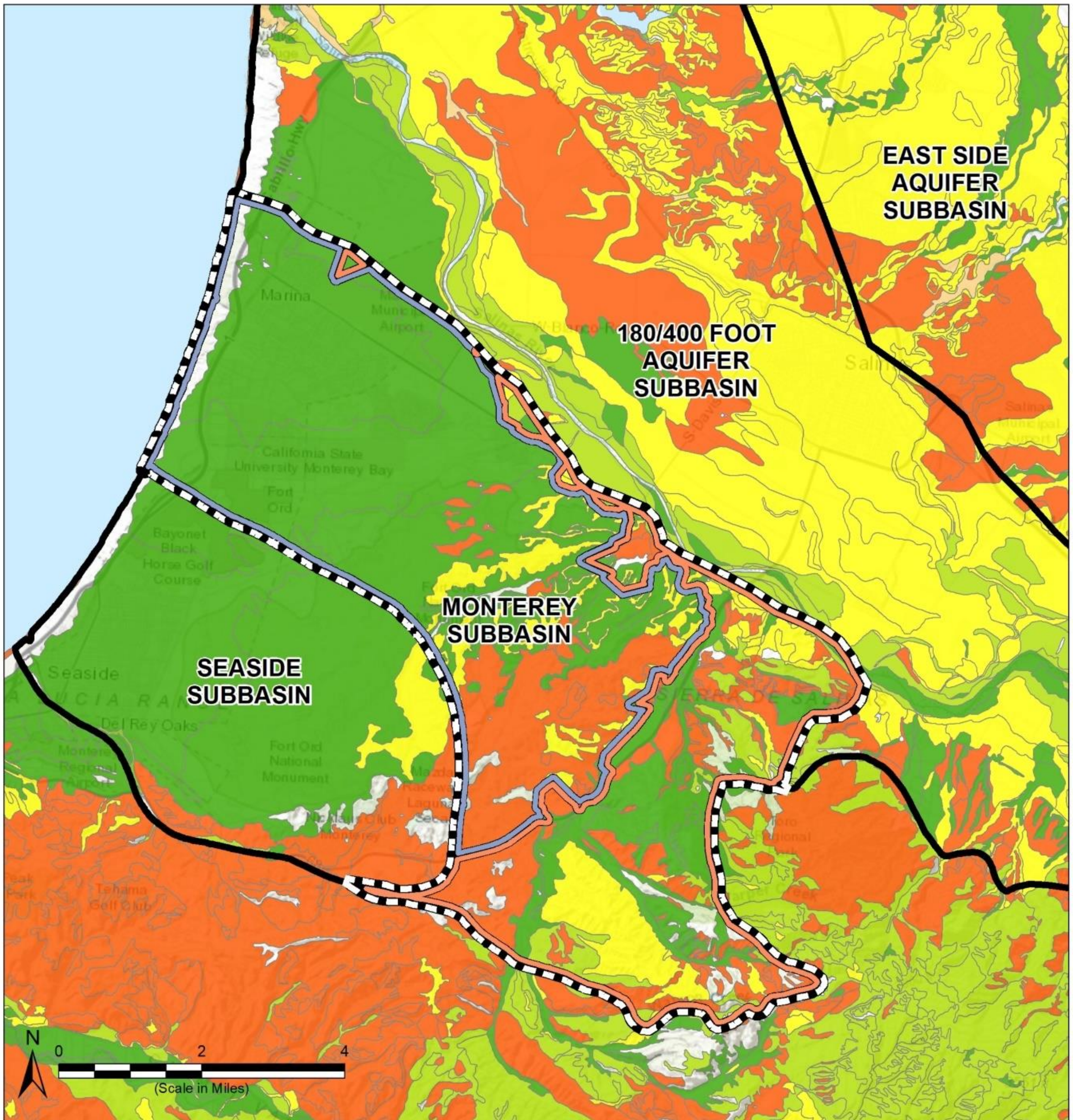

**Topography**
Monterey Subbasin
Groundwater Sustainability Plan
August 2020
**Figure 4-5**




**Soil Map Units**

Monterey Subbasin
Groundwater Sustainability Plan
August 2020

**Figure 4-6**




Legend

- Monterey Subbasin
- Other Groundwater Subbasins within Salinas Valley Basin

**Management Areas**

- Marina-Ord Area
- Corral de Tierra

**Hydrologic Soil Groups**

- A: High Infiltration Rate
- A (Drained Areas) /D (Undrained Areas)
- B: Moderate Infiltration Rate
- C: Slow Infiltration Rate
- C (Drained Areas) /D (Undrained Areas)
- D: Very Slow Infiltration Rate
- Unspecified

Abbreviations

SSURGO = Soil Survey Geographic Database

Notes

1. All locations are approximate.
2. Hydrologic soil groups are per Source 2.

Sources

1. Basemap is ESRI's ArcGIS Online world topographic map, obtained 13 August 2020.
2. Soil data is obtained from SSURGO (https://gdg.sc.egov.usda.gov/GDGOrder.aspx#).

Path: X:\B60094\Maps\2020\08\Fig4-7_HydroSoilGroup.mxd

**Hydrologic Soil Groups**

Monterey Subbasin
Groundwater Sustainability Plan
August 2020

**Figure 4-7**

#### 4.1.3.3 *Recharge and Discharge Areas*

Most of the Marina-Ord Area has good recharge potential for the Dune Sand Aquifer which subsequently recharges the underlying 180-Foot and 400-Foot Aquifers due to the high infiltration potential of the soils. This recharge is discussed further below in the general water quality section. There is uncertainty regarding the location and recharge mechanism for the Deep Aquifers (see discussion for each aquifer in Section 4.2.2). Additionally, due to the prevailing hydraulic gradient, the Subbasin currently receives inflow of seawater across the coastal northwestern boundary. Return flow from urban irrigation is not likely a significant source of recharge, and there are currently no artificial recharge projects within the Subbasin. Discharge of groundwater from the subbasin is predominantly through groundwater pumping from private and municipal supply wells, as well as groundwater remediation extraction wells.

Soils of varying infiltration potential exist in the Corral de Tierra area. Recharge from precipitation to the Aromas Sand/Paso Robles continental deposits and the Santa Margarita Sandstone in the southern Corral de Tierra Area is approximately 2 to 3 inches of the total annual precipitation (GeoSyntec, 2007; Fugro, 1996). This equals around 10 to 20 percent of average precipitation, which is approximately 16 inches of rain per year (Fugro, 1996). There is also a minimal volume of recharge from septic systems, and it is assumed that this recharge is to the shallow alluvial sediments (Yates, 2002). Recharge to the unnamed sandstone and conglomerate likely occurs in areas of higher elevation in the Sierra de Salinas south of the Monterey Subbasin (GeoSyntec, 2007).

Groundwater discharge to El Toro Creek causes the creek to flow perennially starting at a location below the Corral de Tierra Country Club, according to several previous investigations. Streamflow data for the period 1961 to 2002 from USGS gage 11152540, located north of San Benancio Road, indicate a mean annual streamflow of 1,590 AFY (GeoSyntec, 2007). It has not been determined what portion of this mean annual streamflow is attributable to groundwater discharge and what portion is attributable to runoff.

## 4.2 Subbasin Hydrogeology

The Monterey Subbasin is hydrostratigraphically complex and represents a transition zone between the more defined, laterally continuous aquifer system along the central axis of the Salinas Valley and the less continuous aquifer systems towards the Sierra de Salinas. Past hydrostratigraphic analyses of the Subbasin have generally focused on areas where groundwater production and remediation activities have occurred, i.e., in the vicinity of the City of Marina, in the eastern portion of the former Fort Ord, and within the southern Corral de Tierra area. Limited subsurface information exists in the central portion of the basin (i.e. the BLM-managed Federal Land area). The description of the hydrogeology presented herein is based on best available information for the subbasin. Hydrogeologic information for the Marina-Ord Area and the Corral de Tierra Area are described independently given the uncertainty regarding the connections between the different aquifers and strata identified in these areas.

### 4.2.1 Cross Sections

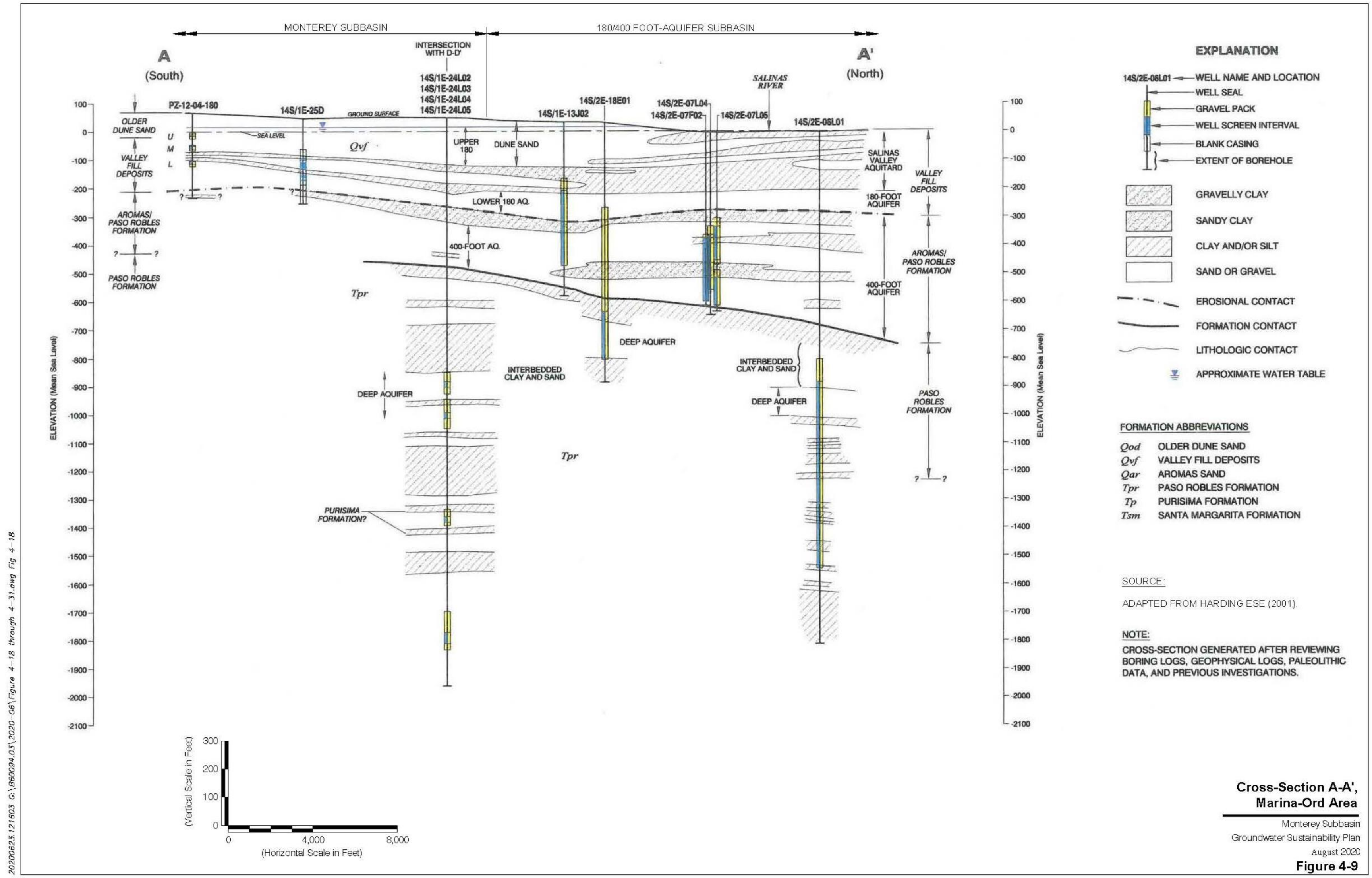
#### 4.2.1.1 *Cross Sections in the Marina-Ord Area*

Figure 4-8 through Figure 4-12 present cross-sections that illustrate the geologic setting and hydrostratigraphy beneath the Marina-Ord Area. These cross-sections are derived from *Hydrogeologic Investigation of the Salina Valley Basin in the Vicinity of the Fort Ord and Marina* (Harding ESE, 2001).


Cross-Section Locations

Monterey Subbasin
Groundwater Sustainability Plan
August 2020

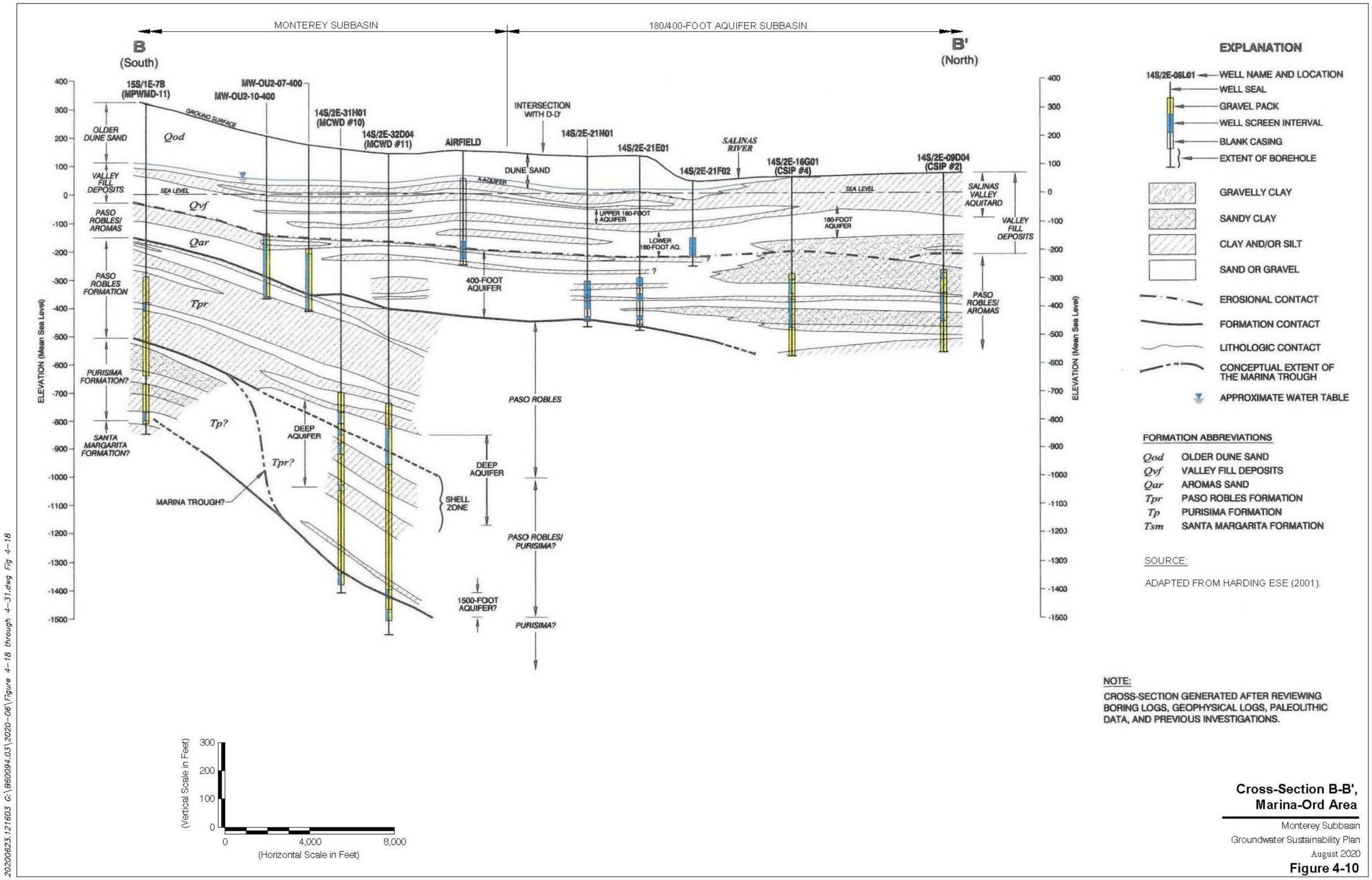
**Figure 4-8**

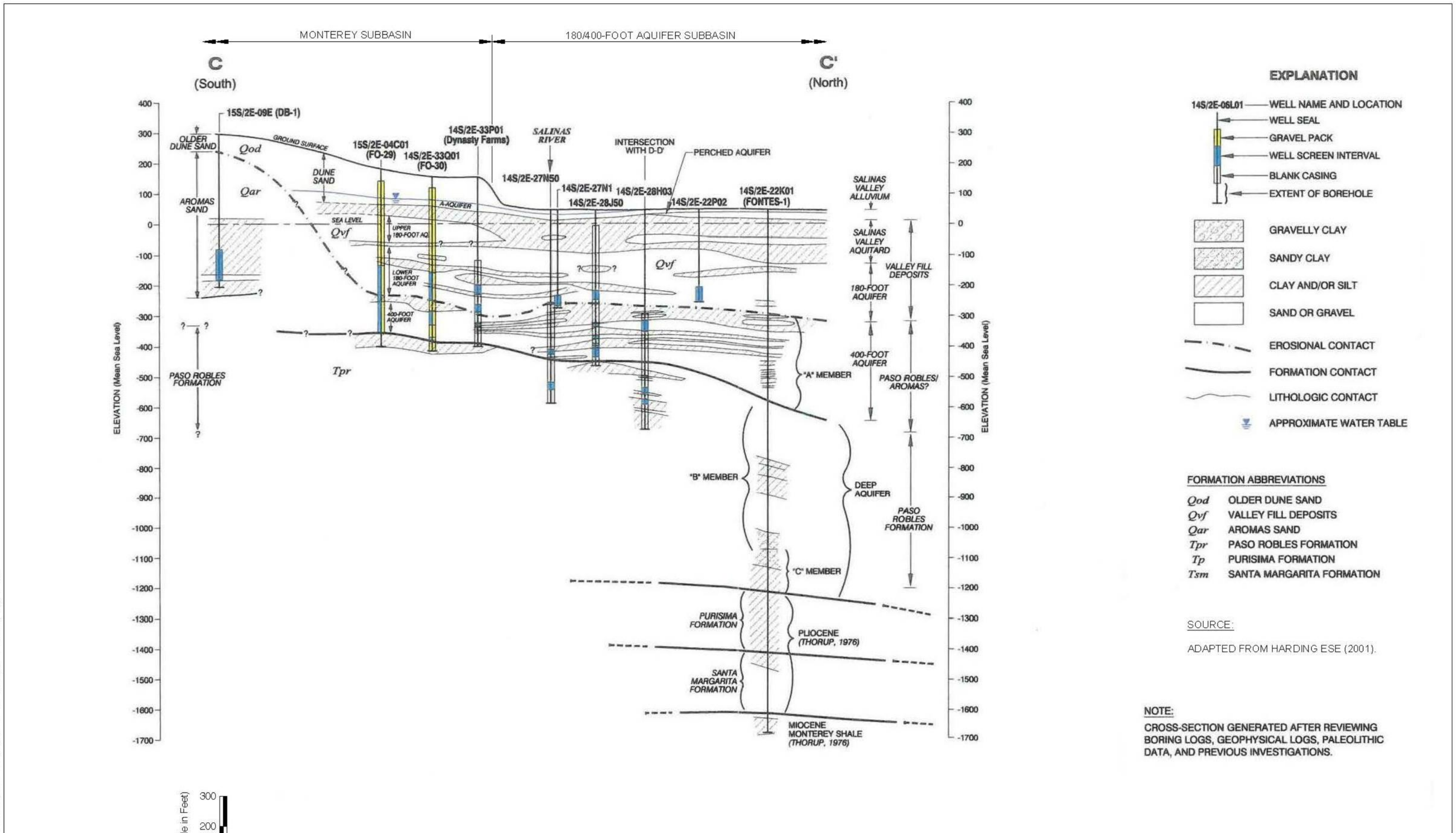



Cross-Section A-A', Marina-Ord Area

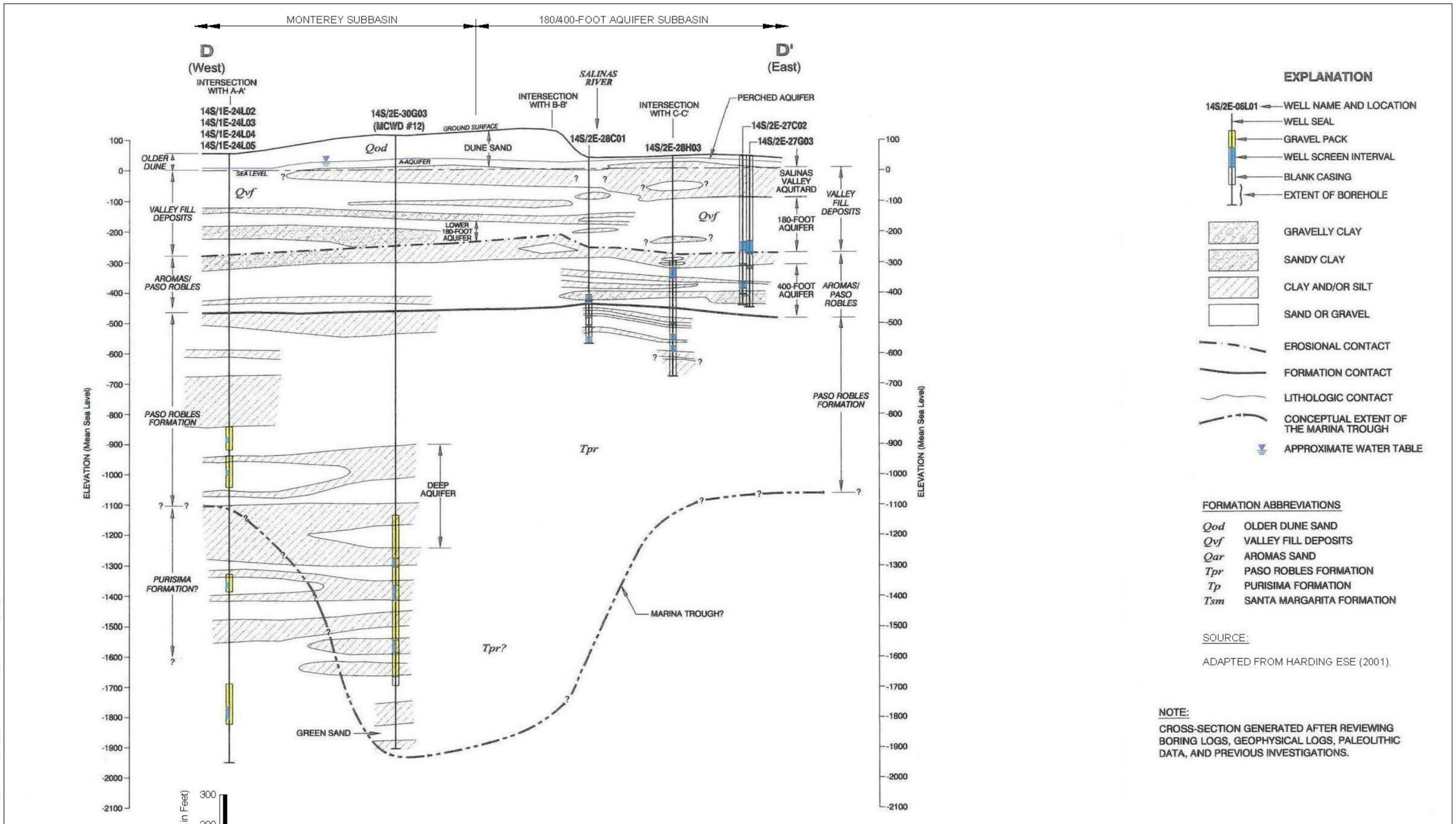
Monterey Subbasin
Groundwater Sustainability Plan
August 2020

**Figure 4-9**


MONTEREY SUBBASIN
180/400-FOOT AQUIFER SUBBASIN
B (South)
B' (North)
EXPLANATION
WELL NAME AND LOCATION
WELL SEAL
GRAVEL PACK
WELL SCREEN INTERVAL
BLANK CASING
EXTENT OF BOREHOLE
GRAVELLY CLAY
SANDY CLAY
CLAY AND/OR SILT
SAND OR GRAVEL
EROSIONAL CONTACT
FORMATION CONTACT
LITHOLOGIC CONTACT
CONCEPTUAL EXTENT OF THE MARINA TROUGH
APPROXIMATE WATER TABLE
FORMATION ABBREVIATIONS
Qod OLDER DUNE SAND
Qvf VALLEY FILL DEPOSITS
Qar AROMAS SAND
Tpr PASO ROBLES FORMATION
Tp PURISIMA FORMATION
Tsm SANTA MARGARITA FORMATION
SOURCE:
ADAPTED FROM HARDING ESE (2001).
NOTE:
CROSS-SECTION GENERATED AFTER REVIEWING BORING LOGS, GEOPHYSICAL LOGS, PALEOLITHIC DATA, AND PREVIOUS INVESTIGATIONS.
ELEVATION (Mean Sea Level)
15S/1E-7B (MPWMD-11)
MW-OU2-07-400
MW-OU2-10-400
14S/2E-31H01 (MCWD #10)
14S/2E-32D04 (MCWD #11)
AIRFIELD
INTERSECTION WITH D-D'
14S/2E-21N01
14S/2E-21E01
14S/2E-21F02
SALINAS RIVER
14S/2E-16G01 (CSIP #4)
14S/2E-09D04 (CSIP #2)
OLDER DUNE SAND
VALLEY FILL DEPOSITS
PASO ROBLES/ AROMAS
PASO ROBLES FORMATION
PURISIMA FORMATION?
SANTA MARGARITA FORMATION?
GROUND SURFACE
SEA LEVEL
DUNE SAND
A-AQUIFER
UPPER 180-FOOT AQUIFER
LOWER 180-FOOT AQ.
180-FOOT AQUIFER
400-FOOT AQUIFER
SALINAS VALLEY AQUITARD
DEEP AQUIFER
SHELL ZONE
MARINA TROUGH?
PASO ROBLES
PASO ROBLES/ PURISIMA?
1500-FOOT AQUIFER?
PURISIMA?
Qod
Qvf
Qar
Tpr
Tp?
Tpr?
(Vertical Scale in Feet)
(Horizontal Scale in Feet)
Cross-Section B-B', Marina-Ord Area
Monterey Subbasin
Groundwater Sustainability Plan
August 2020
Figure 4-10
20200623.121603 G:\B60094.03\2020-06\Figure 4-18 through 4-31.dwg Fig 4-18




Cross-Section C-C', Marina-Ord Area
Monterey Subbasin
Groundwater Sustainability Plan
August 2020
Figure 4-11




**Cross-Section D-D', Marina-Ord Area**

Monterey Subbasin
Groundwater Sustainability Plan
August 2020

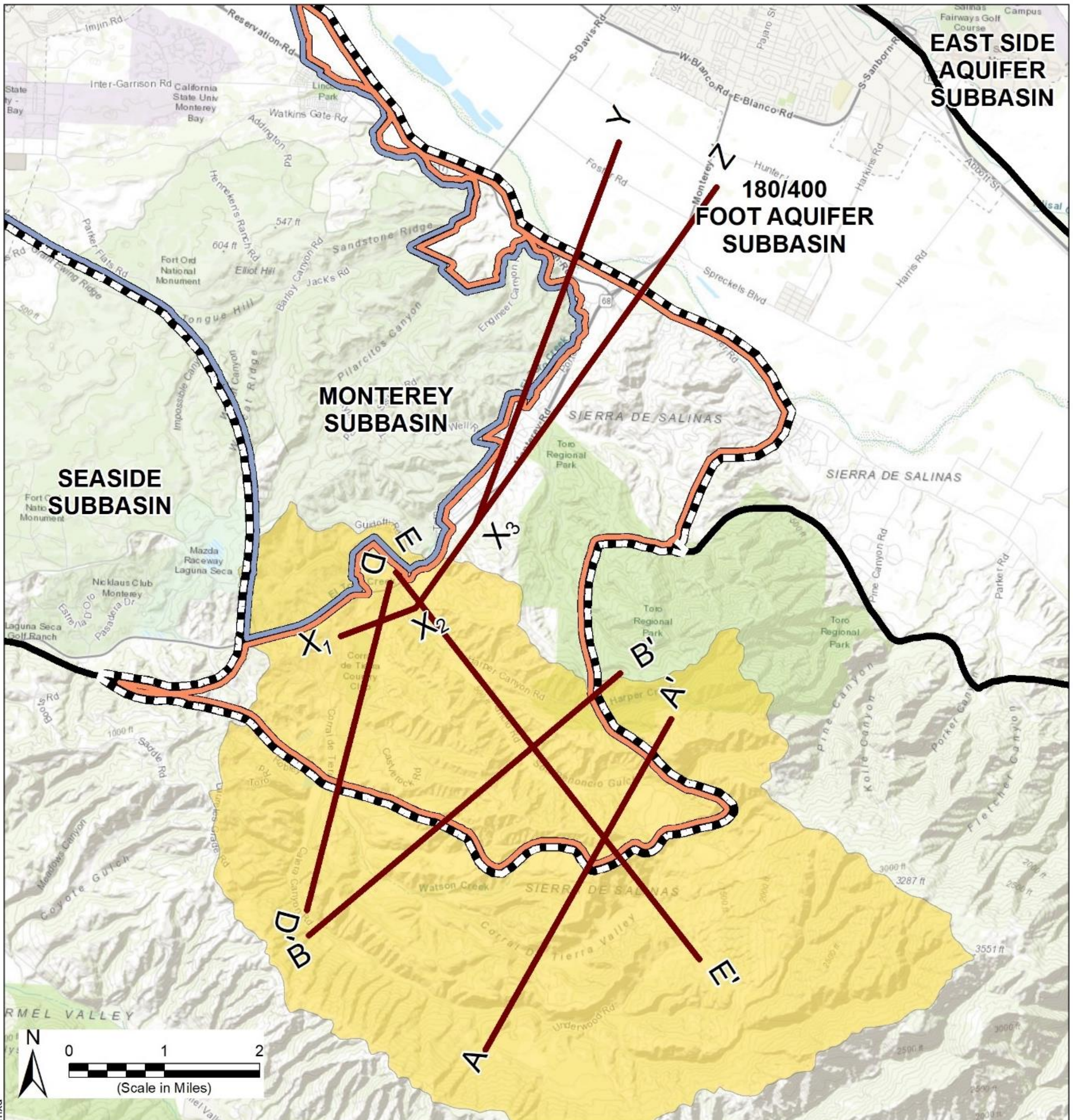
**Figure 4-12**

20200623.121603 G:\B60094.03\2020-06\Figure 4-18 through 4-31.dwg Fig 4-18

#### 4.2.1.2 *Cross Sections in the Corral de Tierra Area*

Figure 4-13 through Figure 4-18 present cross-sections that illustrate the geologic setting beneath the Corral de Tierra Area as well as a geologic map of the area that shows the geologic formations present at ground surface. The legends in each of the figures presents the age sequence of the geologic materials from the youngest unconsolidated Quaternary sediments to the oldest pre-Cretaceous basement rock where it may be present.

The cross-sections for the Corral de Tierra Area are derived from the *El Toro Groundwater Study* (GeoSyntec, 2007) and the *Supplement to the El Toro Study* (GeoSyntec, 2010). These cross-sections illustrate the faulted and warped geologic features of the area.




Path: X:\B60094\Maps\2020\12\Fig4-13_CrossSectLocations_CDT.mxd

Legend

- Monterey Subbasin
- Other Groundwater Subbasins within Salinas Valley Basin
- Cross-Section Locations
- El Toro Planning Area (Note

**Management Areas**

- Marina-Ord Area
- Corral de Tierra Area

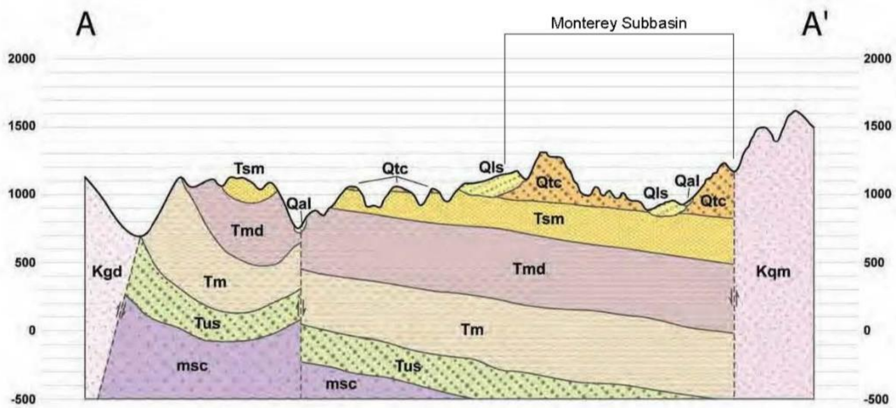
Notes
1. All locations are approximate.
2. Area of interest of the 2007 El Toro Groundwater Study (Geosyntec, 2007).

Sources
1. DWR groundwater basins are based on the boundaries defined in California's Groundwater, Bulletin 118 - 2018 Update.
2. Basemap adapted from Plate 2 of Harding ESE, 2001.

**Cross-Section Locations**
**Corral de Tierra Area**

Monterey Subbasin
Groundwater Sustainability Plan
December 2020

**Figure 4-13**



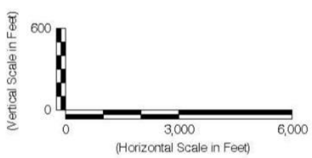

Legend:

- Qal - Alluvial Deposits
- Qls - Landslide Deposits
- Qtc - Continental Deposits (Aromas - Paso Robles)
- Tsm - Santa Margarita*
- Tmd - Monterey Formation (Upper Formation)
- Tm - Monterey Formation (Lower Formation)
- Tus - Basal Sands
- Kgd - Granodiorite
- Kqm - Garnetiferous Quartz Monzonite
- msu - Schist

* El Toro Primary Aquifer System

Source:

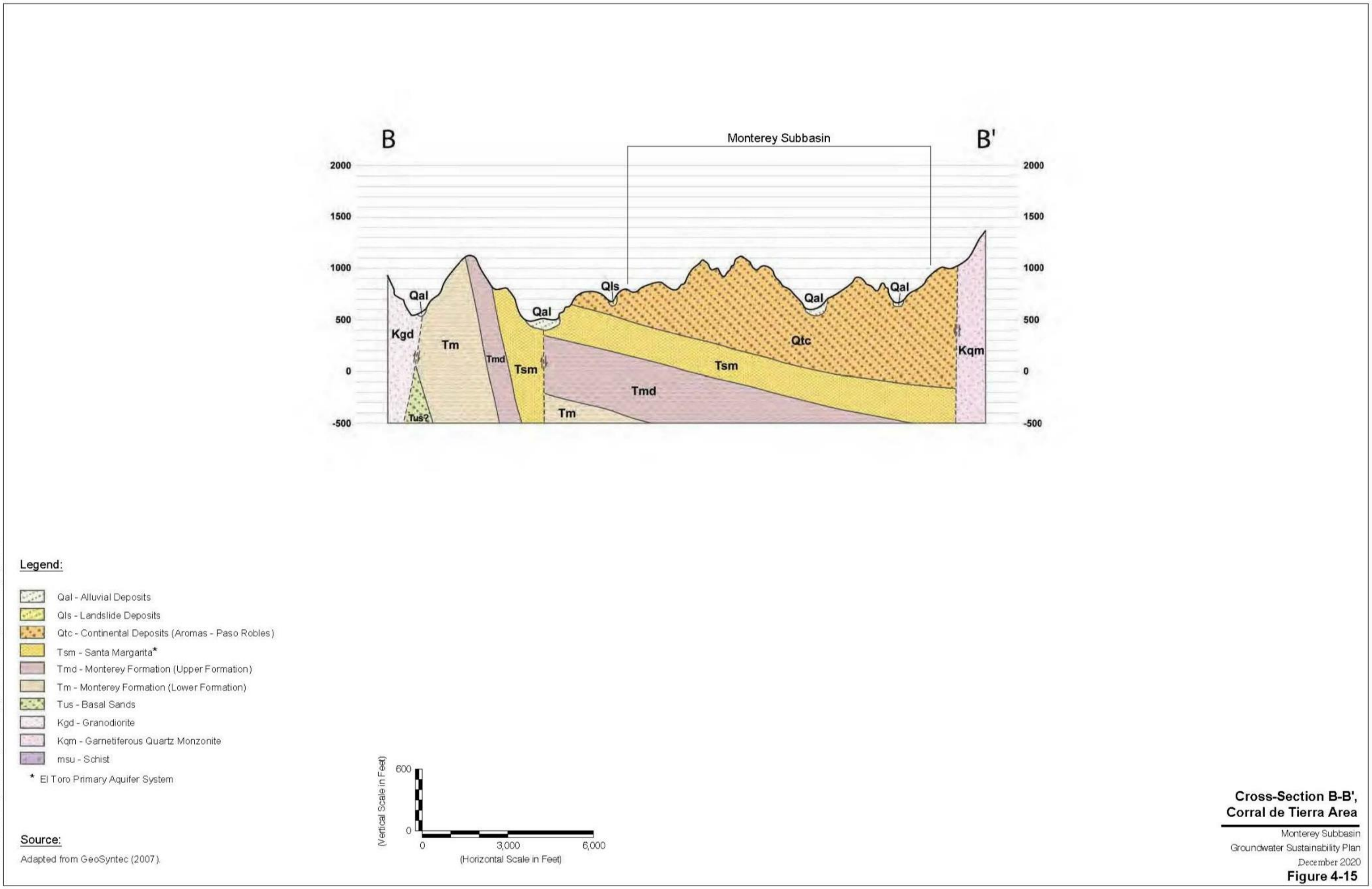
Adapted from GeoSyntec (2007).




**Cross-Section A-A',**
**Corral de Tierra Area**

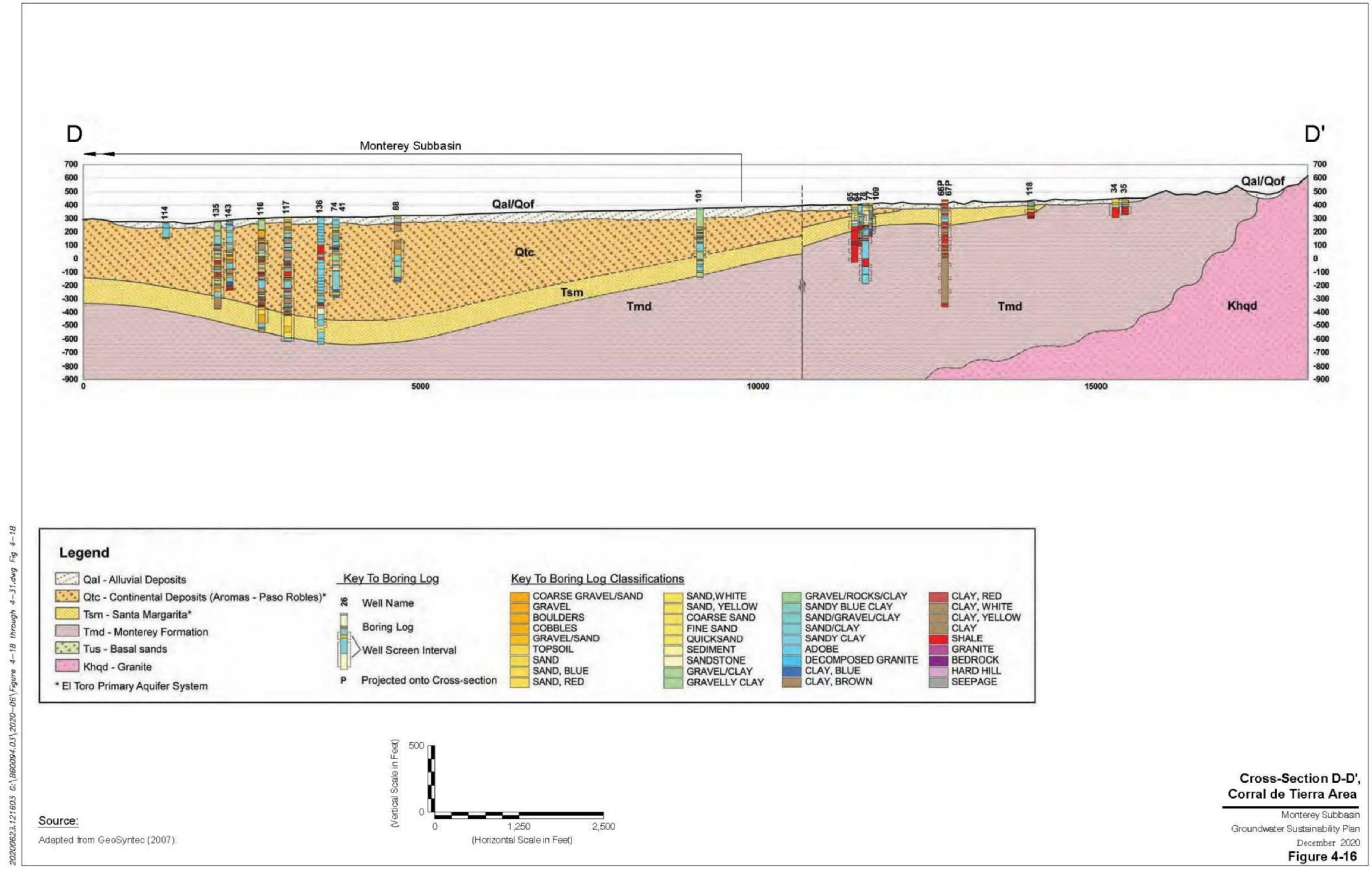
Monterey Subbasin
Groundwater Sustainability Plan
December 2020
**Figure 4-14**

20200623.121603 G:\B60094.03\2020-06\Figure 4-18 through 4-31.dwg Fig 4-18




**Cross-Section B-B', Corral de Tierra Area**

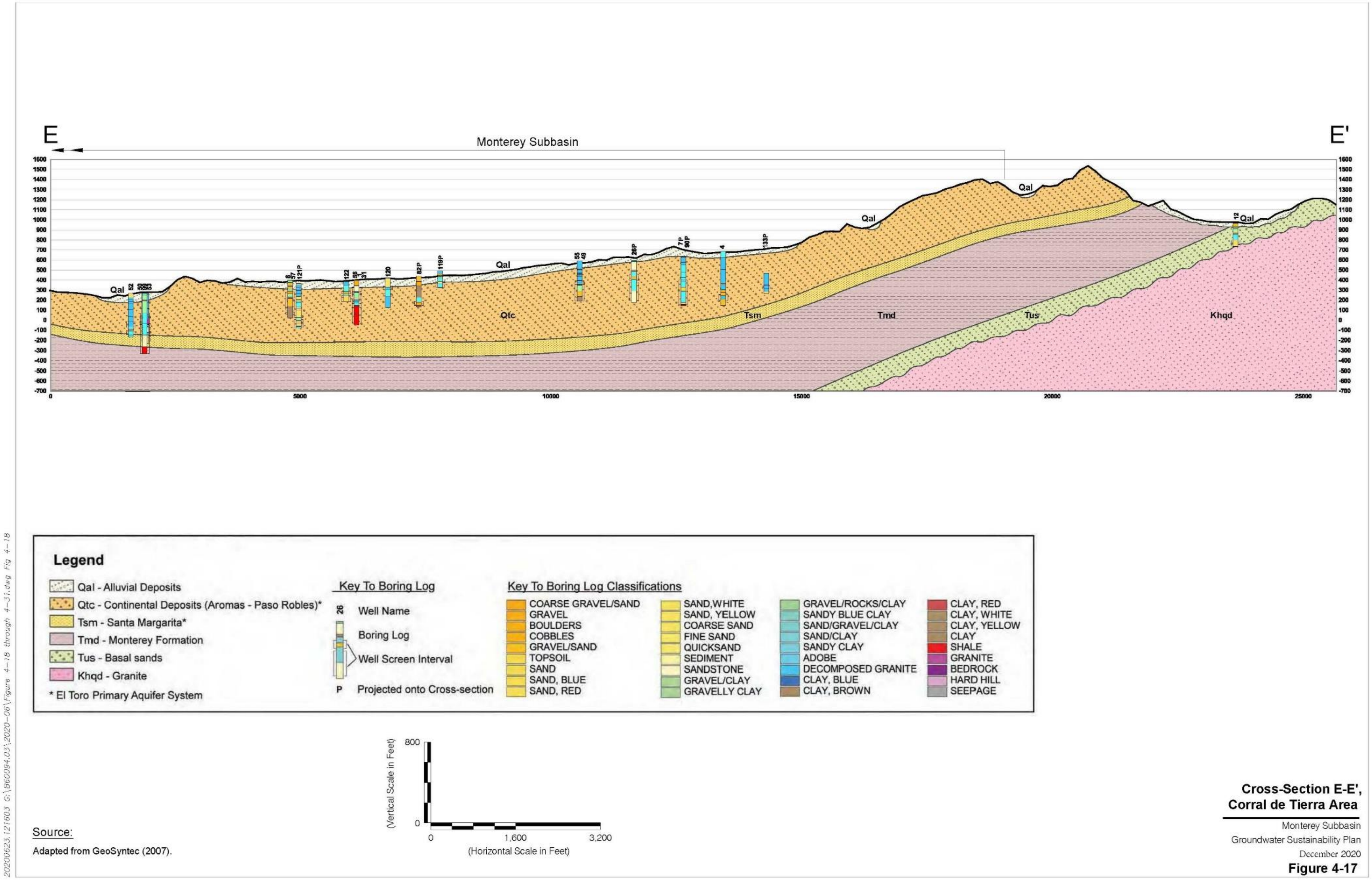
**Figure 4-15**




**Cross-Section D-D', Corral de Tierra Area**

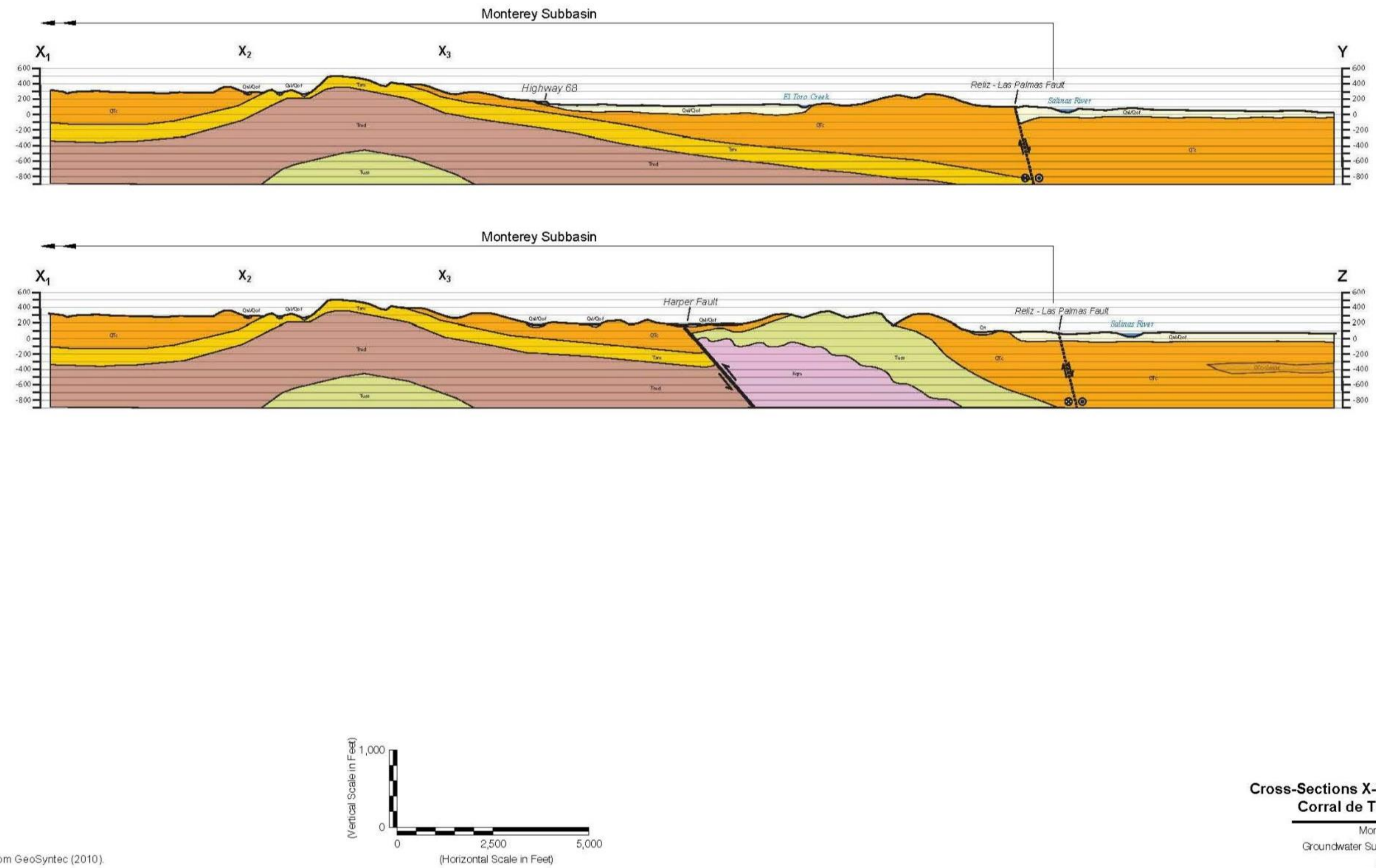
Monterey Subbasin
Groundwater Sustainability Plan
December 2020

**Figure 4-16**




**Cross-Section E-E',**
**Corral de Tierra Area**

Monterey Subbasin
Groundwater Sustainability Plan
December 2020
**Figure 4-17**




Source:
Adapted from GeoSyntec (2010).

**Cross-Sections X-Y and X-Z**
**Corral de Tierra Area**

Monterey Subbasin
Groundwater Sustainability Plan
December 2020
**Figure 4-18**

20200623.121603 G:\B60094.03\2020-06\Figure 4-18 through 4-31.dwg Fig 4-18

### 4.2.2 **Principal Aquifers and Aquitards**

Hydrostratigraphy in the Marina-Ord Area consists of a series of laterally continuous aquifers consistent with the aquifers that form the distinguishing features of the northern Salinas Valley. The aquifers that have historically been identified in the Marina-Ord Area in previous reports include the unconfined Dune Sand Aquifer and the confined aquifers known as the 180-Foot Aquifer, the 400-Foot Aquifer, and the Deep Aquifers. Within the southern Corral de Tierra area, the aquifers have historically been described by their geologic names, such as the Aromas Sand, Paso Robles Formation, and Santa Margarita Sandstone (Geosyntec, 2007; Yates 2005). Based on best available information, these geologic formations are grouped together to form the El Toro Primary Aquifer System for the Corral de Tierra Area, which is described in more detail below. These geologic formations also comprise portions of the 400-Foot Aquifer and the Deep Aquifers in the northern Salinas Valley including the Marina-Ord Area. Even though the geology is the foundation for the principal aquifers of the subbasin, the principal aquifers are not solely determined by the geologic formations. These relationships will be described in more detail in the sections below.

The following set of principal aquifers are defined in the Monterey Subbasin:

- Dune Sand Aquifer
- Fort-Ord/Salinas Valley Aquitard
- 180-Foot Aquifer
- 180/400-Foot Aquitard
- 400-Foot Aquifer
- 400-Foot/Deep Aquitard
- Deep Aquifers
- El Toro Primary Aquifer System

Not all of these principal aquifers occur across the entire Monterey Subbasin due to the complex geologic setting present. The Dune Sand and 180-Foot Aquifers are generally not present in the Corral de Tierra Area, although they are present in the Marina-Ord area. In the Marina-Ord area the 180-Foot Aquifer is connected to the 180-Foot Aquifer in the 180/400-Foot Aquifer Subbasin. The Paso Robles, Santa Margarita, and Purisima Formations are generally present across the whole subbasin, even though the correlated principal aquifers are not. These formations and correlated principal aquifers are also in connection with the equivalent principal aquifers in the 180/400-Foot and Seaside Subbasins. The geologic and hydrostratigraphic transition between Marina-Ord and Corral de Tierra areas through former Fort Ord is not well studied or understood.

#### 4.2.2.1 *Marina-Ord Area*

The principal aquifer and aquitard designations and relationships to geologic formations are illustrated in Table 4-1. This table is based on the 2017 Monterey County Water Resources Agency's *Recommendations* *to address the expansion of seawater intrusion in the Salinas Valley groundwater basin* report, but has been modified to reflect specific hydrogeologic conditions and relationships within the subbasin (Harding ESE, 2001; Rosenberg & Feeney, 2003).

**Table 4-1. Generalized Geologic-Hydrogeologic Relationships**

<table>
<tr><th>Period/Epoch</th><th>Geological Unit</th><th>Principal Aquifers and Aquitards</th></tr>
<tr><td>Holocene</td><td>Recent Dune Sand (Qd)<br>Older Dune Sand (Qod)</td><td>Dune Sand Aquifer</td></tr>
<tr><td rowspan="8">Pleistocene</td><td rowspan="2">Old Alluvium / Valley Fill Deposits (Qo/Qvf)</td><td>Fort Ord-Salinas Valley Aquitard</td></tr>
<tr><td rowspan="2">180-Foot Aquifer</td></tr>
<tr><td rowspan="3">Aromas Sand (Qae)</td></tr>
<tr><td>180/400-Foot Aquitard</td></tr>
<tr><td rowspan="2">400-Foot Aquifer</td></tr>
<tr><td rowspan="3">Paso Robles Formation (QT)</td></tr>
<tr><td>400-Foot/Deep Aquitard</td></tr>
<tr><td rowspan="4">Deep Aquifers</td></tr>
<tr><td rowspan="2">Pliocene</td><td>Purisima Formation (Ppu)</td></tr>
<tr><td rowspan="2">Santa Margarita Formation (Msm)</td></tr>
<tr><td rowspan="2">Miocene</td></tr>
<tr><td>Monterey Formation (</td><td>N/A<br>(Minimally Water-Bearing)</td></tr>
</table>

#### *4.2.2.1.1 Dune Sand Aquifer*

The Dune Sand Aquifer is composed of fine to medium, well sorted dune sands of Holocene age (Ahtna Engineering, 2013). The Dune Sand Aquifer is also sometimes referred to as the "A-Aquifer" beneath Fort Ord (Harding Lawson Associates (HLA, 1994; Jordan et al., 2005; Harding ESE, 2001). Groundwater in the Dune Sand Aquifer is unconfined. The aquifer is perched away from the coast, in areas where the Fort Ord-Salinas Valley Aquitard (FO-SVA) exists and groundwater in the 180-Foot Aquifer has fallen below the bottom elevation of the FO-SVA. It is hydraulically connected to the underlying 180-Foot Aquifer in areas nearer to the coast. The average saturated thickness of the Dune Sand Aquifer is approximately 50 feet. As shown on Figure 4-7, the sandy soils of this aquifer have high infiltration potential.

A north-south trending groundwater divide exists in the Dune Sand Aquifer. West of the groundwater divide, groundwater in the Dune Sand Aquifer flows westward and both recharges the 180-Foot Aquifer and flows to the Pacific Ocean near the edge of the FO-SVA. Water from the Dune Sand Aquifer that recharges the 180-Foot Aquifer flows in response to gradients in the 180-Foot Aquifer, which is currently eastward (i.e. inland). East of the groundwater divide, groundwater in the Dune Sand Aquifer flows northeastward towards the Salinas River. A conceptual model of this groundwater flow is shown on Figure 4-19 below.

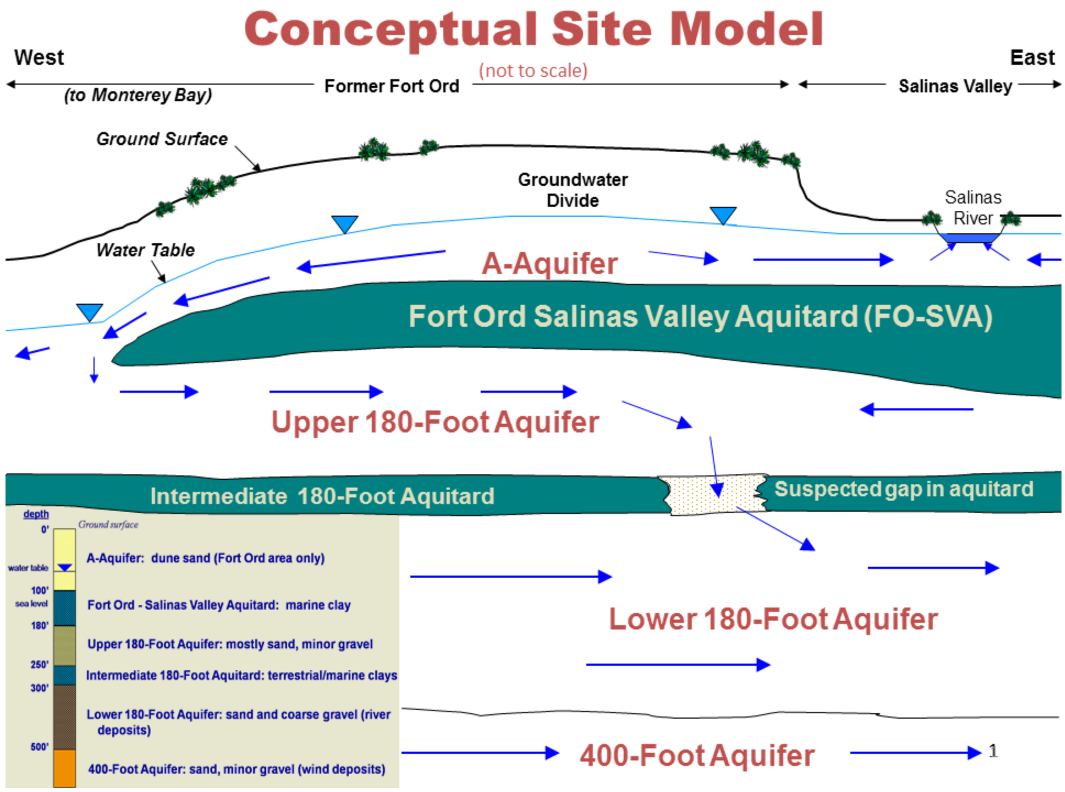



**Figure 4-19. Conceptual Model of Principal Aquifers in the Marina-Ord Area**

This aquifer is recharged primarily by rainfall infiltration and in turn provides a source of deep percolation into the upper 180-Foot aquifer and eventually into the lower 180-Foot and 400-Foot Aquifers in the Monterey Subbasin (HLA, 1994).

Extraction and infiltration activities associated with remediation in the former Fort Ord take place within the Dune Sand Aquifer.

#### *4.2.2.1.2 <u>Fort Ord-Salinas Valley Aquitard</u>*

The Fort Ord-Salinas Valley Aquitard (FO-SVA) is an aquitard composed of laterally extensive blue or yellow sandy clay layers with minor interbedded sand layers (Harding ESE, 2001; DWR, 2003). The FO-SVA generally correlates to the Pleistocene Older Alluvium stratigraphic unit, which is shown as Valley Fill. The FO-SVA was deposited in a shallow sea during a period of relatively high sea level. Harding ESE noted that the FO-SVA beneath the former Fort Ord may be formed under a different depositional event than the Salinas Valley Aquitard (SVA) unit beneath the Salinas Valley (e.g. estuarine deposits vs. flood plain deposits). However, the two clay units are hydraulically equivalent (Harding ESE, 2001).

The FO-SVA is generally encountered at depths of less than 150 feet. While this clay layer is relatively continuous in the northern portion of the Valley, it is not monolithic across the subbasin. The clay layer is missing in some areas and pinches out in certain areas.

Within the Subbasin, the FO-SVA is continuous beneath the City of Marina and most of Fort Ord (Harding ESE, 2001; Kennedy/Jenks, 2004; Ahtna Engineering, 2013; MACTEC, 2006). The extent of the FO-SVA is illustrated on Figure 4-20. The FO-SVA thins towards the Monterey Subbasin/Seaside Subbasin boundary as well as toward the coast, where it appears to pinch out near Highway 1 (Harding ESE, 2001). The thinning and pinching out of the FO-SVA in these locations increases the vertical hydraulic connection between the Dune Sand Aquifer and underlying 180-Foot Aquifer.

#### *4.2.2.1.3 <u>180-Foot Aquifer</u>*

The FO-SVA generally overlies and confines the 180-Foot Aquifer. The 180-Foot Aquifer consists of interconnected sand and gravel beds that are from 50 to 150 feet thick. The sand and gravel layers of this aquifer are interlayered with clay lenses (Ahtna Engineering, 2013). This aquifer is correlated to the Older Alluvium (Valley Fill) or upper Aromas Sand formations (Harding ESE, 2001; Kennedy-Jenks, 2004; Ahtna Engineering, 2013).

The gravels, sands, and interspersed clays of the 180-Foot Aquifer are found in the vicinity of the City of Marina and extend a short distance southwest beyond the extent of the FO-SVA (HLA, 1994). Beneath the ocean, the sediments "extend to submarine outcrops on the floor and canyon walls of Monterey Bay (Harding ESE, 2001; Todd Engineers, 1989; Greene, 1977; DWR, 1946). As discussed above, the aquifer is confined where overlain by the FO-SVA. It may become unsaturated where groundwater elevation is lower than the bottom elevation of the FO-SVA, or unconfined where the FO-SVA pinches out. The 180-Foot Aquifer is found generally at depths between 100 and 400 ft bgs beneath the Marina-Ord Area, with varying thickness.

South of the City of Marina, in a portion of the former Fort Ord, the 180-Foot Aquifer is separated into an "upper" zone of sandy deposits with some gravel and a "lower" zone of gravel with sand and clay lenses; the two zones are separated by a thin clay layer (Ahtna Engineering, 2013). Data collected within the former Fort Ord show that significant head differences exist between the upper and lower zones of the 180-Foot Aquifer.

The 180-Foot Aquifer receives recharge from the overlying Dune Sand Aquifer as well as percolation through the FO-SVA, and rainfall and surface water infiltration in areas where the FO-SVA does not exist. This recharge mechanism is also supported by the similar geochemistry between the Dune Sand Aquifer and the 180-Foot Aquifer (Section 4.2.4.1). Subsurface inflows and outflows to the 180-Foot Aquifer also occur from 180-Foot Aquifer of the 180/400 Foot Aquifer Subbasin and from the Aromas Sand southeast of the former Fort Ord where there may be hydrologic connection (HLA, 1994).

The primary uses of the 180-Foot Aquifer are for municipal water supply in the lower 180-Foot Aquifer. Extraction and infiltration activities associated with remediation in the former Fort Ord also take place within the 180-Foot Aquifer.

*4.2.2.1.4 <u>180/400-Foot Aquitard</u>*

The base of the 180-Foot Aquifer is the 180/400-Foot Aquitard. This aquitard consists of interlayered clay and sand layers, including a marine blue clay layer (DWR, 2003). The 180/400-Foot aquitard varies in thickness and quality across the basin, and "varies laterally throughout the Fort Ord area" (MACTEC, 2006). Therefore, areas of hydrologic connection between the 400-Foot and 180-Foot Aquifers exist, and Fort Ord is one of several locations where this aquitard is thin or discontinuous (Kennedy-Jenks, 2004).

*4.2.2.1.5 <u>400-Foot Aquifer</u>*

The 400-Foot Aquifer is comprised of fine to medium-grained sand with varying degrees of interbedded clay lenses (Ahtna Engineering, 2013). The 400-Foot Aquifer appears to be composed of portions of the Aromas Sand near the coast, and the upper 200 feet of the Paso Robles Formation (HLA, 1994; Harding ESE, 2001), although it is sometimes difficult to delineate the transition between the two formations (Harding ESE, 2001). It is usually encountered between 270 and 470 feet below ground surface in the Marina-Ord area. The upper portion of the 400-Foot Aquifer merges and interfingers with the 180-Foot Aquifer in some areas where the 180/400-Foot Aquitard is missing (DWR, 1973).

Due to its geologic composition, the 400-Foot Aquifer has been believed to be connected to the shallow Paso Robles aquifer in Seaside Subbasin (Yates, 2005). In the Seaside Basin, this aquifer consists of several continuous water producing zones and unconfined zones where granular materials of the Paso Robles Formation are in contact with surficial deposits.

Recharge to this aquifer likely occurs from both the overlying 180-Foot Aquifer and outcrops of the Aromas Sand and Paso Robles Formations in and near the Corral de Tierra Area. Groundwater flow direction in the 400-Foot Aquifer is influenced by groundwater pumping, and the connection with neighboring Subbasins.

The primary uses of the 400-Foot Aquifer are for municipal supply in the Marina-Ord Area.

*4.2.2.1.6 <u>400-Foot/Deep Aquitard</u>*

The base of the 400-Foot Aquifer is the 400-Foot/Deep Aquitard. In some areas of the Salinas Valley Basin, this aquitard can be several hundred feet thick (Kennedy-Jenks, 2004). However, boring logs in the Marina-Ord Area indicates that a series of aquitards underly 400-Foot Aquifer and extend into the Deep Aquifers. There is no analysis available for the spatial occurrence or geologic composition of the 400-Foot/Deep Aquitard. It is likely comprised of Paso Robles Formation deposits.

*4.2.2.1.7 <u>Deep Aquifers</u>*

The Deep Aquifers are also collectively referred to as the 900-Foot Aquifer or 900-Foot and 1500-Foot Aquifers in the northern Salinas Valley. The Deep Aquifers are up to 900 feet thick and have alternating sandy-gravel layers and clay layers which do not differentiate into distinct aquifer and aquitard units (DWR, 2003). The Deep Aquifers may also refer to all the water-bearing sediments beneath the 400-Foot Aquifer.

Within the Monterey Subbasin, the Deep Aquifers comprise the middle and lower portions of the Paso Robles Formation, the Purisima Formation and the Santa Margarita Sandstone (Hanson et al., 2002; Yates, 2005). The Deep Aquifers are also likely connected to the deep Santa Margarita aquifer in Seaside

Subbasin (Yates, 2005). The Deep Aquifers overlie the low permeability Monterey Formation, which is the bottom of the subbasin.

Due to the geologic formations' depositional environments, the Deep Aquifers consist of alternating layers of sand and gravel mixtures with discontinuous clays rather than distinct, coherent aquifers and aquitards (Brown and Caldwell, 2015). There is a strong likelihood of flow through these confining layers (MCWRA, 2018).

The recharge mechanisms for the Deep Aquifers are not well known. There is likely some recharge from overlying aquifers, as downward vertical gradients exist (Thorup, 1976; Feeney and Rosenberg, 2003). Additional recharge may come from outcrops of Santa Margarita Sandstone or Paso Robles Formation in the Corral de Tierra area. There are no known recharge mechanisms or pathways for the Purisima Formation other than from leakage from overlying aquifers and there are no surficial outcrops of the Purisima Formation in the Salinas Valley Basin (Feeney and Rosenberg, 2003). Some extractions may be supported by depletion of ground water storage (Feeney and Rosenberg, 2003). Specific storage was calculated at 0.000013, which suggests that the volume of ground water that can be removed from storage is not large (Feeney and Rosenberg, 2003).

Oxygen and deuterium analyses of water from the Deep Aquifers suggest that, unlike the upper aquifer system (i.e. 180-Foot and 400-Foot Aquifers), water in the Deep was not recharged under current climatic conditions (MCWRA, 2017). Additionally, tritium and carbon-14 analyses of Deep Aquifers water indicate that it was recharged thousands of years before present (Hanson et al., 2002). Age dating of groundwater by USGS indicates that groundwater in the Deep Aquifers near the Monterey Coast may be 25,000 to 30,000 years old (Hanson et al., 2002).

The Deep Aquifers are used primarily for municipal water supply in the Marina-Ord Area.

#### 4.2.2.2 *Corral de Tierra Area*

There is one single principal aquifer in the Corral de Tierra Area called the El Toro Primary Aquifer System. Groundwater is produced from the following water-bearing geologic units: the Aromas Sands, the Paso Robles Formation, and the Santa Margarita Sandstone. These water-bearing geologic units are grouped together to form the El Toro Primary Aquifer System (GeoSyntec, 2007). These formations are grouped into one functional primary aquifer due to many wells being screened across more than one formation in this area. The longer screen lengths allow for better well yields as this design accesses more saturated thickness of the aquifer.

The shallowest water-bearing sediments within the Corral de Tierra Area are thin and occur along stream corridors. These sediments range from 0 to 120 feet thick and are a part of the Holocene alluvium unit (GeoSyntec, 2007). The geologic map in Figure 4-2 shows this unit as Q; the cross-sections in Figure 4-14 through Figure 4-18 show this unit as Qal and Qof. Several small domestic wells draw groundwater from these local alluvial aquifers, but these volumes of groundwater are minimal (GeoSyntec, 2007). Since this volume of groundwater is neither economic nor significant, these shallow sediments are not considered a principal aquifer, nor are they included in the El Toro Primary Aquifer System. Groundwater in these sediments is hydraulically connected to both the small streams found in the area and the principal aquifer due to a lack of continuous or regional aquitard to interrupt infiltration and percolation (El Toro Creek, San Benancio Gulch, Watson Creek, and Calera Creek; see Section 4.3) (GeoSyntec, 2007).

Beneath the shallow sediments, the following principal aquifer is recognized as the distinguishing hydrostratigraphic feature of this area:

- El Toro Primary Aquifer System

Immediately outside the southern end of the Subbasin, small amounts of groundwater are also produced from the Monterey Formation and the unnamed sandstone which underlies the Monterey Formation (Anderson-Nichols and Co., 1981). Additional information regarding hydrogeology of these formations can be found in the *El Toro Groundwater Study* and the *Seaside Groundwater Basin Modeling and Protective Groundwater Elevations* report (Geosyntec, 2007; HydroMetrics, 2009). This volume of groundwater is neither economic nor significant, there is no known extraction from the unnamed sandstone within the Corral de Tierra Area. Additionally, the Monterey Formation is defined as the bottom of the basin. As such, neither the Monterey Formation nor the unnamed sandstone are considered a principal aquifer, nor are they included in the El Toro Primary Aquifer System.

#### *4.2.2.2.1 El Toro Primary Aquifer System*

The El Toro Primary Aquifer System is comprised of the Aromas Sands, the Paso Robles Formation, and the Santa Margarita Sandstone together since many production wells are screened across more than one unit in the Corral de Tierra Area, thereby causing the hydrostratigraphy to effectively function as one aquifer.

Within the Corral de Tierra Area, the eolian Aromas Sands deposits are up to 200 feet thick and comprise the hills in the Area. The Paso Robles Formation comprises a series of nonmarine, semi-consolidated continental deposits that consist of fine to coarse-grained sands and gravels of Plio-Pleistocene age. Due to local variations of conformability and similarity of sediments, these units are sometimes referred to collectively as continental deposits (GeoSyntec, 2007). The geologic map in Figure 4-2 shows the Aromas Sand and Paso Robles Formation units as Qae and QT, respectively. The Aromas Sand and Paso Robles units are grouped together and shown on the cross-sections as undifferentiated Qtc.

The Paso Robles Formation is frequently found at the surface in the Corral de Tierra area. The uppermost 200 feet of the Paso Robles Formation deposits are recognized as forming much of the 400-Foot Aquifers in the greater Salinas Valley Groundwater Basin (Harding ESE, 2001). The remaining portions of the Paso Robles Formation form portions of the Deep Aquifers closer to the coast. Erosion has impacted the available thickness of the Paso Robles Formation, and the transition between the outcropped locations in the Corral de Tierra area to the subterranean portions in the Marina-Ord area is not well understood due to the lack of available data through the Fort Ord area. Subsequently, the relationship to the 400-Foot Aquifer through this area is not yet defined.

The Santa Margarita Sandstone is a Miocene-aged, marine, white, thick and locally cross-bedded, very fine to coarse-grained sandstone with an average thickness of 100 to 300 feet in the Subbasin. The geologic map in Figure 4-2 shows this unit as Msm. In the geologic cross-sections, this unit is shown as Tsm. The Santa Margarita Sandstone correlated with the Deep Aquifers closer to the coast, and where it is encountered at significant depth from the surface. However, there are portions of the Santa Margarita

Sandstone that crop out in the hills northwest of highway 68, which is more northwest than the cross-sections shown in Figure 4-27 and Figure 4-28. This exemplifies the extent to which structural deformation has shaped this region's hydrostratigraphy and added complexity to understanding the principal aquifers across the subbasin.

Recharge to the El Toro Principal Aquifer System is through precipitation and through the streambeds and alluvial sediments. Groundwater flow direction is generally northward, and towards heavy pumping centers like the Laguna Seca region and the lower Corral de Tierra Canyon region.

The primary use of groundwater from the El Toro Primary Aquifer System is urban (municipal and domestic), with minimal agricultural supply.

### 4.2.3 **Structural Restrictions to Flow**

There are no known structural restrictions to flow beneath the Marina-Ord Area.

A buried trace of the Reliz Fault (also known as the Reliz-King City Fault or King City Fault) has been said to generally align with the boundary between the Monterey Subbasin and the 180/400-Foot Aquifer Subbasin. However, the location of this fault is poorly constrained or defined. Beneath the bottom of the Subbasin, the Monterey Formation is displaced downward on the northeast side of the Reliz Fault by as much as 1,000 ft (Durbin, 2007). There is no sign of fault affecting "late Pleistocene or younger sediments" (HLA, 1994; Feeney and Rosenberg, 2003). This fault does not appear to impede groundwater flow in the Dune Sand Aquifer, the 180-Foot Aquifer, or the 400-Foot Aquifer, based on observed groundwater elevation and seawater intrusion conditions across the Subbasin boundary (see Chapter 5).

The Corral de Tierra Area is surrounded by several structural features. It is bounded on the east by the Reliz Fault and the Corral de Tierra Fault to the southwest (GeoSyntec, 2007). The Harper Fault is between these two other faults, closer to the Reliz Fault (GeoSyntec, 2007). All of these faults strike to the northwest and steeply dip to the northeast. A northeast striking syncline occurs roughly along Highway 68. A deeper anticlinal feature is shown in Figure 4-2 near San Benancio Creek and appears to be orthogonal to the syncline which parallels Highway 68 (GeoSyntec, 2010). Additional east-trending anticlines are shown near the boundary between the Seaside Subbasin and the Corral de Tierra Area. Despite all structural features which bound and deform the Corral de Tierra area, none seem to indicate any barrier to flow to the rest of the Monterey Subbasin, or to the neighboring Seaside or 180/400-Foot Aquifer Subbasins. Rather, the corner of the Seaside and Corral de Tierra boundary seems to be a location of divergence of groundwater flow, where some groundwater continues to the Seaside Subbasin by way of the Laguna Seca area, and some groundwater continues to the Marina area by way of the Fort Ord National Monument, as shown in Chapter 5. This corner features a dip-rise-dip appearance in the surface of the Monterey Formation.

### 4.2.4 **General Water Quality**

This section presents a general discussion of the natural fresh groundwater quality in the Monterey Subbasin, focusing on general geochemistry. The distribution and concentrations of specific constituents of concern, including seawater intrusion, are discussed further in Chapter 5. This discussion is based on data from previous reports. Key diagrams are included in Appendix 4-A.

#### 4.2.4.1 *Marina-Ord Area*

**Dune Sand Aquifer**

Groundwater in the Dune Sand Aquifer has a sodium-chloride chemical character. Groundwater in this aquifer is primarily fresh; minimal seawater intrusion has occurred in this aquifer.

**180-Foot Aquifer**

Water quality in the 180-Foot Aquifer beneath the Marina-Ord Area is distinct from the water quality in the Salinas Valley and has a more sodium-chloride chemical character (i.e., a higher proportion of sodium and chloride) (HLA, 1994). West of the SVA, groundwater quality is similar throughout the combined Dune Sand Aquifer and 180-Foot Aquifer (HLA, 1994). Groundwater in both aquifers is likely recharged from precipitation infiltrating through similar geologic materials.

The Dune Sand Aquifer contributes recharge to the 180-Foot Aquifer, as groundwater from this aquifer flows westward until it reaches the SVA, after which it turns eastward within the 180-Foot aquifer.While seawater intrusion has occurred in the lower 180-Foot Aquifer in the northern portion of the Subbasin, groundwater the upper 180-Foot Aquifer remains fresh.

**400-Foot Aquifer**

Water quality in the 400-Foot Aquifer is chemically distinct from the water quality of the overlying Dune Sand and 180-Foot Aquifer. The 400-Foot Aquifer has a calcium-bicarbonate chemical character (HLA, 1994). However, some wells have higher concentrations of chloride, which is indicative of seawater intrusion. Wells screened in the gravel layers of the 400-Foot Aquifer have elevated concentrations of sodium. This characteristic is similar to that of wells screened in the gravel layers of the 180-Foot Aquifer and those in the Salinas Valley (HLA, 1994).

Seawater intrusion has occurred in the 400-Foot Aquifer in the northern portion of the Subbasin.

**Deep Aquifers**

Groundwater in the Deep Aquifer system is distinct from the overlaying aquifers, having a sodium-bicarbonate chemical character with relatively low concentrations of calcium (Harding ESE, 2001; Hanson et al., 2002). Water quality generally worsens (i.e., increasing chloride concentrations) with depth (Feeney and Rosenberg, 2003). Ratios of chloride-to-boron and isotope analysis (18O, 2H, 3H, 14C) were used to infer the sources and age of groundwater (Hanson et al., 2002). Groundwater in the upper portions of the Deep Aquifers had similar chloride-to-boron ratios to groundwater in the overlaying aquifers, which suggests a similar source of recharge. Groundwater in the deepest sections of the Deep Aquifers is enriched in chloride with respect to surface waters in the Salinas Valley and isotope analysis indicated the Deep Aquifers were not recharged under recent climatic conditions. Isotope analysis also revealed that the groundwater in the Deep Aquifers may have been recharged thousands of years ago (Hanson et al., 2002).

No seawater intrusion has been observed in the Deep Aquifers.

#### 4.2.4.2 *Corral de Tierra Area*

Groundwater in the El Toro Primary Aquifer System has an intermediate chemical character (no dominant cation or anion) but the chemical composition varies slightly between lithologic units. Uniform moderate to high TDS concentrations were found throughout the El Toro Primary Aquifer System, which supports the hydraulically connected geologic units. Isotope analysis further indicates that groundwater throughout the El Toro Primary Aquifer System has similar recharge sources (Geosyntec, 2007).

### 4.2.5 **Aquifer Properties**

#### 4.2.5.1 *Marina-Ord Area*

Hydraulic conductivity of the aquifers underlying the Marina-Ord Area are obtained from previous reports and presented below. Transmissivity information are included in Appendix 4-A.

**Dune Sand Aquifer**

The measured horizontal hydraulic conductivity of the Dune Sand Aquifer ranges from 0.14 to 120 feet per day (ft/d), and vertical conductivity ranges from 0.6 to 4.0 ft/d (HLA, 1994; HLA, 1999; MACTEC, 2006; HydroGeoLogic, Inc., 2006; Jordan et al., 2005). Measured horizontal hydraulic conductivity of the Dune Sand Aquifer is shown on Figure 4-20.

**180-Foot Aquifer**

Measured horizontal hydraulic conductivities in the 180-Foot Aquifer in the Fort Ord area range from 1.7 to 390 ft/d (HLA, 1994; HLA, 1999; MACTEC, 2006; HydroGeoLogic, Inc., 2006; Jordan et al., 2005). Measured horizontal hydraulic conductivities of the 180-Foot and 400-Foot Aquifers are shown on Figure 4-21.

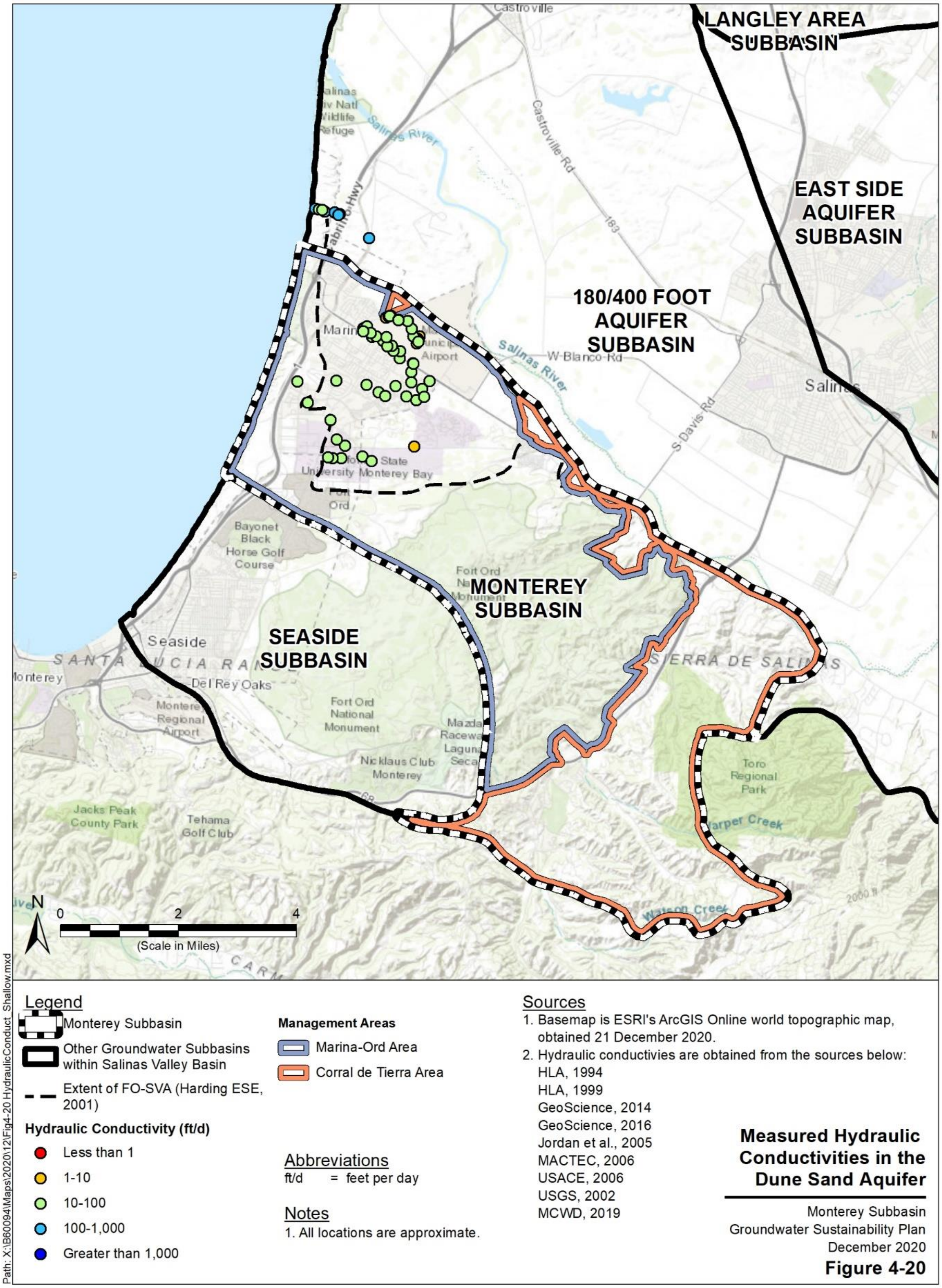
**400-Foot Aquifer**

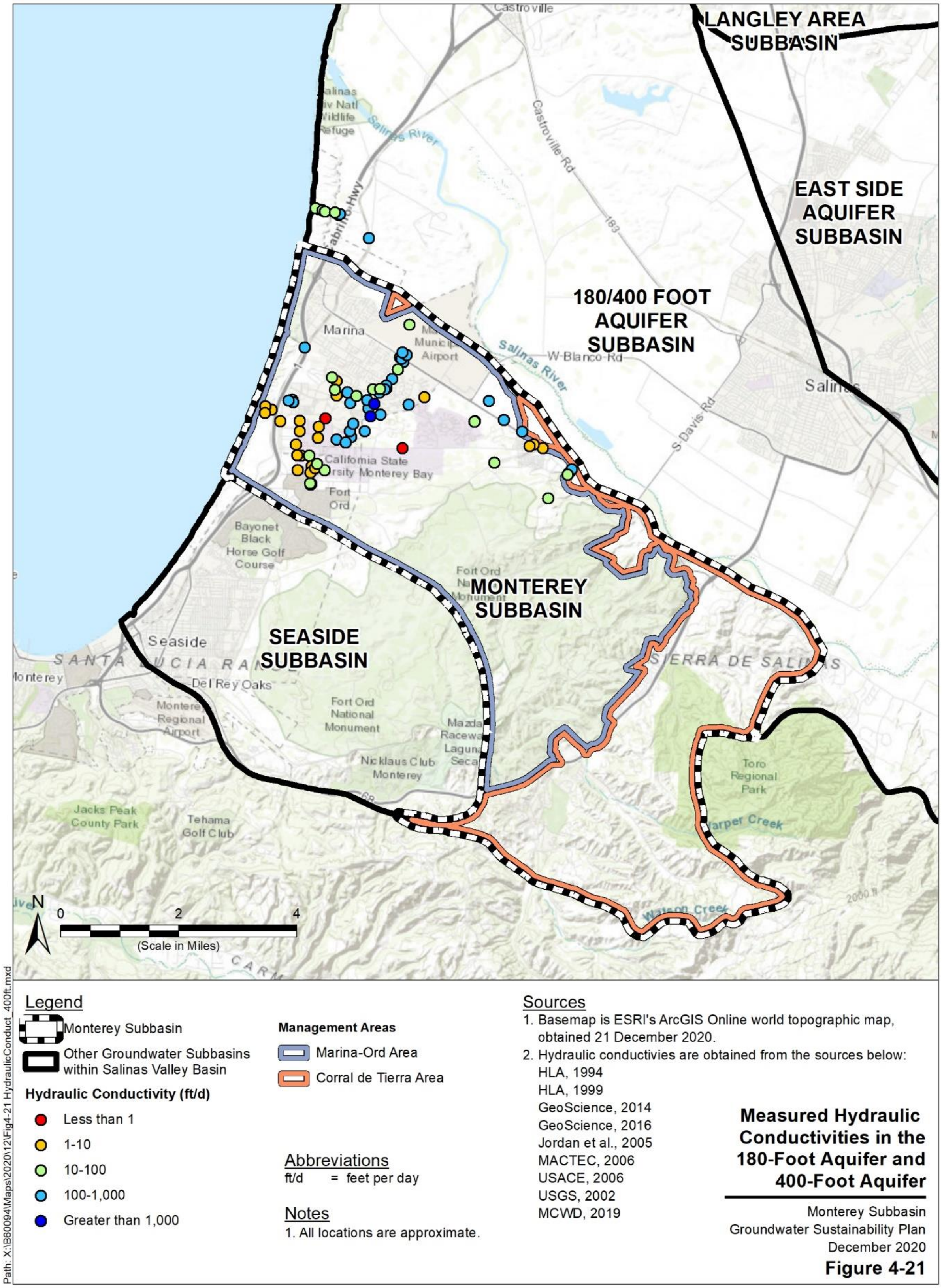
Measured horizontal hydraulic conductivities in the 400-Foot Aquifer in the Fort Ord area range from 33 to 237 ft/d. MCWD's production wells MCWD-29, MCWD-30, and MCWD-31 have specific capacities ranging from 70 gallons per minute per foot ("gpm/ft") to 127.3 gpm/ft (MCWD, 2019).

**Deep Aquifers**

Measured horizontal hydraulic conductivities in the Deep Aquifers are generally lower than the overlying 180-Foot and 400-Foot Aquifers. The measured horizontal hydraulic conductivity in Deep Aquifers ranges from 2.2 to 37 ft/d (Figure 4-22). Specific capacities of MCWD's Deep Aquifer wells range from 10.8 gpm/ft to 22.5 gpm/ft (MCWD, 2019).

Age dating of groundwater by USGS indicates that groundwater in the Deep Aquifers near the Monterey Coast may be 25,000 to 30,000 years old (Hanson et al., 2002). An interval with dated marine water was found at approximately 1,000 ft bgs in this area. MCWRA agreed that additional study to assess the recharge to this aquifer zone was needed but no study or funds was in progress (SVBGSA, 2020).


Castroville
LANGLEY AREA SUBBASIN
EAST SIDE AQUIFER SUBBASIN
180/400 FOOT AQUIFER SUBBASIN
MONTEREY SUBBASIN
SEASIDE SUBBASIN
Salinas River
W Blanco Rd
Castroville Rd
S Davis Rd
Marina Municipal Airport
State University Monterey Bay
Fort Ord
Bayonet Black Horse Golf Course
Fort Ord National Monument
Seaside
Del Rey Oaks
SANTA LUCIA RANGE
SIERRA DE SALINAS
Monterey Regional Airport
Nicklaus Club Monterey
Mazda Raceway Laguna Seca
Toro Regional Park
Jacks Peak County Park
Tehama Golf Club
Watson Creek
N
0
2
4
(Scale in Miles)
Path: X:\B60094\Maps\2020\12\Fig4-20 HydraulicConduct_Shallow.mxd
Legend
Monterey Subbasin
Other Groundwater Subbasins within Salinas Valley Basin
Extent of FO-SVA (Harding ESE, 2001)
Hydraulic Conductivity (ft/d)
Less than 1
1-10
10-100
100-1,000
Greater than 1,000
Management Areas
Marina-Ord Area
Corral de Tierra Area
Abbreviations
ft/d = feet per day
Notes
1. All locations are approximate.
Sources
1. Basemap is ESRI's ArcGIS Online world topographic map, obtained 21 December 2020.
2. Hydraulic conductivies are obtained from the sources below:
HLA, 1994
HLA, 1999
GeoScience, 2014
GeoScience, 2016
Jordan et al., 2005
MACTEC, 2006
USACE, 2006
USGS, 2002
MCWD, 2019
Measured Hydraulic Conductivities in the Dune Sand Aquifer
Monterey Subbasin
Groundwater Sustainability Plan
December 2020
Figure 4-20


LANGLEY AREA SUBBASIN
EAST SIDE AQUIFER SUBBASIN
180/400 FOOT AQUIFER SUBBASIN
MONTEREY SUBBASIN
SEASIDE SUBBASIN
Castroville
Marina
Salinas River
W Blanco Rd
Salinas
California State University Monterey Bay
Fort Ord
Seaside
Del Rey Oaks
Monterey
Fort Ord National Monument
Toro Regional Park
Watson Creek
SIERRA DE SALINAS
0
2
4
(Scale in Miles)
N
Legend
Monterey Subbasin
Other Groundwater Subbasins within Salinas Valley Basin
Hydraulic Conductivity (ft/d)
Less than 1
1-10
10-100
100-1,000
Greater than 1,000
Management Areas
Marina-Ord Area
Corral de Tierra Area
Abbreviations
ft/d = feet per day
Notes
1. All locations are approximate.
Sources
1. Basemap is ESRI's ArcGIS Online world topographic map, obtained 21 December 2020.
2. Hydraulic conductivies are obtained from the sources below:
HLA, 1994
HLA, 1999
GeoScience, 2014
GeoScience, 2016
Jordan et al., 2005
MACTEC, 2006
USACE, 2006
USGS, 2002
MCWD, 2019
Measured Hydraulic Conductivities in the 180-Foot Aquifer and 400-Foot Aquifer
Monterey Subbasin Groundwater Sustainability Plan
December 2020
Figure 4-21
Path: X:\B60094\Maps\2020\12\Fig4-21 HydraulicConduct_400ft.mxd

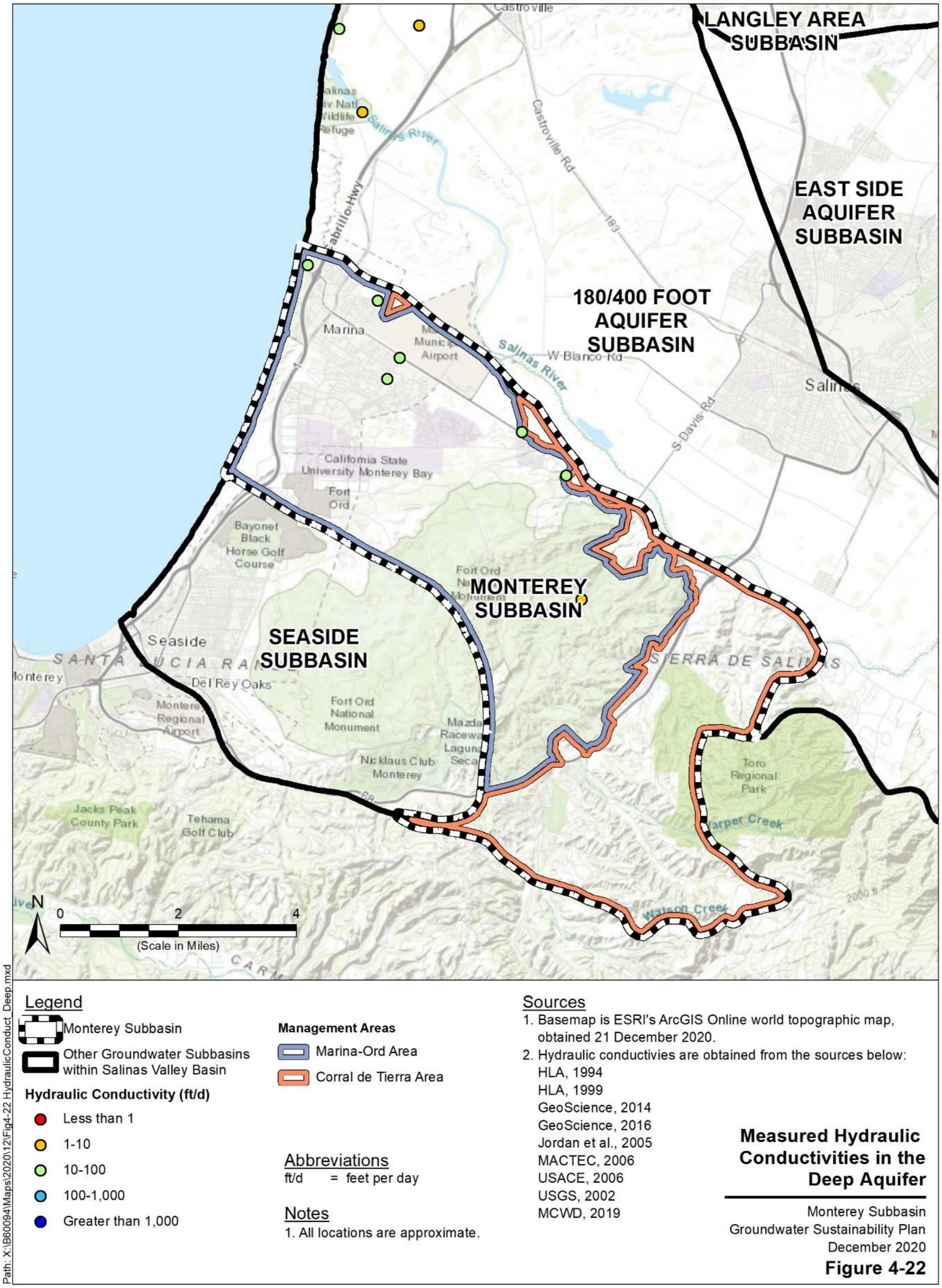

LANGLEY AREA SUBBASIN
EAST SIDE AQUIFER SUBBASIN
180/400 FOOT AQUIFER SUBBASIN
MONTEREY SUBBASIN
SEASIDE SUBBASIN
Castroville
Marina
Salinas
Seaside
Del Rey Oaks
Salinas River
California State University Monterey Bay
Fort Ord
Bayonet Black Horse Golf Course
Fort Ord National Monument
Nicklaus Club Monterey
Jacks Peak County Park
Tehama Golf Club
Toro Regional Park
Watson Creek
SIERRA DE SALINAS
W Blanco Rd
S Davis Rd
Castroville Rd
Cabrillo Hwy
N
0
2
4
(Scale in Miles)
Path: X:\B60094\Maps\2020\12\Fig4-22 HydraulicConduct_Deep.mxd
Legend
Monterey Subbasin
Other Groundwater Subbasins within Salinas Valley Basin
Hydraulic Conductivity (ft/d)
Less than 1
1-10
10-100
100-1,000
Greater than 1,000
Management Areas
Marina-Ord Area
Corral de Tierra Area
Abbreviations
ft/d = feet per day
Notes
1. All locations are approximate.
Sources
1. Basemap is ESRI's ArcGIS Online world topographic map, obtained 21 December 2020.
2. Hydraulic conductivies are obtained from the sources below:
HLA, 1994
HLA, 1999
GeoScience, 2014
GeoScience, 2016
Jordan et al., 2005
MACTEC, 2006
USACE, 2006
USGS, 2002
MCWD, 2019
Measured Hydraulic Conductivities in the Deep Aquifer
Monterey Subbasin
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Figure 4-22

#### 4.2.5.2 *Corral de Tierra Area*

The most comprehensive compilation of hydraulic conductivities in the Corral de Tierra Area comes from the *Seaside Groundwater Basin Modeling and Protective Groundwater Elevations* (HydroMetrics, 2009). This study describes a model that covers the adjudicated Seaside Subbasin and the Monterey Subbasin. This study collected previously published hydraulic conductivity values for the geologic units encountered in the region. The model separates the aquifer by geologic formation, and Table 4-2 shows hydraulic conductivity estimated for the Paso Robles Formation and the Santa Margarita Sandstone.

The study also estimated storage coefficients, which relate to an aquifer's ability to store groundwater, for each of the principal aquifers. These include specific yield (set at a value of 0.08 for the unconfined aquifers), and specific storage (set at a value of 0.0006 for the confined aquifers) (HydroMetrics, 2009). These values were selected for the Seaside model. Specific storage values range from $5\times10^{-5}$ to $5\times10^{-3}$ for confined aquifers, and specific yield values may range from 0.1 to 0.01 in unconfined aquifers (Todd, 1980).

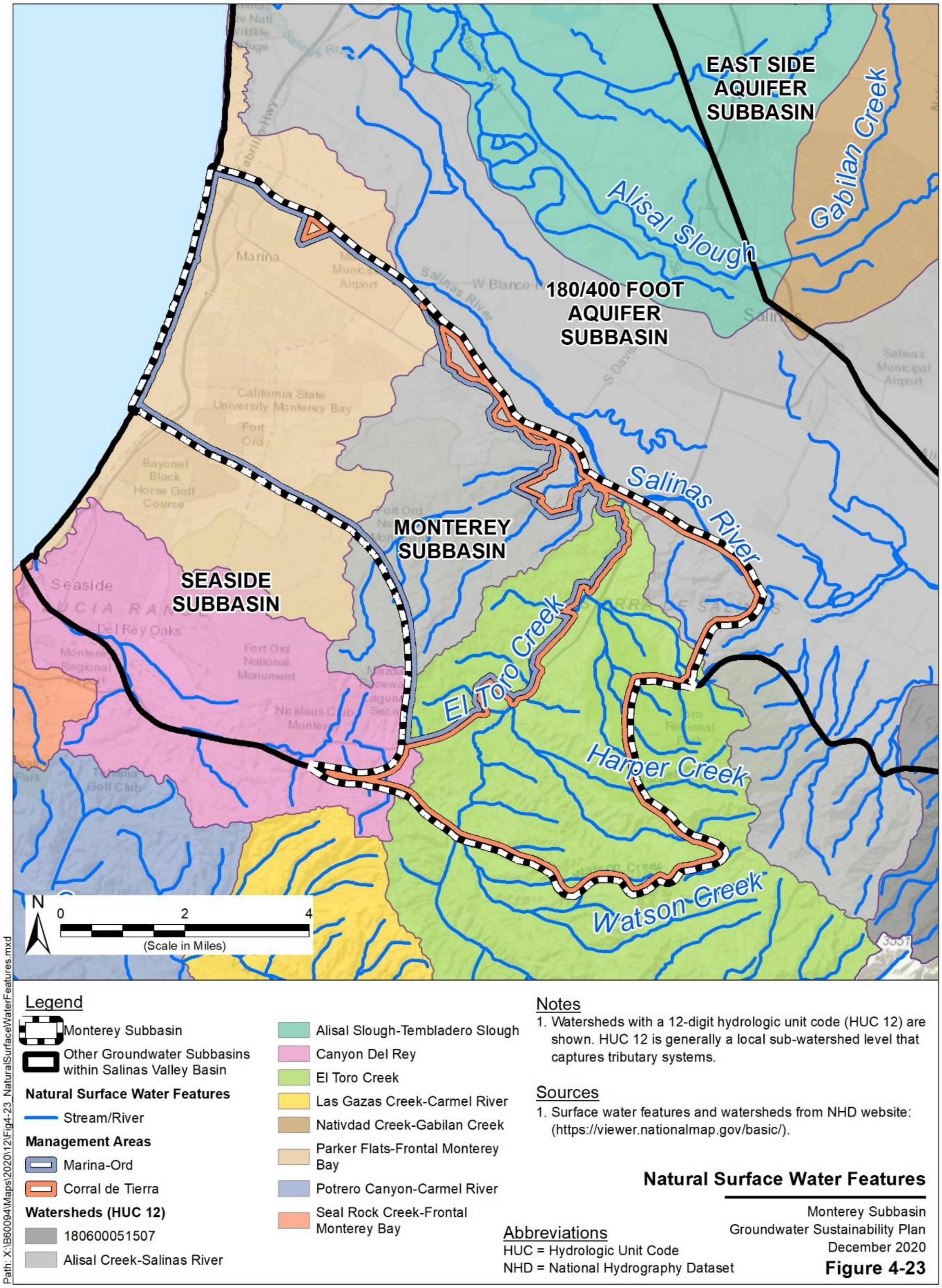
**Table 4-2. El Toro Primary Aquifer Hydraulic Conductivity Values (modified from HydroMetrics WRI, 2009)**

| Principal Aquifer | Geologic Formation | Hydraulic Conductivity (feet per day) | Source | Reference |
|---|---|---|---|---|
| El Toro Primary Aquifer System | Paso Robles | 20 | Pump Test | Fugro West, Inc., 1997 |
| | | 2 | Model Calibration | Yates et al., 2005 |
| | Santa Margarita | 63 | Pump Test | Fugro West, Inc., 1997 |
| | | 3-5 | Model Calibration | Yates et al., 2005 |

Since many wells are screened across both the Paso Robles Formation and the Santa Margarita Sandstone, aquifer properties for the El Toro Primary Aquifer System reflect a composite of properties (GeoSyntec, 2007). The saturated thickness of the El Toro Primary Aquifer System is greatest near highway 68, as shown by high well yields and significant storage (GeoSyntec, 2007).

## 4.3 Surface Water Bodies

Surface water features and subwatersheds at the 12-digit Hydrological Code (HUC-12) level within the Subbasin are shown on Figure 4-23.




**Natural Surface Water Features**

Monterey Subbasin
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**Figure 4-23**

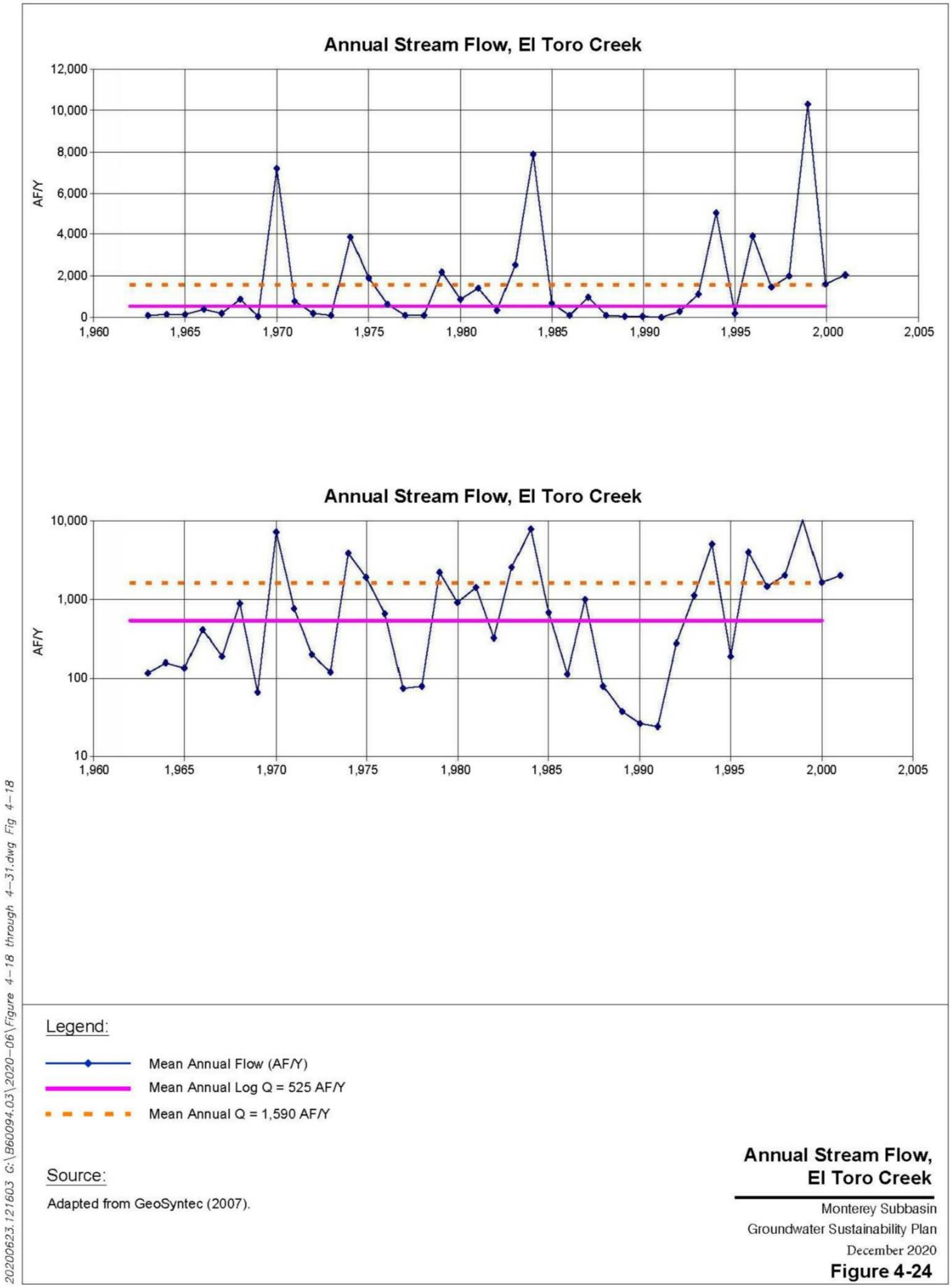
Coastal areas of the Subbasin drain toward Monterey Bay. Runoff is minimal due to the high rate of surface water infiltration into the permeable dune sand. Consequently, well-developed natural drainages are absent throughout much of this area (Harding, 2004).

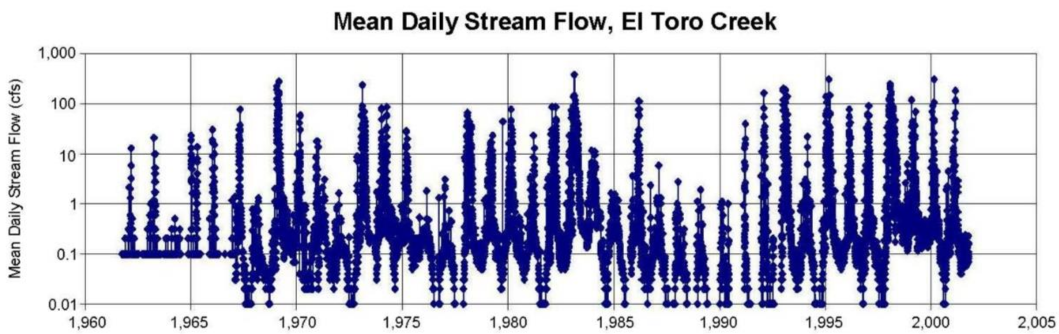
Small intermittent streams found in the Subbasin include the San Benancio Gulch, Watson Creek, and Calera Creek (GeoSyntec, 2007). These streams generally flow northeastward and are tributaries to the Salinas River. Flows in these creeks respond rapidly to rainfall, and they are usually dry in the summer months. These creeks have a “flashy” nature and readily lose water to streambed seepage. (Hydrometrics, 2009). These streams flow less than 25 percent of the year (GeoSyntec, 2007).

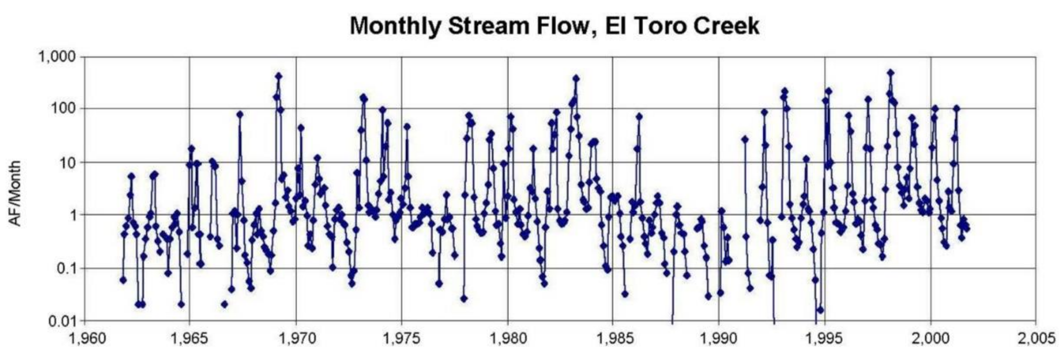
El Toro Creek is a perennial stream below the confluence with Watson Creek below the Corral de Tierra golf course (Feikert, 2001). Recorded streamflows at USGS gage 11152540 from 1961 to 2001 indicate a mean annual streamflow of 1,590 AFY (GeoSyntec, 2007). This mean annual streamflow was calculated for the entire record from 1961 to 2001. However, El Toro Creek did not record flow every year, with notable dry periods from 1985 to 1992 (Figure 4-24).

Yates and others (2005) concluded that local streams (i.e., El Toro Creek and smaller streams) contribute insignificantly to groundwater recharge. Along limited reaches, these streams gain streamflow from groundwater discharge. However, the stream-aquifer exchanges are not thought to be significant to either the groundwater budget or to the response of the groundwater basin to pumping (Durbin, 2007).

Due to the intermittent nature and minimal amount of streamflow, there are no surface water rights registered with the SWRCB within the Subbasin.


Annual Stream Flow, El Toro Creek
AF/Y
12,000
10,000
8,000
6,000
4,000
2,000
0
1,960
1,965
1,970
1,975
1,980
1,985
1,990
1,995
2,000
2,005
Annual Stream Flow, El Toro Creek
AF/Y
10,000
1,000
100
10
1,960
1,965
1,970
1,975
1,980
1,985
1,990
1,995
2,000
2,005
Legend:
Mean Annual Flow (AF/Y)
Mean Annual Log Q = 525 AF/Y
Mean Annual Q = 1,590 AF/Y
Source:
Adapted from GeoSyntec (2007).
Annual Stream Flow,
El Toro Creek
Monterey Subbasin
Groundwater Sustainability Plan
December 2020
Figure 4-24
20200623.121603 G:\B60094.03\2020-06\Figure 4-18 through 4-31.dwg Fig 4-18




Legend:

Mean Daily and Monthly Flow

Source:

Adapted from GeoSyntec (2007).

**Daily and Monthly Stream Flow, El Toro Creek**

Monterey Subbasin
Groundwater Sustainability Plan
December 2020

**Figure 4-25**

20200623.121603 G:\B60094.03\2020-06\Figure 4-18 through 4-31.dwg Fig 4-18

### 4.3.1 **Source and Point of Delivery for Imported Water Supplies**

There are no known sources of imported water for this subbasin. Groundwater is the only source of water for this subbasin.

## 4.4 Data Gaps

A significant portion of the subbasin remains undeveloped to date, which includes federal lands located in the Fort Ord hills area and lands in the lower El Toro Creek area (i.e. northern portion of the Corral de Tierra area). As such, limited to no subsurface information is available in these areas. Regardless, many comprehensive studies have been conducted in areas where groundwater development has been active; and the hydrogeologic conceptual model for those areas is well developed.

One significant data gap exists in the hydrogeologic conceptual model for the Subbasin. This data gap relates to the location and magnitude of recharge to the Marina-Ord Area Deep Aquifers, one of the major production aquifers within the Subbasin and within other subbasins of the Salinas Valley Groundwater Basin. As described in Chapters 7, the GSP will include ongoing data collection and monitoring that will allow continued refinement and quantification of the groundwater system. Chapter 10 includes activities to address the identified data gaps and improve the hydrogeologic conceptual model.