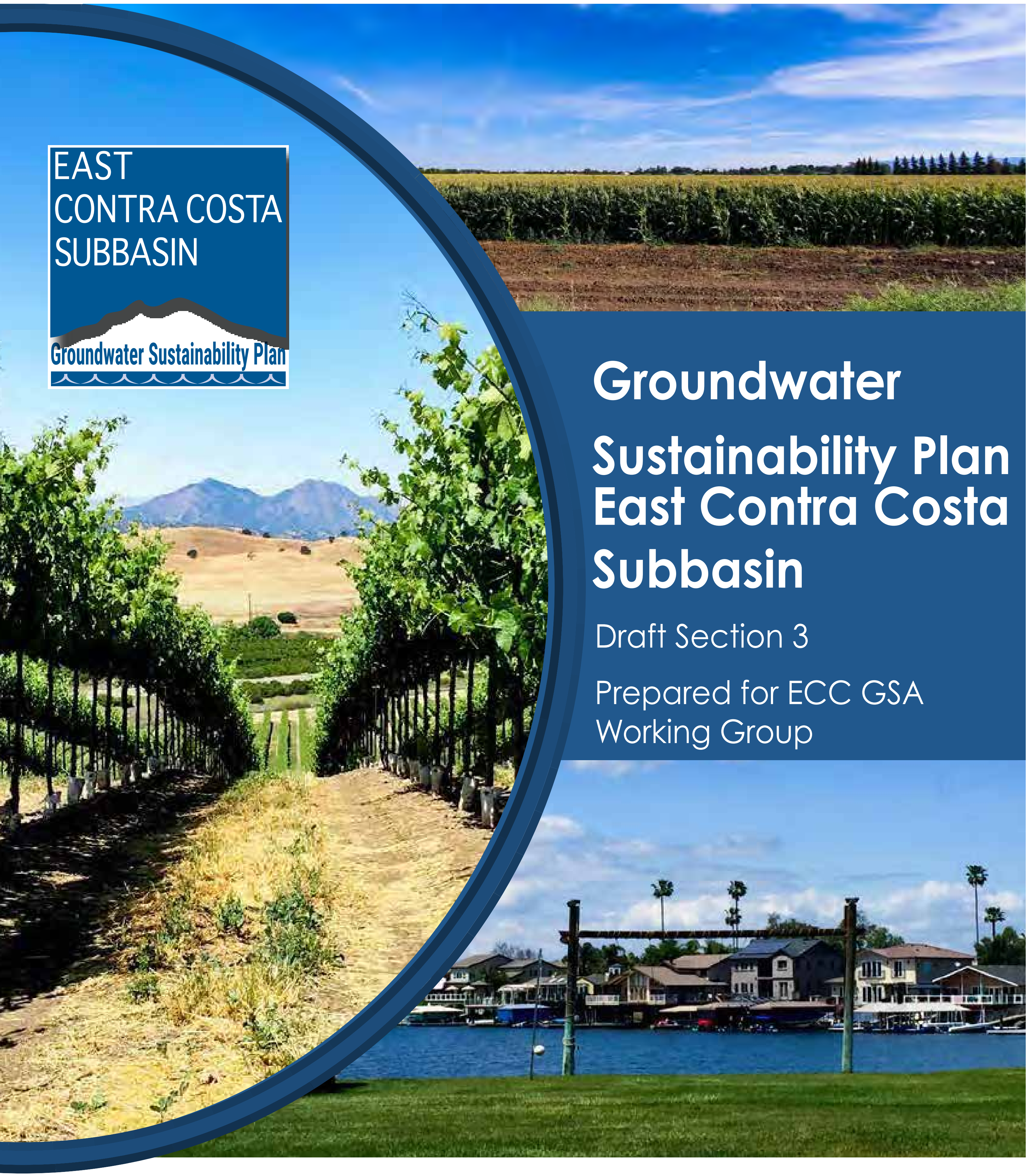


EAST CONTRA COSTA SUBBASIN

Groundwater Sustainability Plan

Groundwater Sustainability Plan East Contra Costa Subbasin

Draft Section 3

Prepared for ECC GSA Working Group

Luhdorff & Scalmanini Consulting Engineers

October 2020

This Page is Intentionally Blank

Groundwater Sustainability Plan
East Contra Costa Subbasin

Draft Section 3

October 2020

Prepared for

ECC GSA Working Group

Prepared by

Luhdorff & Scalmanini
Consulting Engineers

This Page is Intentionally Blank

SECTION 3 CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

3. BASIN SETTING

3.1 Overview

This Basin Setting section of the East Contra Costa (ECC) Groundwater Sustainability Plan (GSP) describes the Hydrogeologic Conceptual Model (HCM) (Section 3.2) and historical and current Groundwater Conditions (Section 3.3). The sections were developed using best available science and serve as the basis upon which ECC GSAs will select management criteria to maintain sustainable groundwater conditions in the ECC Subbasin. Groundwater Sustainability Agencies (GSAs) "have the responsibility for adopting a Plan that defines the basin setting and establishes criteria that will maintain or achieve sustainable groundwater management" as detailed by DWR in the GSP regulations (Title 23 California Code of Regulations [CCR] Section 350.4e). The required GSP elements (Elements Guide) addressed in Section 3 and their location are detailed in **Appendix 3i**. The two main topics covered in this section include:

- **Hydrogeologic Conceptual Model (HCM):** Section 3.2 describes the physical components of the Subbasin including the regional geology, structural properties, boundaries of the Subbasin, principal aquifer descriptions with cross sections, topographic and soil characteristics, recharge areas, and significant surface water bodies.
- **Groundwater Conditions:** Section 3.3 provides current and historical groundwater conditions including discussions of groundwater level maps and time-series graphs, groundwater storage, seawater intrusion, groundwater quality, land subsidence, interconnected surface water systems, and groundwater dependent ecosystems.

3.2 Hydrogeologic Conceptual Model

The HCM describes the geologic and hydrologic framework that governs how water moves through the ECC Subbasin. This description provides the basis to develop water budgets, monitoring networks, and ultimately a surface water/groundwater mathematical model (Section 5 of this GSP). This section includes information about the regional geologic and structural setting, lateral and vertical basin boundaries, and principal aquifers. This section is based on technical studies and maps that characterize the physical components and interaction of the surface water and groundwater systems, pursuant to Section 354.14 Hydrogeologic Conceptual Model. Information was compiled for this section from two main references: *Investigation of Ground-Water Resources in the East Contra Costa Area* (LSCE, 1999) and *An Evaluation of Geological Conditions, East Contra Costa County* (LSCE, 2016). Both reports are included in this document as **Appendices 3a and 3b**.

3.2.1 Regional Geological and Structural Setting

The San Joaquin Valley formed between two mountain ranges (Coast Ranges and the Sierras). The ECC Subbasin lies on the western side of the northern San Joaquin Valley portion of the Great Valley province of California. The western boundary of the Subbasin is a no flow boundary with respect to groundwater and is delineated by exposed bedrock of highly deformed Tertiary age and older marine sediments of the Coast Range Diablo Mountains. Most of the Subbasin is filled with freshwater-bearing alluvium, eroded continental sediments from the Coast Ranges, that are Quaternary in age. Surficial geology from multiple sources is provided in **Figure 3-1a** and a detailed legend is in **Figure 3-1b and c**.

3.2.1.1 Topographic Information

The topography of the Subbasin is generally flat with land surface elevations that slope gently downward to the east. Topographic elevations vary from about 200 feet above mean sea level (msl) in the west to less than 10 feet from msl in the delta area over a distance of about 10 miles (**Figure 3-2**). There are portions of the Subbasin (e.g., Delta islands) in the northeast and southeast that are below sea level.

3.2.1.2 Depositional Model

Regional geologic studies (Bartow, 1991; and Bertoldi and others, 1991) reported that Miocene marine deposition occurred in the area as shown by the Tertiary marine rocks exposed in the Coast Ranges. During the following Pliocene epoch, the San Joaquin Valley drained south to the ocean via the Salinas Valley. The Sacramento Valley drained westward through the Delta area, and the Coast Range locally had not yet been uplifted. Deposition may have been confined to distal fluvial plains sourced from the Sierra Nevada area, such that little sand was carried into the area. Similar aged fine-grained deposits are seen in southern Sacramento County, near Vacaville, and around Rio Vista reaching thicknesses of 2,000 to 2,500 feet.

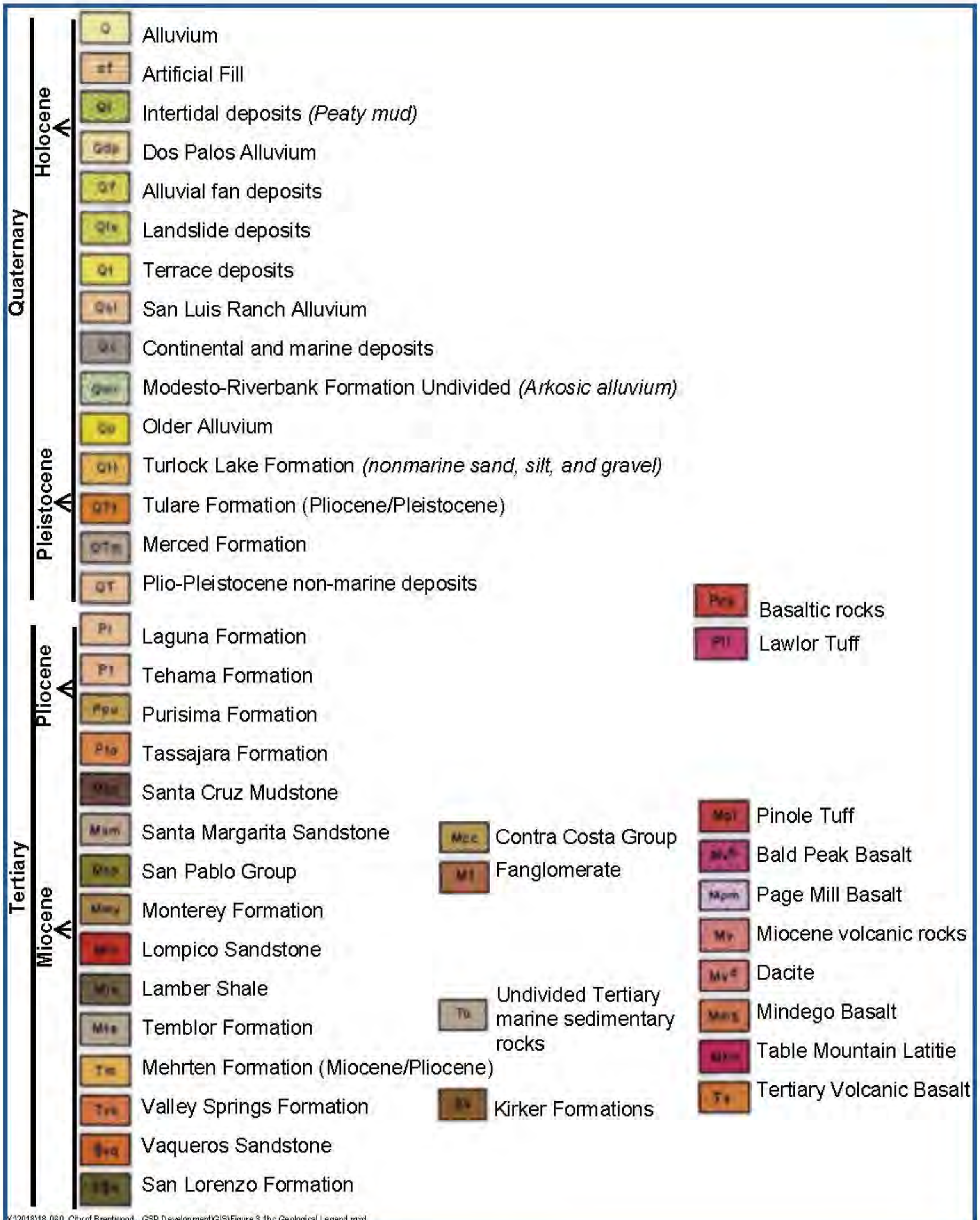
In the Quaternary (mid-Pleistocene) period, the San Joaquin Valley south of Tracy was occupied by a large freshwater lake known as Corcoran Lake. Associated with the lake was deposition of the Corcoran Clay, also termed E-Clay unit. Neither the lake nor the Corcoran Clay unit extended as far north as the ECC Subbasin distinguishing the subbasin from other parts of the San Joaquin Valley Groundwater Basin to the south and east. At about 600,000 years ago, northern San Joaquin River drainage and local Coast Range uplift began. It is suspected that this activity marked the beginning of the alluvium deposition where coarse-grained deposits were formed and carried into the area by the San Joaquin River and from erosion of the uplifting Coast Ranges.

Luhdorff & Scalmanini
Consulting Engineers

Surficial Geology and Faults

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-1a

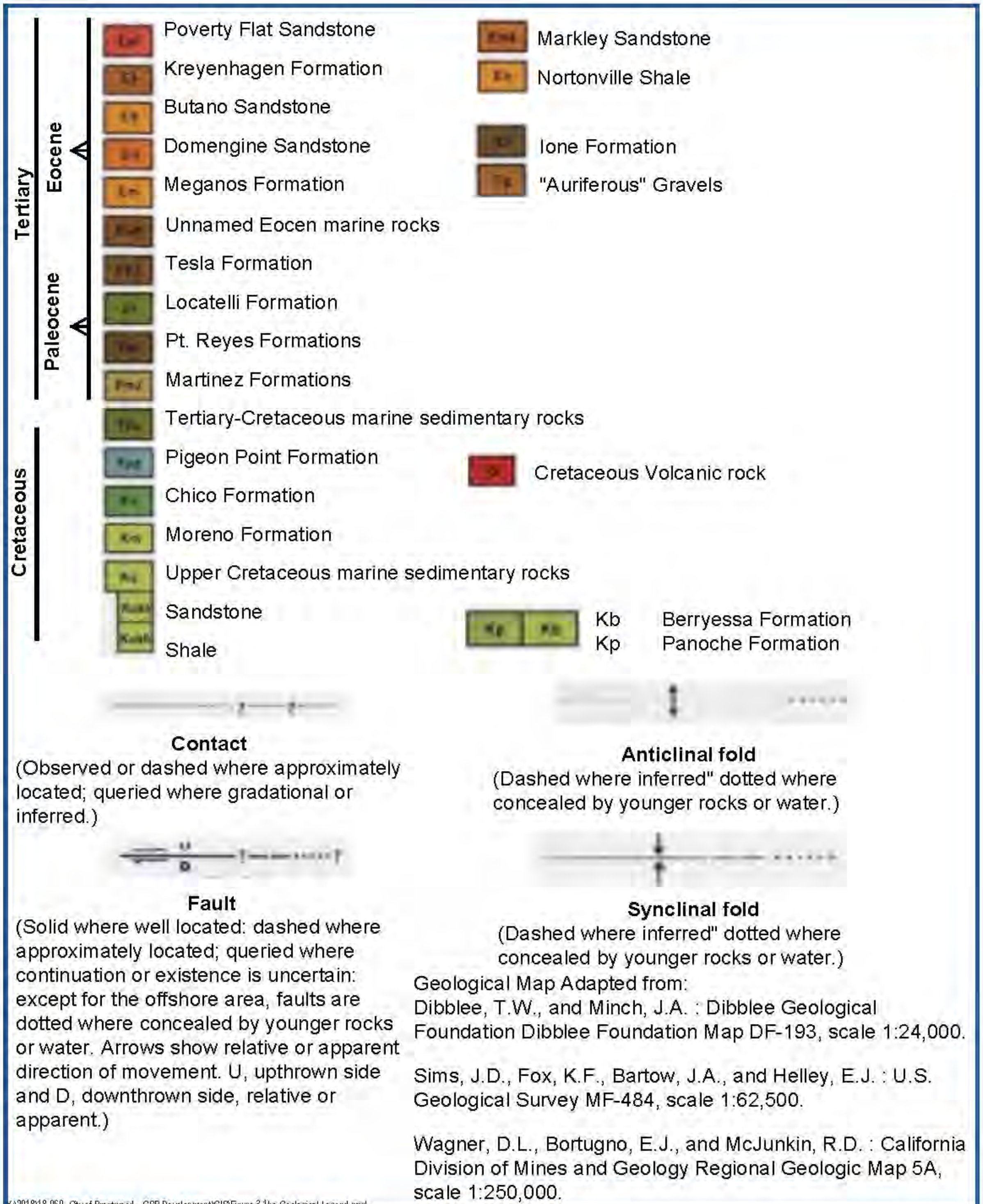


Luhdorff & Scalmanini Consulting Engineers

Surficial Geology Legend

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-1b

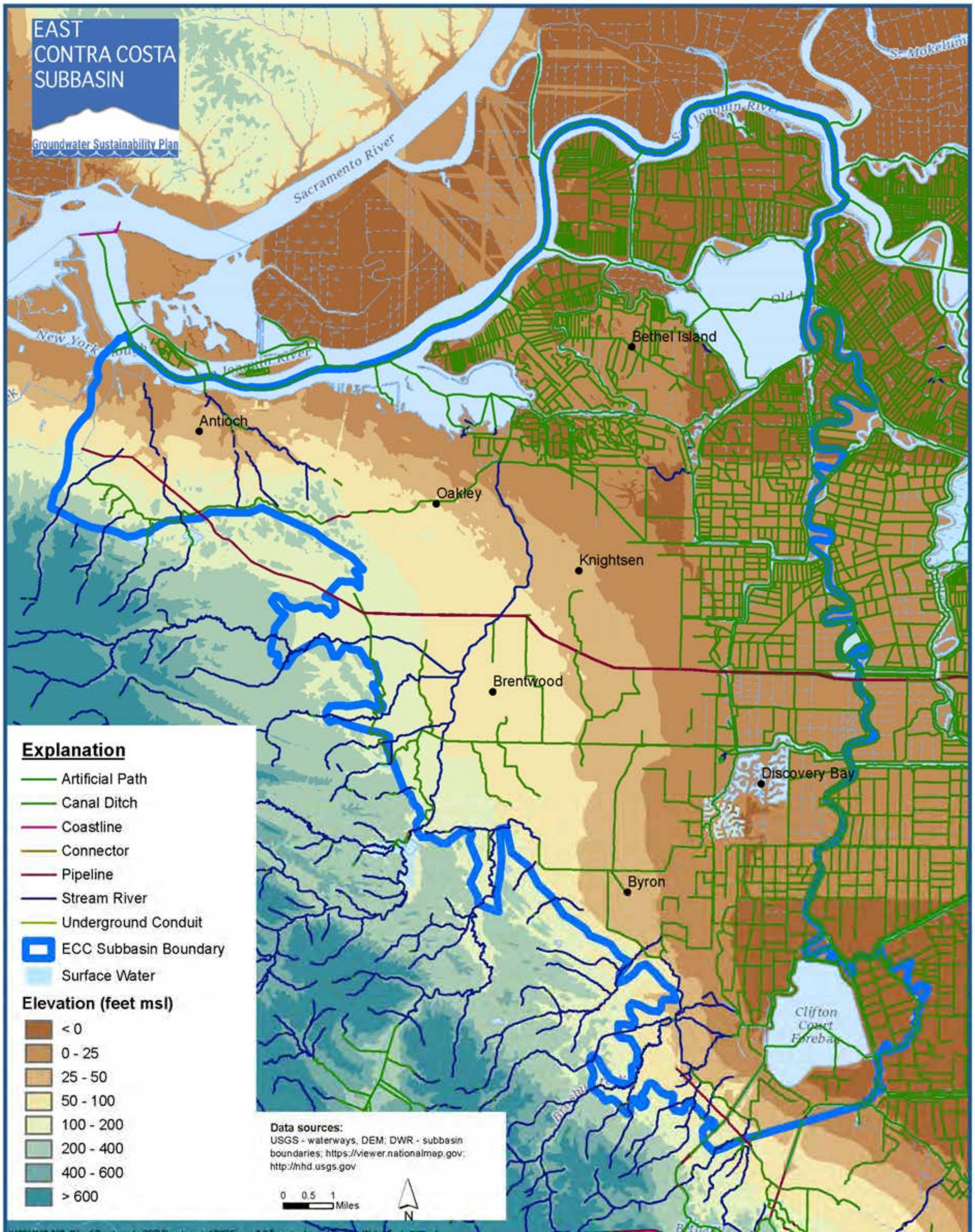


Luhdorff & Scalmanini Consulting Engineers

Surficial Geology Legend

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-1c



Luhdorff & Scalmanini Consulting Engineers

Topography and Surface Water Features

Figure 3-2

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

3.2.1.3 Surficial Geology and Geological Formations

Bedrock formations observed in outcrops along the western boundary of the ECC Subbasin consist of strongly deformed marine sedimentary rocks that range in age from over 63 million years [my] to 5 my. The Tertiary marine rocks of sandstones, shales and mudstones dip east beneath the San Joaquin Valley with increasing depths. Because of their marine origin, well consolidated nature, and saline water, the Mesozoic and Tertiary marine rocks are not a source of fresh groundwater in the Subbasin (LSCE, 1999; 2016). Additional information about these units can be found in **Appendix 3a**.

Overlying the Tertiary marine rocks are a sequence of Tertiary-Quaternary non-marine sedimentary deposits (Pliocene to Pleistocene). These older sediments have limited areas of exposure along the edge of the Coast Range. These deposits are not well understood in the study area, but they are believed to consist of fine-grained clays, silts, and mudstones with a few sand beds. They dip moderately to the east and northeast under the San Joaquin Valley. Limited information from a few deep water well boreholes indicate they occur from 400 feet to depths of over 1,500 feet below the San Joaquin River. The lower portion of these deposits may be equivalent to the Mehrten Formation on the east side of the San Joaquin Valley. The upper portion of these older non-marine sediments may be equivalent to the Tulare Formation to the south of the Subbasin and the Tehama Formation to the north. Water quality appears to become brackish with depth (LSCE, 1999 and 2016).

Overlying the Tertiary/Quaternary non-marine sediments are the primary groundwater-bearing units in the ECC Subbasin. These Quaternary alluvium deposits are unconsolidated beds of gravel, sand, silts, and clays becoming weakly consolidated with increasing age and burial depth. The alluvium thickens eastward to over 300 feet beneath Brentwood and about 400 feet below Old River. As discussed in Section 3.2.4, the units around Brentwood are believed to have been deposited by streams forming alluvial fans of silts and clays off the uplifted Diablo Mountains. Units around Discovery Bay are believed to be stream channel deposits of coarser sands and gravels. Separation of the alluvium into distinct units is difficult using well drillers' reports. The sand and gravel can be correlated locally, but the fine-grained sand and clays are so massive, a greater spatial correlation is not possible (LSCE, 1999). Sand and gravel beds and their distribution are discussed further in this chapter.

About 600,000 years before present, Corcoran Lake formed in nearly the entire San Joaquin Valley northward to the Stockton-Tracy area. A blue lake clay was deposited across the San Joaquin Valley and is known as the Corcoran Clay or E-clay. However, as cited above, this clay unit has not been identified north of the Stockton-Tracy area into the Delta area of Contra Costa County or in the Sacramento Valley (LSCE, 2016).

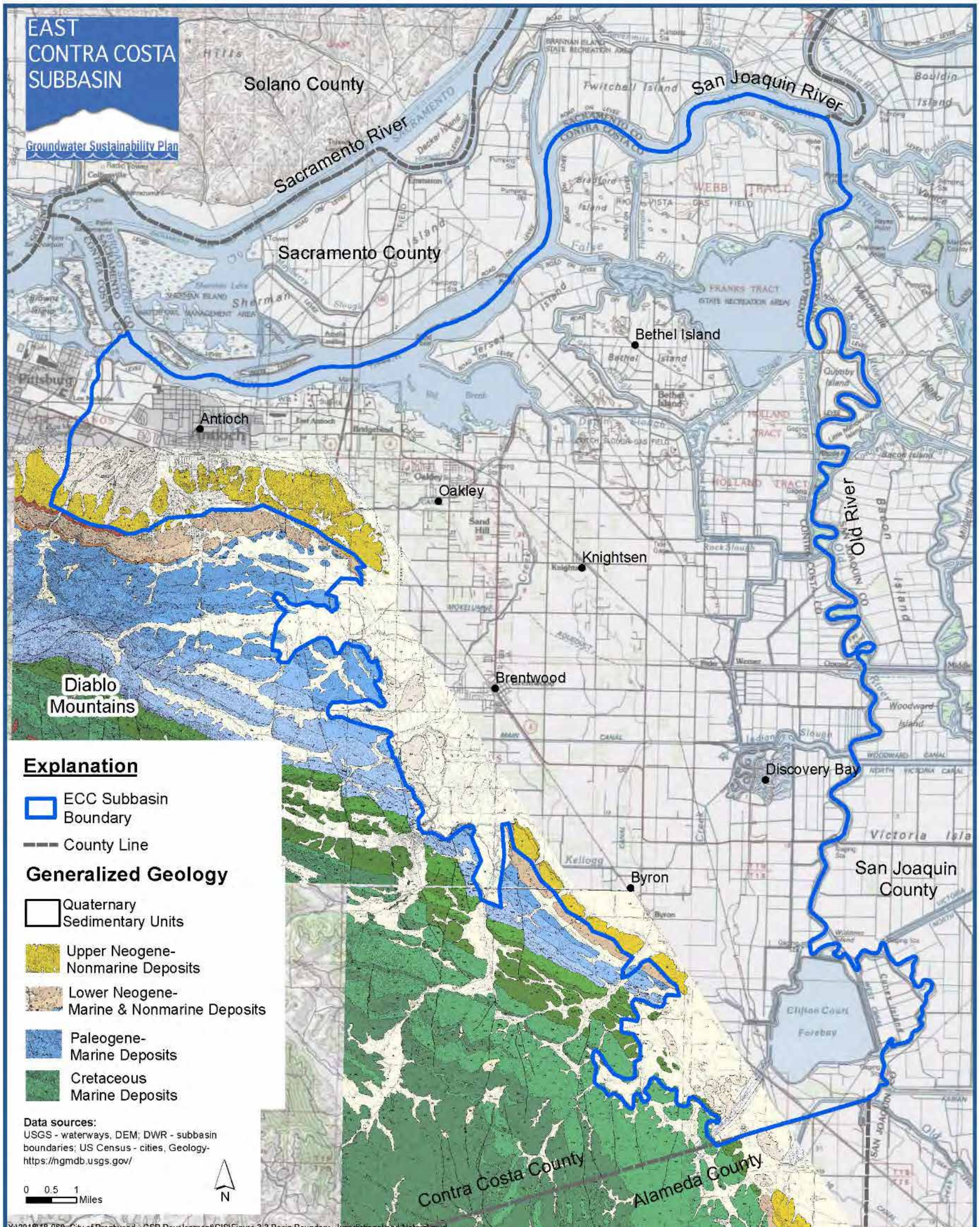
3.2.2 Faults and Structural Features

Three inactive faults (Midland, Sherman, and Antioch) trend in a north-south direction across the Subbasin (**Figure 3-1,** dashed lines). They are not known to inhibit groundwater flow or to impact water conveyance infrastructure. The Vernalis Fault is located southeast of Clifton Court Forebay (off of the geology map, **Figure 3-1**). Uplift or deformation along this fault may have caused a ridge that may influence groundwater flow as discussed below. No surface expression has been noted of this fault (LSCE, 2016).

3.2.3 Basin Boundaries

The lateral extent of the ECC Subbasin is defined primarily by jurisdictional and surface water boundaries (**Figure 3-3**). ECC Subbasin is bounded on the north, east, and south by the Contra Costa County line, which is contiguous with the San Joaquin River (north) and Old River (east). In the west, a non-jurisdictional Subbasin boundary corresponds to the non-water bearing geologic units which form a bedrock barrier to groundwater flow. **Figure 3-3** is a diagrammatic illustration of the western ECC Subbasin boundary in relation to the bedrock outcrop of older consolidated marine sediments (green, blue, and tan colors).

The base of the ECC Subbasin is defined by the vertical extent of available and extractable freshwater. The base of freshwater has been mapped previously in the general area by Page (1973) and Berkstresser (1973), and in a detailed map of the ECC Subbasin constructed by LSCE (2016). The base of freshwater map prepared by LSCE (**Figure 3-4**) updates the delineation of freshwater resources through additional oil and gas well electric logs in Montezuma Hills, Rio Vista, and the northwestern hills of Mount Diablo (Davis et al., 2018). The base of freshwater aquifers was determined from electric log responses in thick sand beds that had high resistivity values, and the character of the spontaneous-potential (S-P). This approach distinguished zones of poor water quality within sand beds, though it did not quantify salinity. Nevertheless, the geophysical characteristics of sand beds from electric logs provide a sound estimate of the vertical extent of freshwater in the subbasin. Deeper sandy units with low resistivity values and indeterminable S-P characteristics were considered to be non-viable as aquifers. The examination by LSCE (2016) showed the deepest base of freshwater is to the northeast and east near the Subbasin boundary (-1,000 to -1,200 feet from msl) and rising to the west to elevations of 200 feet msl. In the Clifton Court Forebay area a subsurface ridge-like feature, possibly caused by the Vernalis Fault, extends eastward from the valley edge and may influence groundwater flow around the ridge or impede any northwest flow from the south at depths below -400 feet elevation.

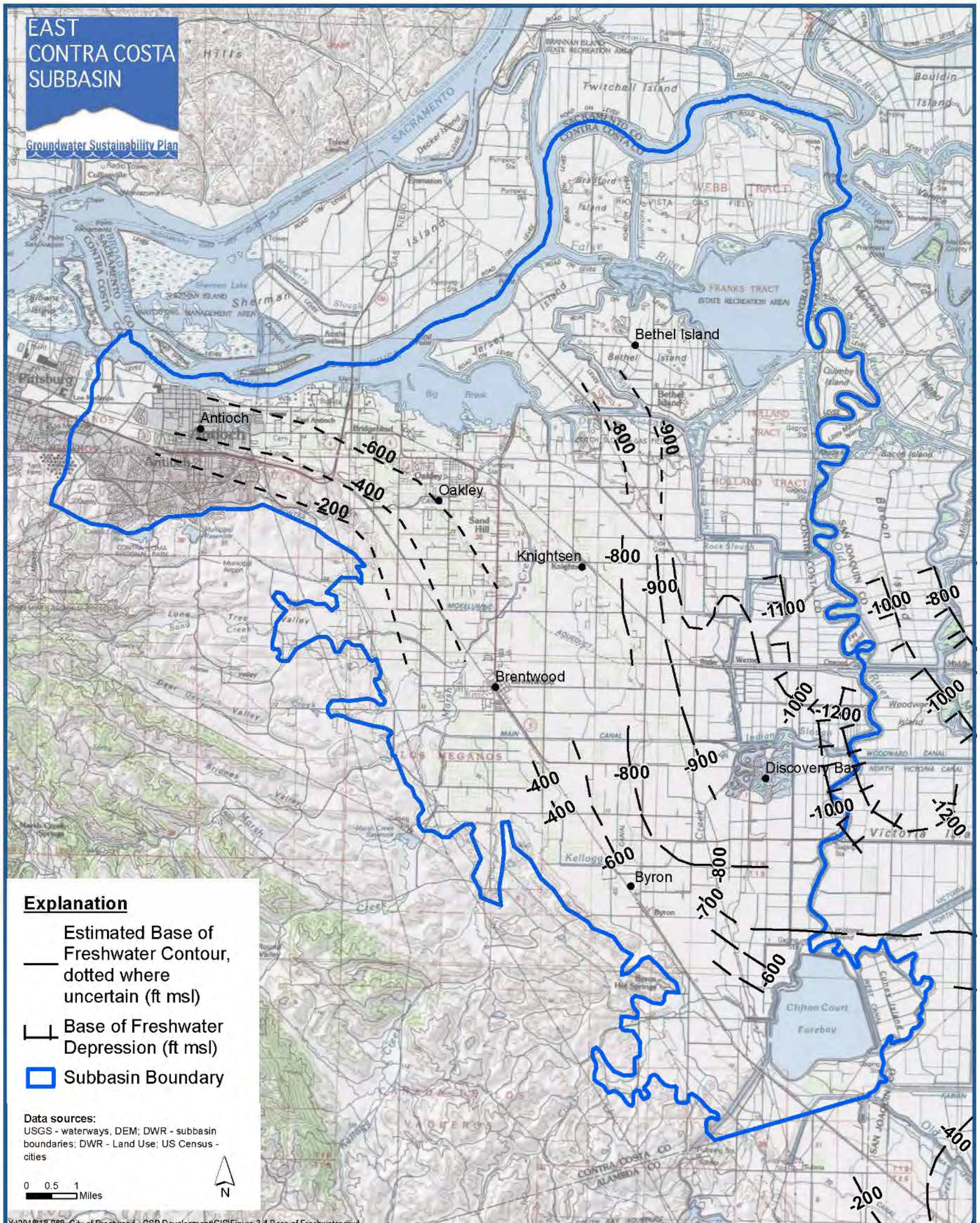


Luhdorff & Scalmanini
Consulting Engineers

Basin Boundary- Jurisdictional and Natural

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-3



Luhdorff & Scalmanini Consulting Engineers

Base of Freshwater

Figure 3-4

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

3.2.4 Geologic Cross Sections and Depositional Facies Model

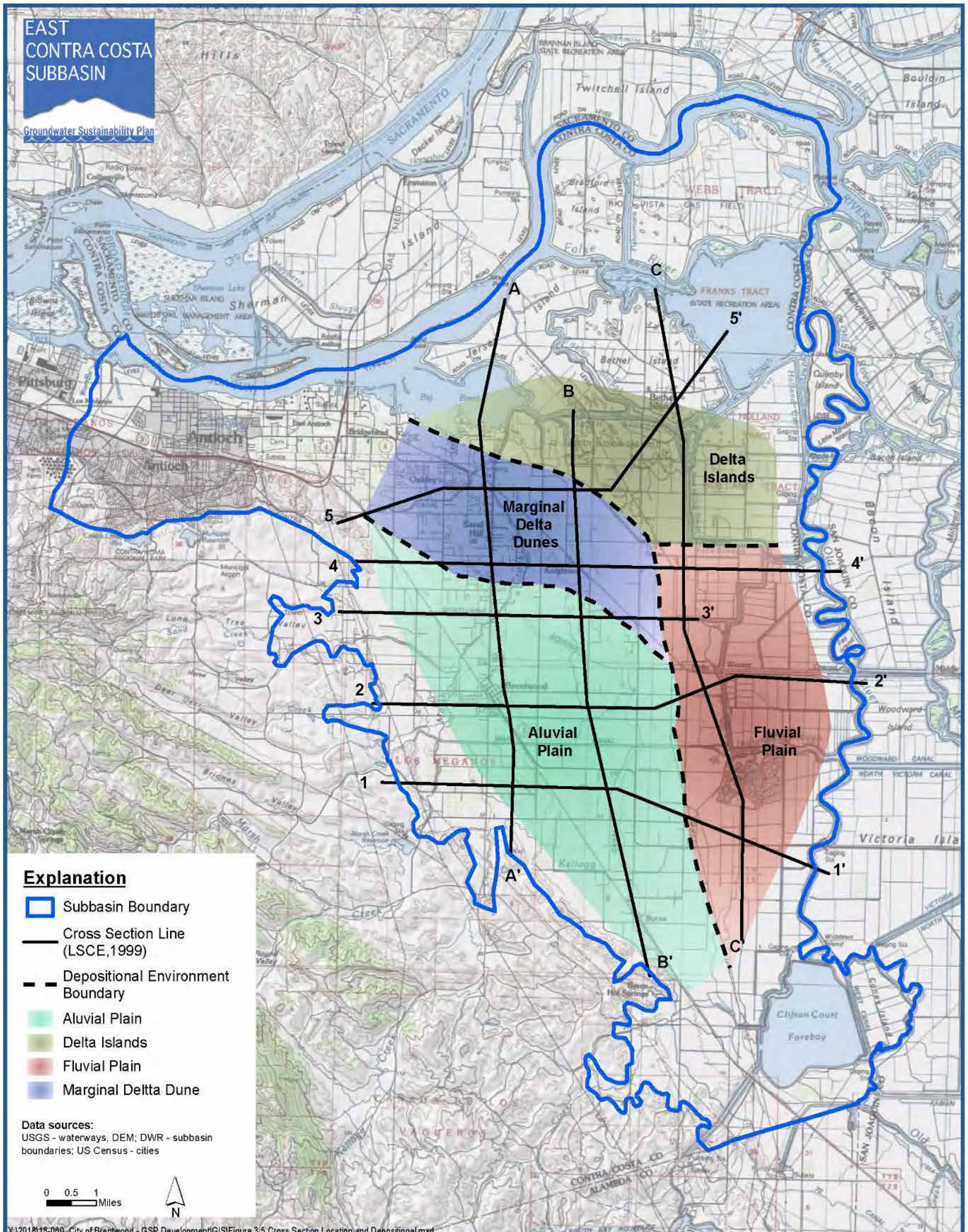
In 1999, LSCE performed a detailed hydrogeologic study of eastern Contra Costa County groundwater. The focus of the study was the uppermost 500 feet where most water wells are completed in the region. This study included construction of cross sections from drillers' logs and oil and gas logs to assess sand bed characteristics and their extent. Five cross sections were constructed in an east-west direction perpendicular to the Coast Range and three were drawn in a north-south direction (**Figure 3-5**). Two cross sections (4-4' and C-C', **Figures 3-6a and 3-6b**) are included in this report and all eight cross sections are included in **Appendix 3a**. These sections illustrate the ground surface, lithology associated with each well log, and the base of fresh water (LSCE, 2016).

The geologic cross-sections show the interbedded and variable nature of fine- and coarse-grained sediments both laterally and vertically and throughout the study area. They illustrate in detail the primary water-bearing units for water supply purposes. Coarse-grained units were identified primarily in the upper 400 feet where the majority of public supply wells are perforated however, it was noted that the units are difficult to correlate laterally. Well information was lacking for depths below 400 feet below ground surface (bgs) but consistent with the discussion in the previous section, it was expected that the units are fine grained and become brackish at depth.

From the vertical and lateral variability in sediments reflected in cross sections, general patterns in the occurrence and character of sand and gravel aquifers could be identified. These variations were explained by different depositional environments (e.g., stream and delta) as detailed below. In addition, these depositional environments were used to inform groundwater model calibration and for other quantitative purposes.

From the work described above, a facies model for four depositional regions in the Subbasin was developed as part of the subbasin HCM (**Figure 3-5**). The depositional regions are detailed below:

Fluvial Plain This is representative of the eastern portions of the Subbasin including Discovery Bay. It is defined by a zone of well-defined, thick-bedded sands and gravels with sand thickness of generally 30 feet or more per 100 feet. The depositional environment was probably similar to that which occurs in the present-day area with northward flowing river channels, distributaries, and sloughs across floodplains of overbank areas. Deposits extend to depths of about 350 feet, below which occur largely fine-grained silts and clays with poor to brackish water quality (TODB et al., 2017).

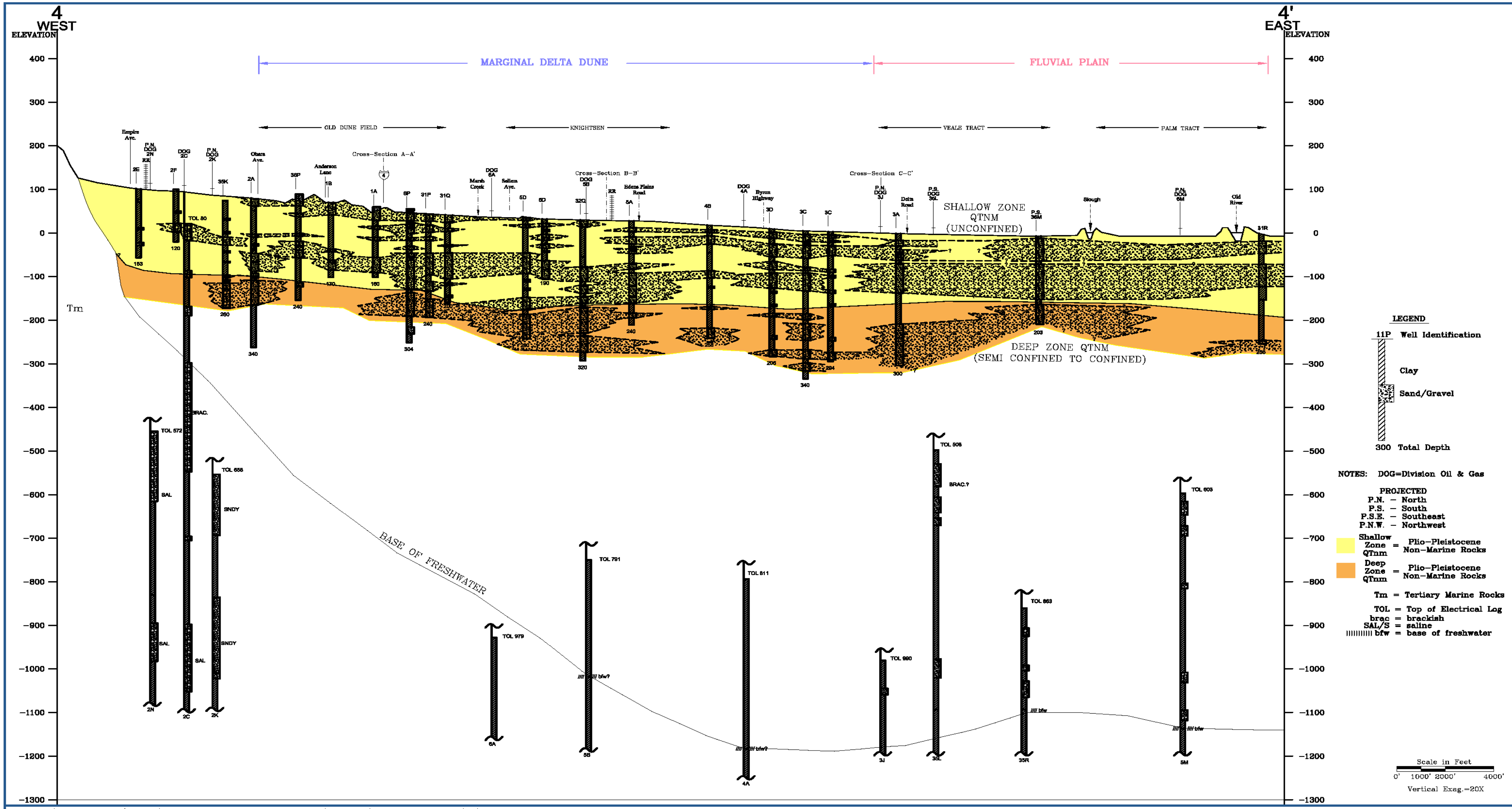


Cross Section Location and Depositional Environment

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-5

Luhdorff & Scalmanini Consulting Engineers

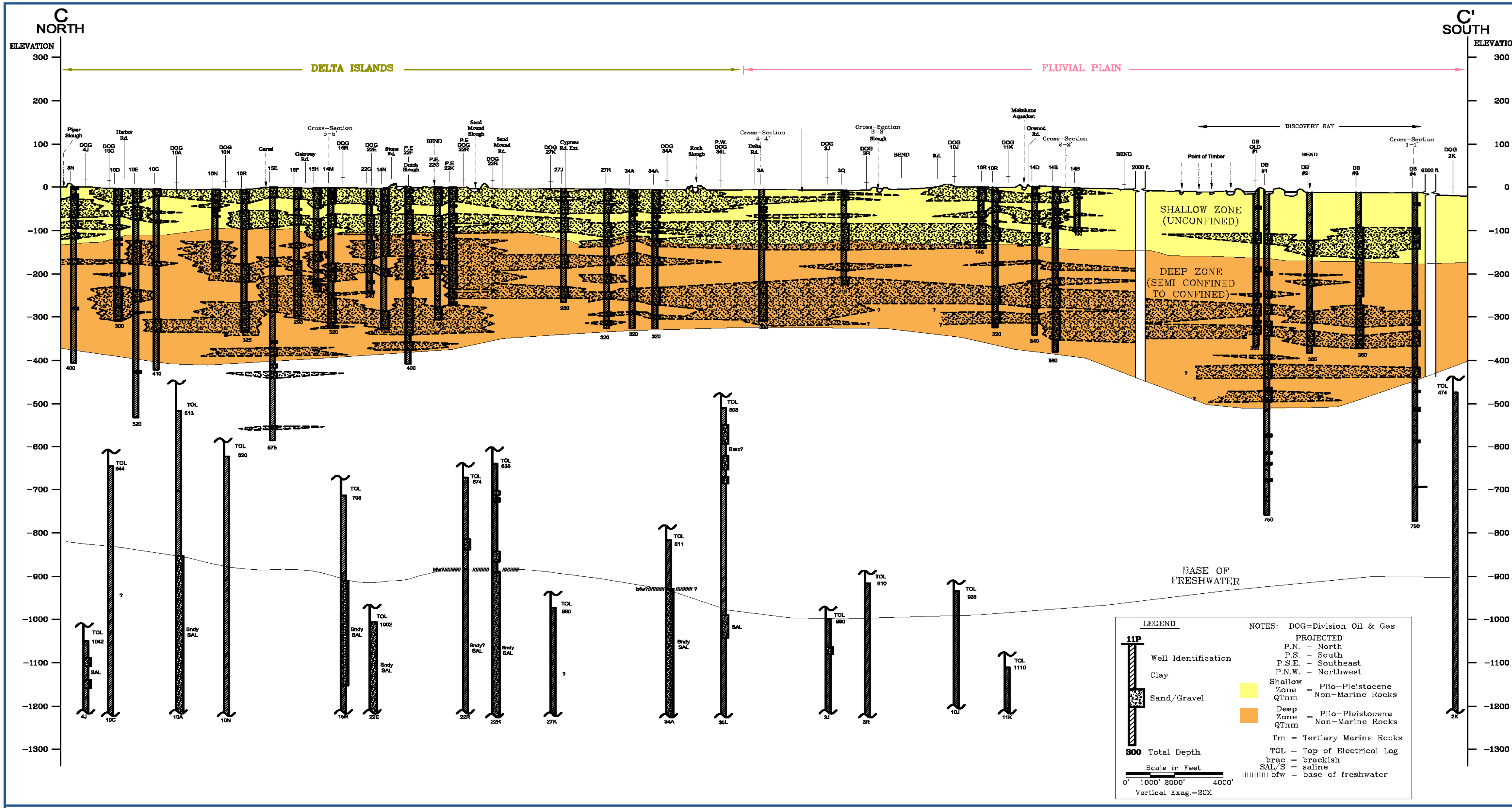


Luhdorff & Scalmanini
Consulting Engineers

Geologic Cross Section 4-4'

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-6a



Luhdorff & Scalmanini
Consulting Engineers

Geologic Cross Section C-C'

Figure 3-6b

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Delta Islands

This is representative of the northeastern portion of Subbasin (Diablo Water District GSA and encompasses Bethel Island and vicinity). Sand and gravel beds may correlate to the Fluvial Plain, but net sand thicknesses increase northward from about 30 to 60 feet per 100 feet below Bethel Island. Sand beds exist to depths of about 300 to 350 feet bgs. There is evidence of shallow saline or brackish water that may be present in shallow sand beds below the Delta Islands. The depositional environment is interpreted as multiple stream channels meandering between islands. Channels would be active with through-flowing waters, then abandoned as new channels developed. Possibly slower stream flow and tidal fluctuations allowed thicker, fine-grained sand deposits to form.

Marginal Delta Dunes

This is representative of the Oakley area and defined by numerous thin to thick sand beds that are on the order of 30 to 60 feet thick per 100 feet. The depositional environment is a mixture of delta fluvial distributary channels and possibly aeolian dune fields. A surface deposit of rolling gentle hills of relic sand dunes occurs between Oakley and northern Brentwood. These sand dunes are believed to have been generated by strong winds blowing sand off the delta margins. Some deeper sand beds across the Marginal Delta Dunes area may be older dune fields.

Alluvial Plain

This is representative of greater Brentwood south of the Marginal Delta Dune and City of Oakley, and west of the Fluvial Plain and defined by thin sand and gravel beds with a lower sand thickness (less than 20 feet per 100 feet). The depositional environment is small streams draining eastward from the Coast Range foothills to the west. Flood flows of these streams spread out from the hills depositing fine-grained materials, possibly as mudflows with high sediment content. Stream flows deposited thicker sand and gravel beds that tended to stack upon each other causing the thicker bands of sand beds. The thicker stream deposited sand and gravel bands extend eastward until the sands either thin out or have not been reached by wells. In the north, the stream deposits appear to reach into the Marginal Delta Dunes area, blending into the sand units that are present there.

Antioch and Byron Areas

Due to lack of well control, these two areas could not be examined in detail. The Antioch area is poorly defined, but it appears to be a thin alluvial plain with thin sand beds overlying Plio-Pleistocene non-marine deposits. The Byron area appears to have only a few thin sand beds in a small alluvial plan area that is marginal to the Fluvial Plain region where fine-grained deposits dominate.

3.2.5 Principal Aquifers and Aquitards

Two primary aquifer zones are identified in the East Contra Costa Subbasin: an unconfined to semi- confined Shallow Zone and a semi-confined to confined Deep Zone, with clay layers separating the two. These aquifers are composed of alluvial deposits as illustrated on the representative cross sections (**Figures 3-6a** and **3-6b)**. The Shallow Zone extends from ground surface to a less permeable material (i.e. clay and silt) generally to a depth of less than 150 feet bgs. The Deep Zone directly underlies the shallow zone, is the primary production zone for public supply wells (generally 200-400 feet in depth, LSCE, 2011), and extends to the base of fresh water (a maximum of 1,200 feet from mean sea level).

As indicated previously, the Corcoran Clay does not extend into the ECC Subbasin nor does a similar feature occur that separates major aquifer units. However, in the Alluvial Plain (around the City of Brentwood) there appears to be local confinement by multiple clay layers which separates shallow and deep zones (LSCE, 1999). This separation is seen through distinctive water levels (see **Section 3.3.1**). The Fluvial Plain (around Discovery Bay, **Figure 3-6a**) and Marginal Delta Dune (around Oakley) both have a confined Deep Zone with an extensive layer of clay separating a shallow zone from the deep zone that serves as the primary production aquifer. The Delta Islands area does not have clay layers separating a deep confined zone from shallower aquifer materials nor water levels that reflect it.

The primary use of the Shallow Zone is by domestic wells and small community water systems which may have poorer water quality due to Bay-Delta influences. The primary use of the Deep Zone is for municipal supply (City of Brentwood, Discovery Bay and DWD) and agricultural irrigation supply (ECCID and BBID).

Groundwater System Conceptualization

The ECC Subbasin aquifer system is subdivided into two zones: an upper unconfined Shallow Zone that sits above discontinuous to locally continuous clay layers and, a lower semi-confined to confined Deep Zone. As illustrated in the geologic cross-sections described above, the upper 400 feet of sediments is comprised of alluvial deposits with discontinuous clay layers interspersed with more permeable coarse-grained units. Most water wells are constructed within the upper 400 feet where coarse grained units are identified. Water well information is lacking for depths below 400 feet bgs to the base of fresh water but the units are likely fine grained and become brackish at and below that depth based on the current HCM.

3.2.6 Soil Characteristics

There are many soil types found throughout the Subbasin (**Figure 3-7a**). The soil data were gathered from the Natural Resource Conservation Service (NRCS) as part of the Soil Survey Geographic Database (SSURGO). The data are compiled from various maps, which are updated on a yearly basis.

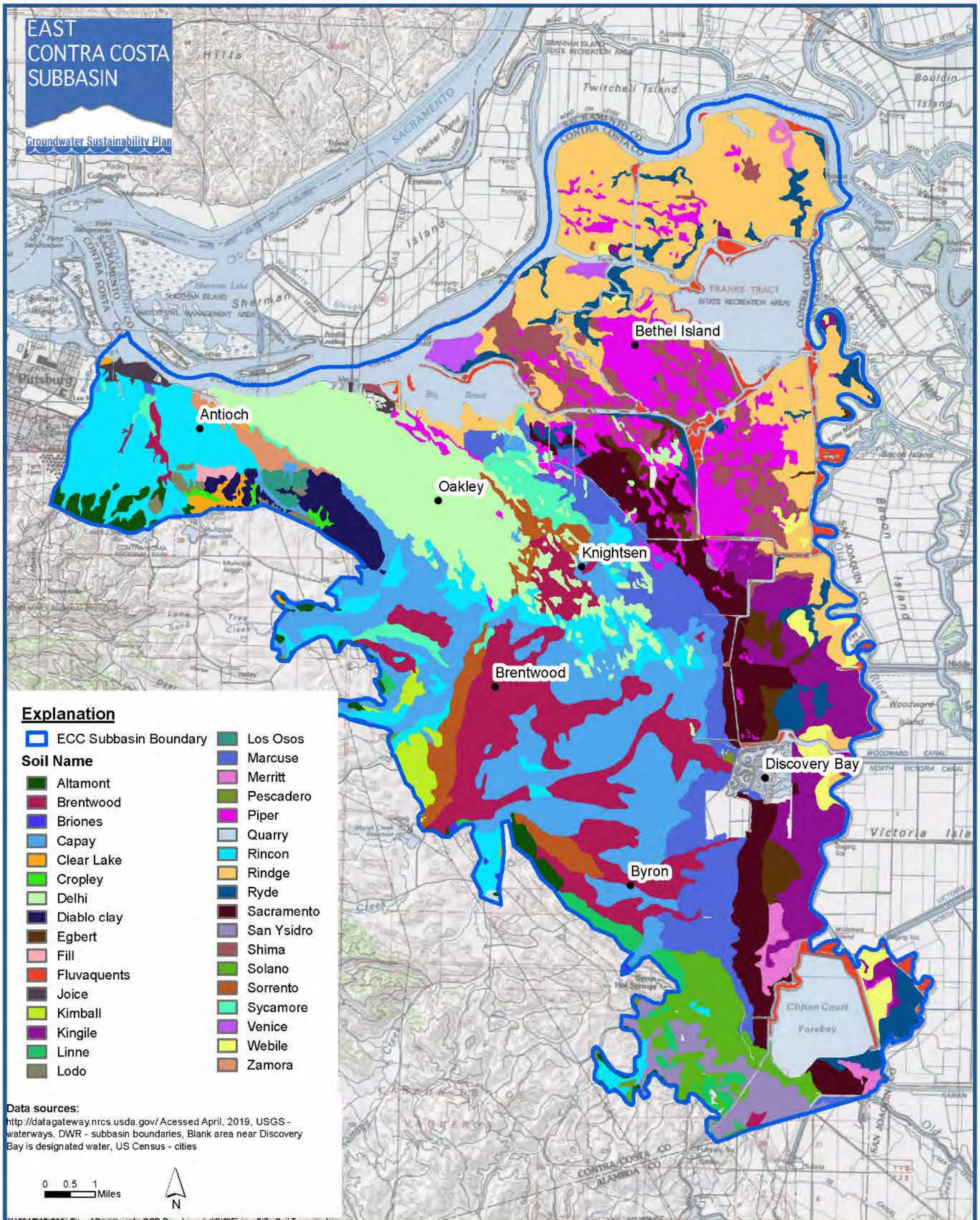
The predominate soil types in the Subbasin are the Brentwood, Capay, Delhi, Marcuse, and Rindge series. The Brentwood series is reported to be a well-drained silty clay loam found in valleys and valley floors near Brentwood. The Capay series is noted to be a moderately well-drained clay and is found throughout the Subbasin often near the Brentwood series. The Delhi series is noted to be a somewhat excessively drained sand found primarily in Oakley and Antioch and is derived from eolian deposits. The Marcuse series is noted to be a poorly drained clay and silty clay with a small amount of sand and is found throughout the center of the Subbasin. The Rindge is noted to be a very poorly drained silty clay loam to muck, and is found along the Delta Islands (i.e., Bethel Island) and near the Old River boundary.

3.2.6.1 Soil Properties

Soil properties are important to the HCM to the extent that they provide a pathway for groundwater infiltration through the soil and have high or low runoff potential. This information is used to calculate surface water recharge and to estimate deep percolation for surface water/ groundwater models. **Figure 3-7b** illustrates the soil texture of the surficial soils found in the Subbasin as outlined by NRCS. The dominant soil textures are clay, clay loam, sand, and muck. Clays and clay loams are found throughout the Subbasin. Sand is concentrated near Antioch and Oakley in the northwestern part of the Subbasin. Muck is found in the eastern portion of the Subbasin along the Old River and the Delta Islands. Muck is defined by the NRCS as “the most highly decomposed of all organic soil material. Muck has the least amount of plant fiber, the highest bulk density, and the lowest water content at saturation of all organic material”.

Figure 3-7c presents the average hydraulic conductivity[1] for soils in the Subbasin. The hydraulic conductivity of soils ranges from less than 1 ft per day to more than 15 ft per day (ft/day). The highest conductivity areas are those with soil textures of muck, sand, or loamy sand. The areas around Oakley and on the northeastern and eastern border of the Subbasin have the highest hydraulic conductivity possibly due to the occurrence of dune sands.

[1] Capacity for soil to transmit water with units of Length/Time. Units used in this report are feet/day.

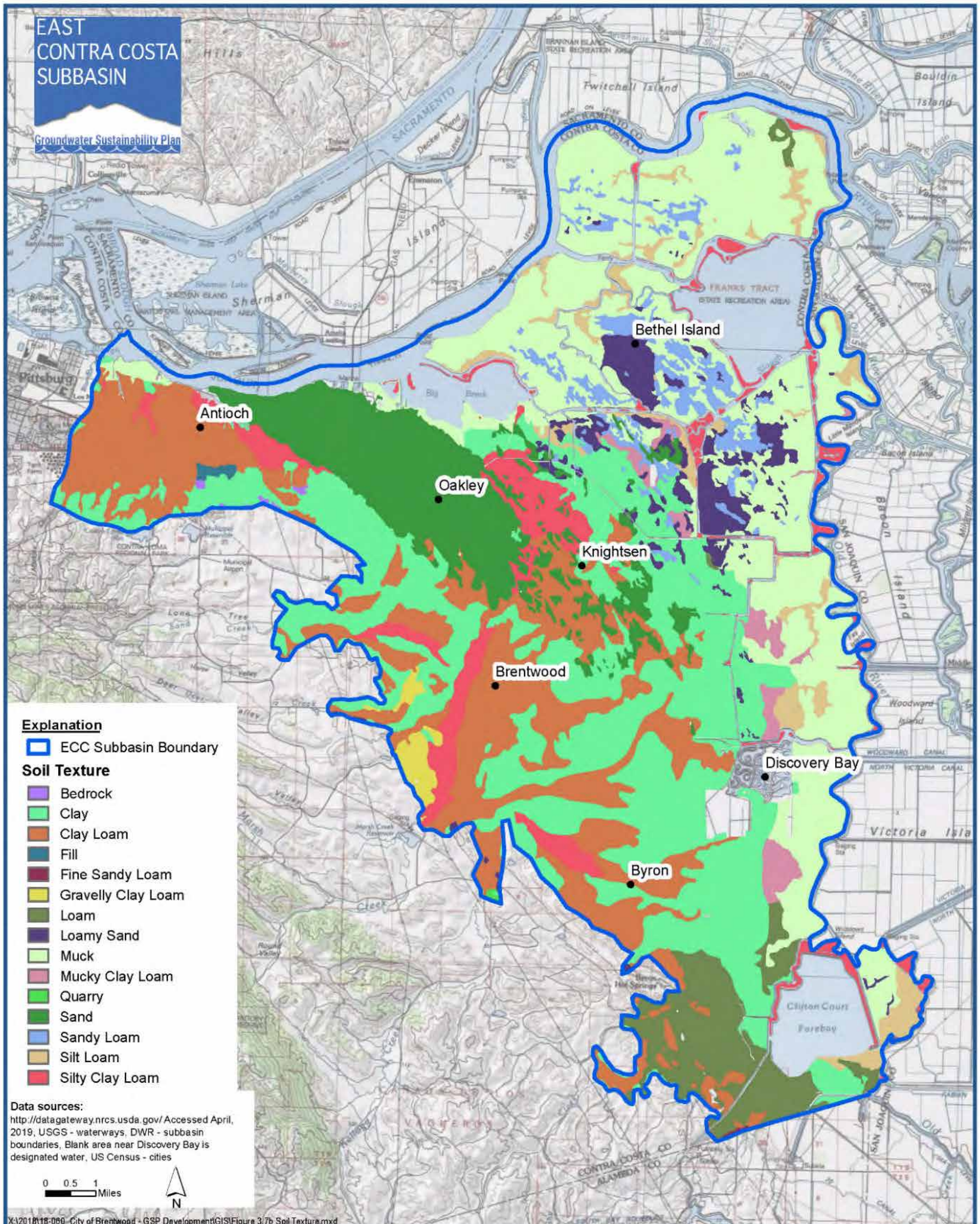


Luhdorff & Scalmanini Consulting Engineers

Soil - Type

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

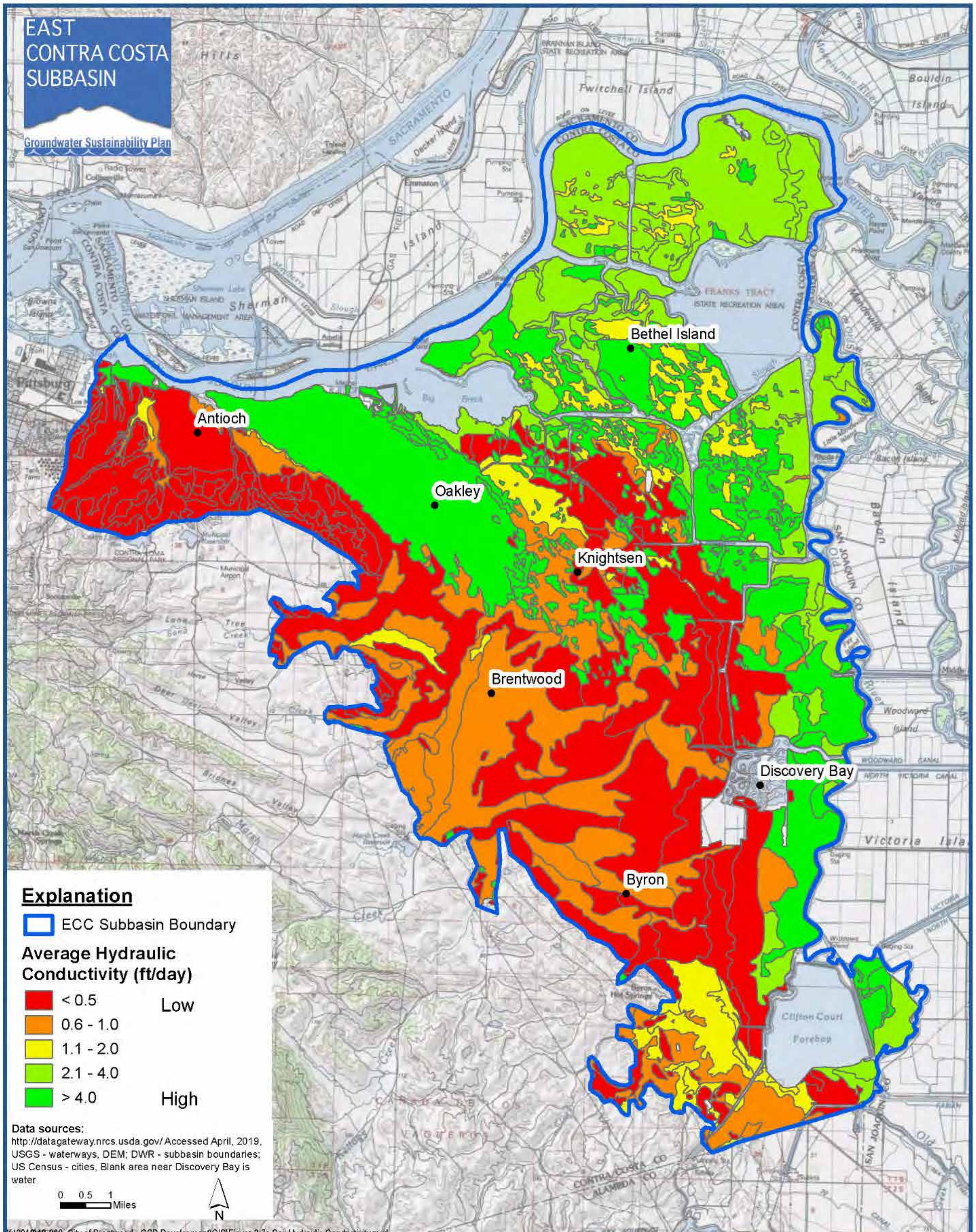
Figure 3-7a



Soil - Texture

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-7b



Luhdorff & Scalmanini Consulting Engineers

Soil - Hydraulic Conductivity

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-7c

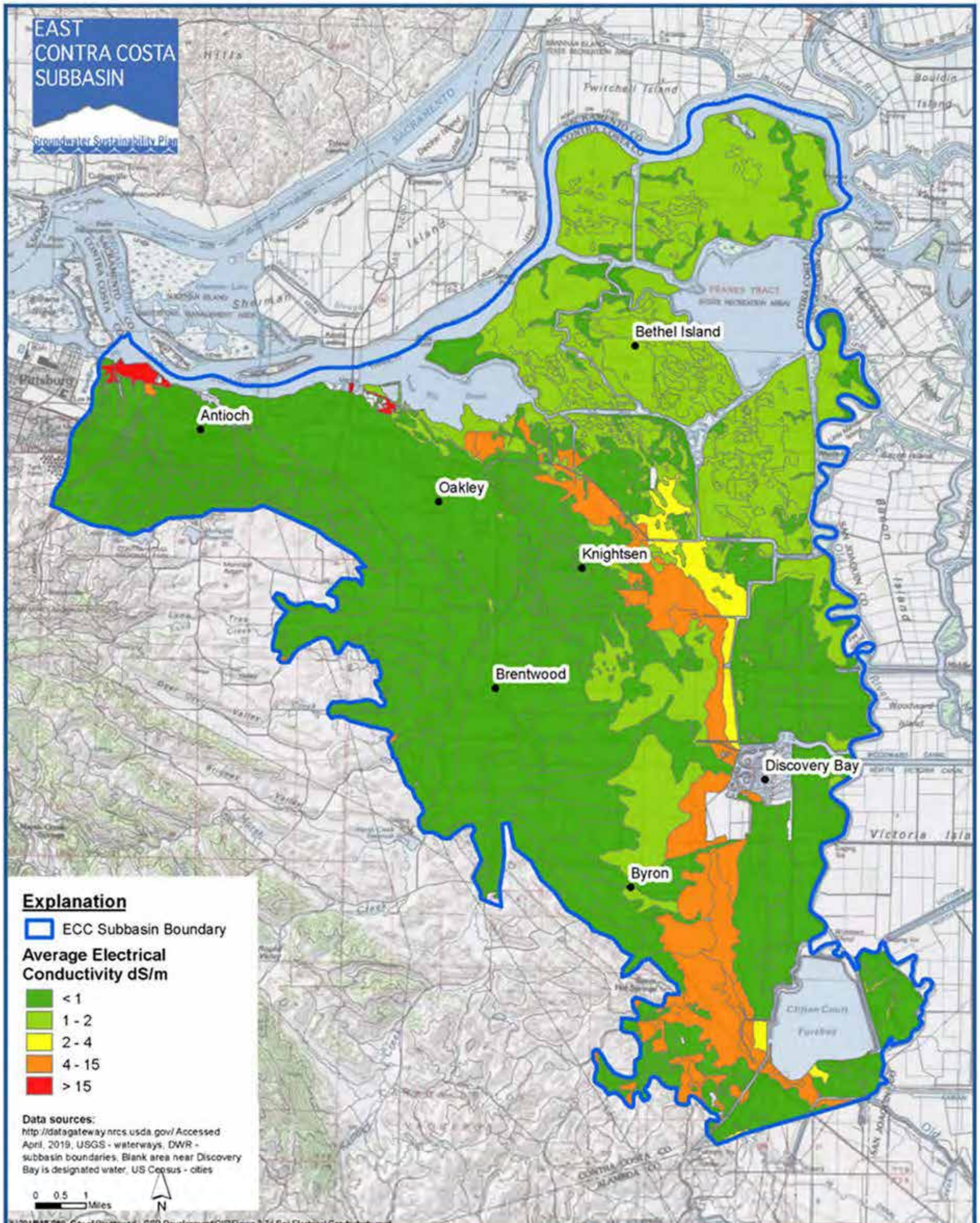
Figure 3-7d shows the soil salinity for the Subbasin. Soil salinity is measured by electric conductivity (EC) and is measured by the amount of soluble salts in the soil. Almost the entire Subbasin has electric conductivity values of less than 2 deSiemens per meter (dS/m) which is low. Higher EC is noted in the center of the Subbasin, following a similar pattern as the distribution of the Marcuse soil, which was noted to be poorly drained clay. There is also a small area near Antioch that has ECs greater than 15 dS/m, in an area with a muck texture.

3.2.7 Groundwater Recharge and Discharge Areas

Groundwater recharge can occur from infiltration of precipitation and applied water (e.g., irrigation), surface water infiltration, subsurface inflows from outside the subbasin, and unintentional recharge (e.g., leaky pipes). This section identifies the areas that may provide greater potential for future managed surficial recharge under the GSP implementation. Surface areas with favorable recharge potential (**Figure 3-8**) were evaluated using soil mapping data and the Soil Agricultural Groundwater Banking Index (SAGBI). The SAGBI provides a characterization of potential for groundwater recharge on agricultural land. The SAGBI score is based on five elements: deep percolation, root zone residence time, topography, chemical limitations, and soil surface conditions. **Figure 3-8** illustrates the main areas of percolation; however, these are not the same areas as those with high hydraulic conductivity (**Figure 3-7c**) and high infiltration potential (**Figure 3-7d**). The areas with highest recharge potential are along Marsh Creek near Brentwood and Kellogg Creek in the Byron area (moderately good), and the dune sands in the Oakley area (moderately poor). However, as discussed below, water levels indicate very little space, if any, available in the aquifer for additional recharge.

Due to the different depositional environments that occur in the Subbasin, there are a variety of natural recharge sources. The Alluvial Plain area is recharged from the Coast Range Foothills and groundwater moves through the Alluvial Plain and the Marginal Delta Dunes' area. The Fluvial Plain area likely has a different recharge source from the south as a function of its fluvial setting (LSCE, 1999). Recharge for the Delta Islands may be a combination of different sources, including fluvial influence from the Delta.

Groundwater discharge from the Subbasin can occur from discharge to surface water and springs, subsurface outflow from the subbasin, and groundwater extraction by wells. Groundwater discharge from the Subbasin is from groundwater pumping (agricultural, municipal, domestic, and industrial uses). Maps of general locations of wells are provided in **Figures 2-6a** to **2-6d**. These maps indicate that the majority of domestic wells are located in the western portion of the Subbasin, public supply wells are mostly concentrated in urban centers of Discovery Bay, Brentwood, and Oakley, and agricultural wells are located on the western side of the Subbasin. Maps of the average depths (in feet) of domestic, agricultural, and public

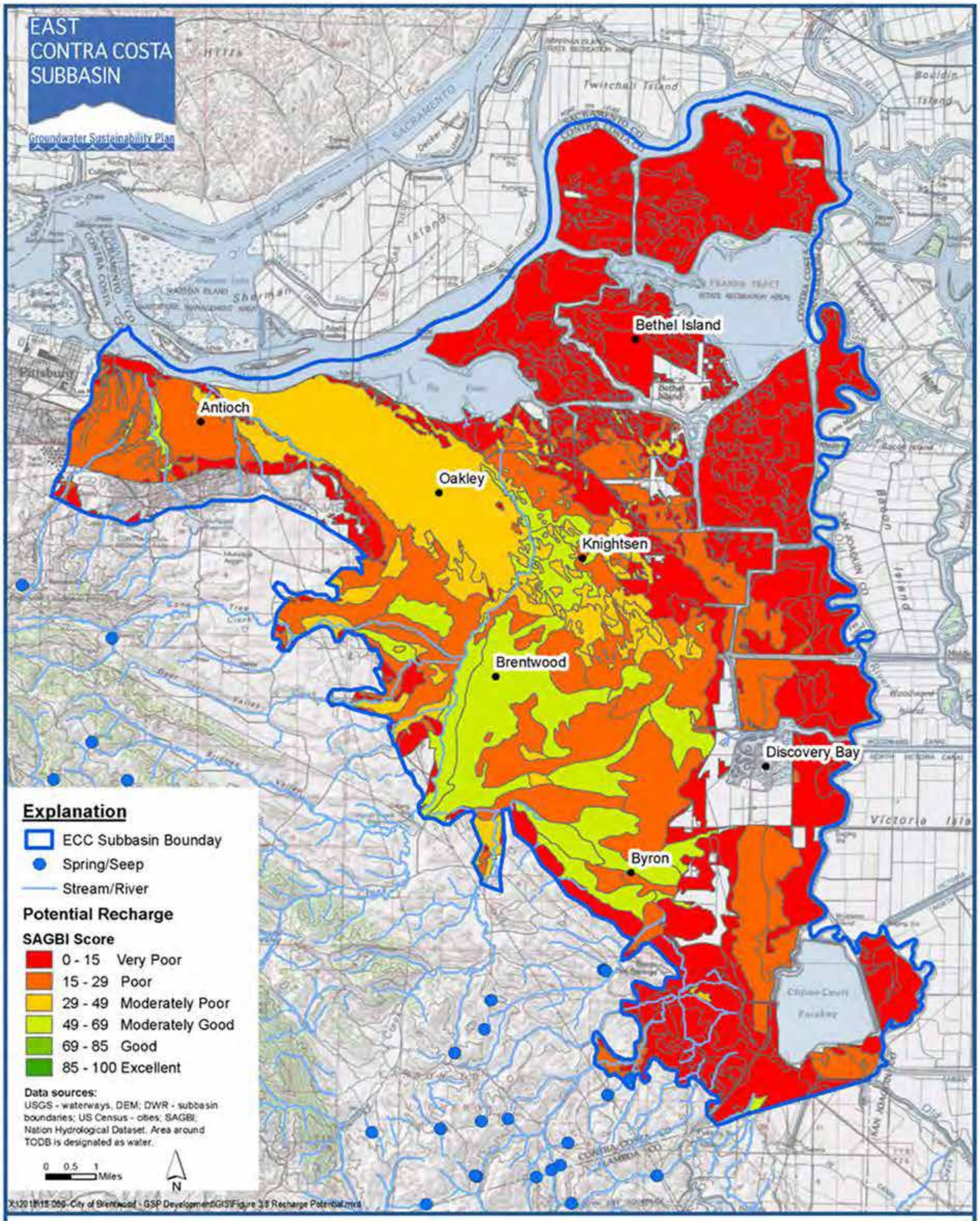


Luhdorff & Scalmanini Consulting Engineers

Soil - Electrical Conductivity

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-7d



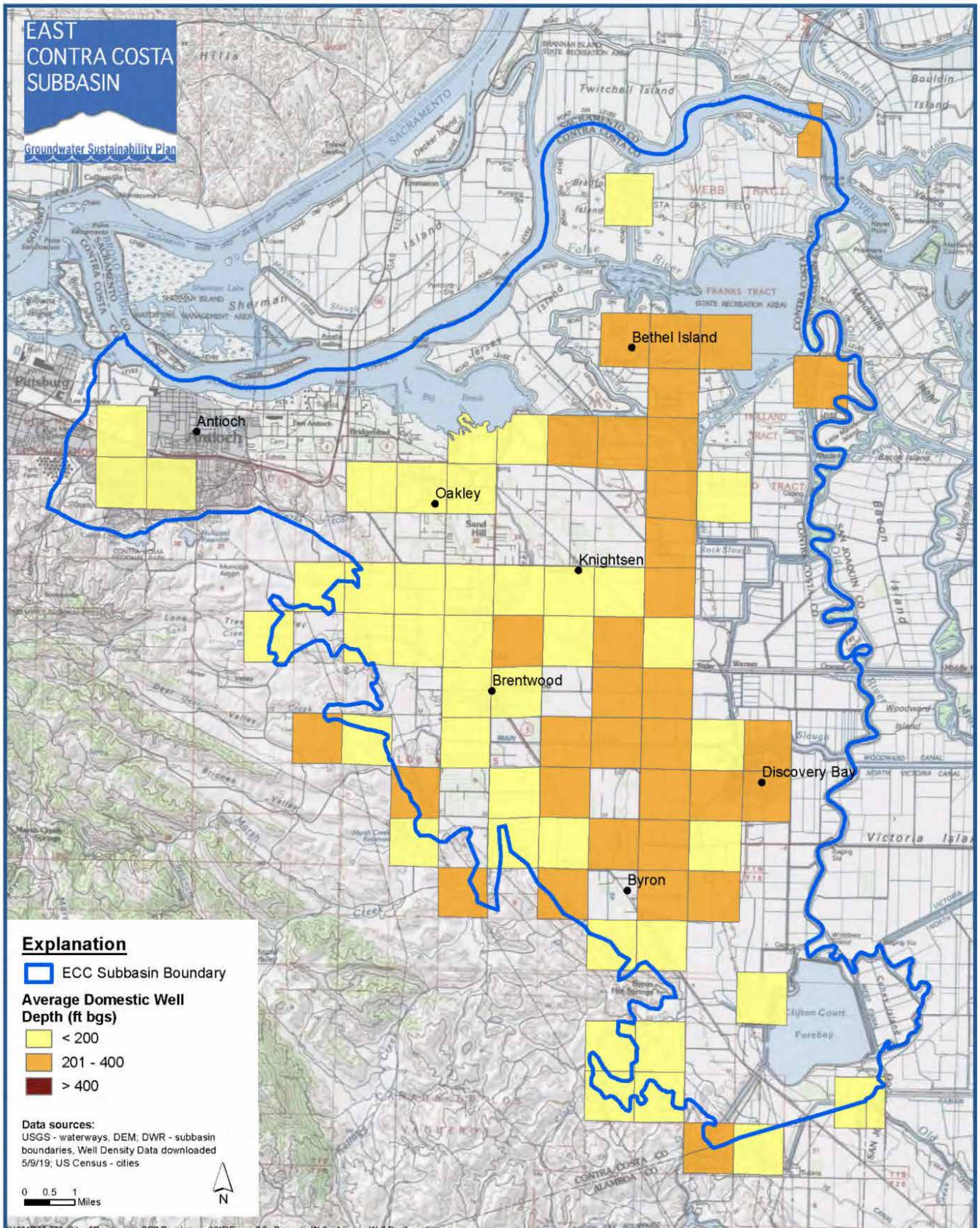
Soil - Potential Recharge

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-8

supply wells by section are provided in **Figures 3-9a** to **3-9c**. Domestic well depths are generally less than 200 feet bgs (**Figure 3-9d**). Agricultural well depths vary across the Subbasin with ranges from 60 to 800 feet bgs. Public supply wells are most commonly in the 200 to 400-foot bgs range.

The USGS's National Hydrography Dataset (NHD) maps one spring in the Subbasin located along the southwestern boundary. There are multiple springs that could be sources of recharge, in addition to streams, located in the foothills west of the Subbasin boundary (**Figure 3-8**).

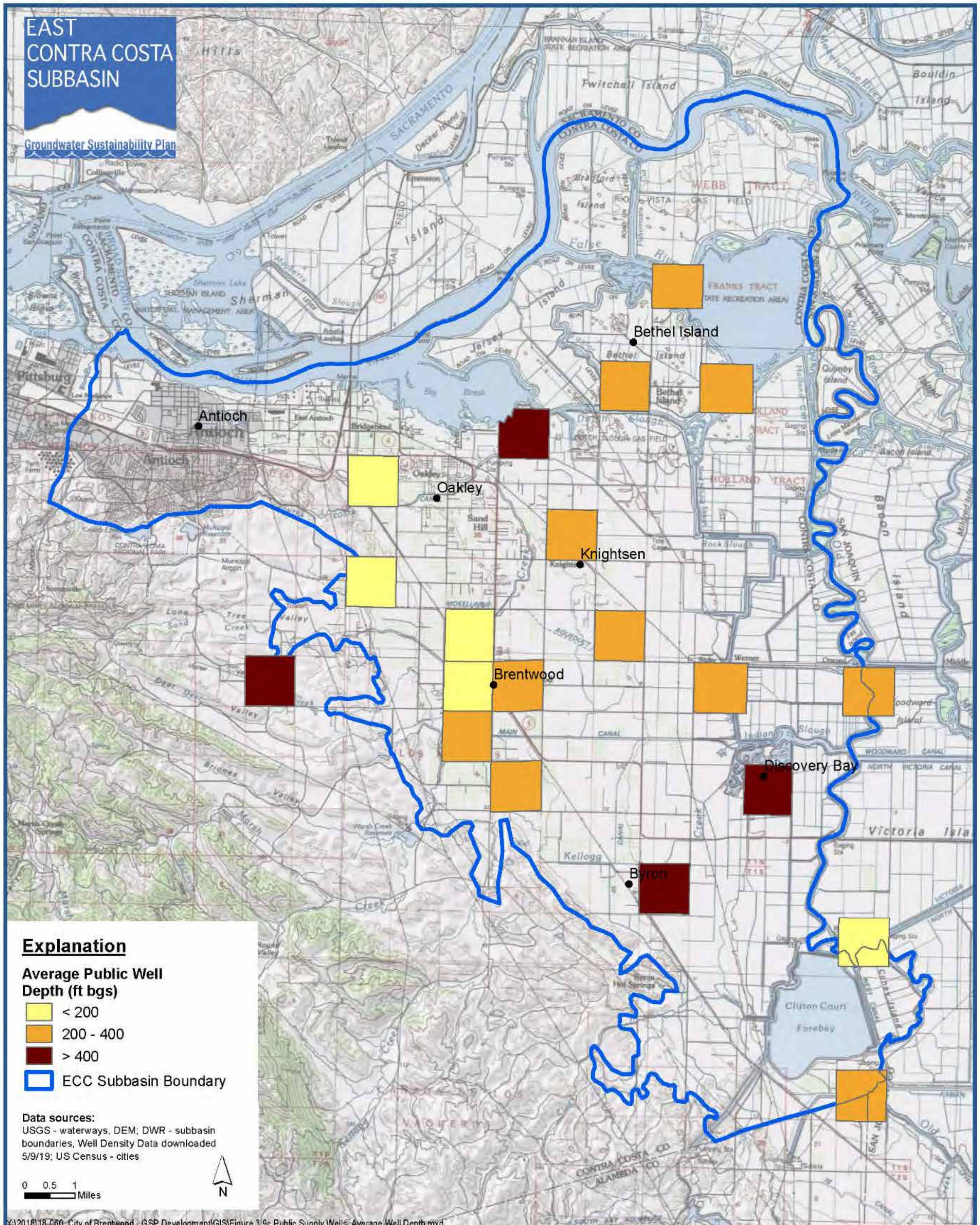


Luhdorff & Scalmanini Consulting Engineers

Domestic Wells - Average Depth

Figure 3-9a

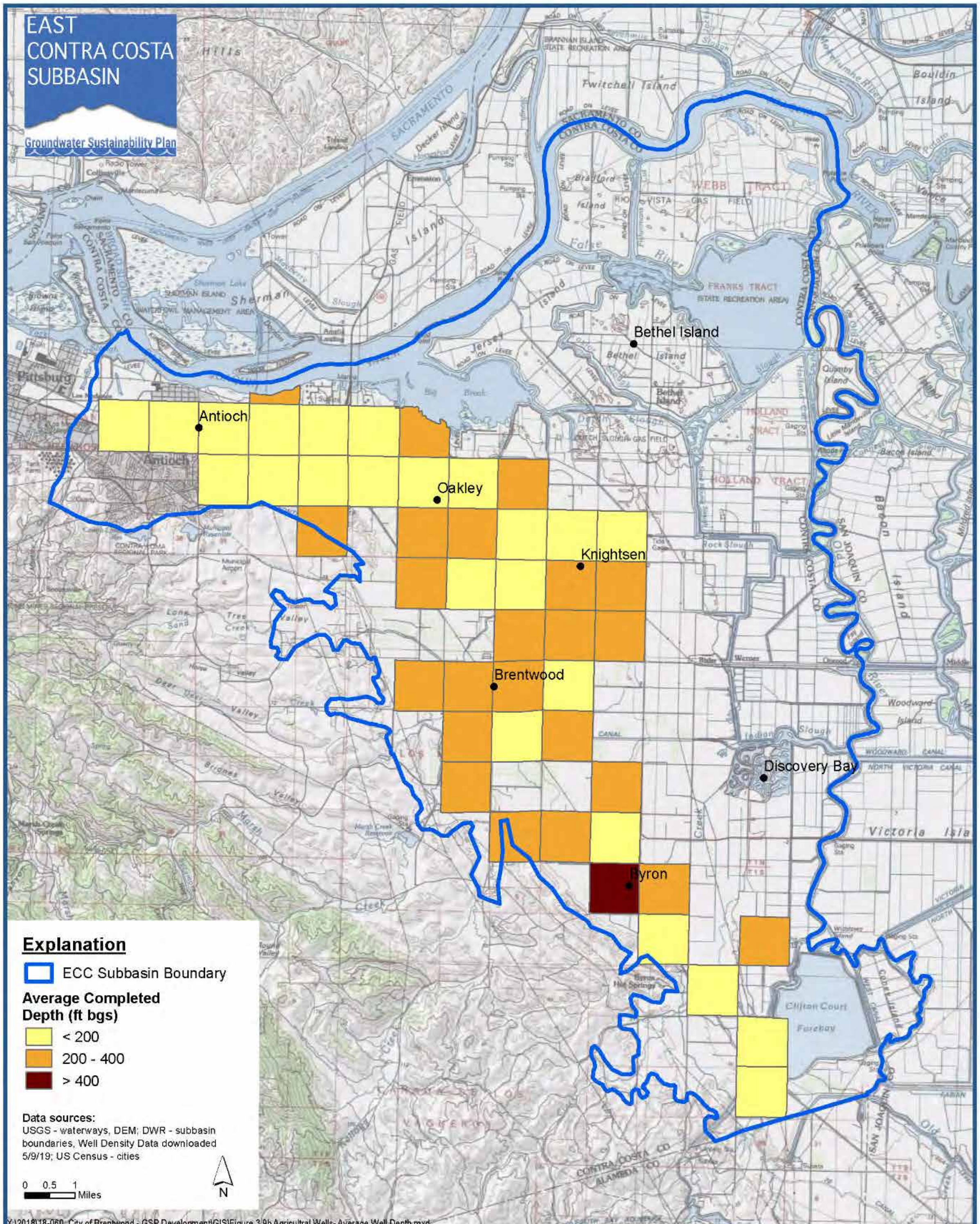
East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California



Public Supply Wells - Average Depth

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

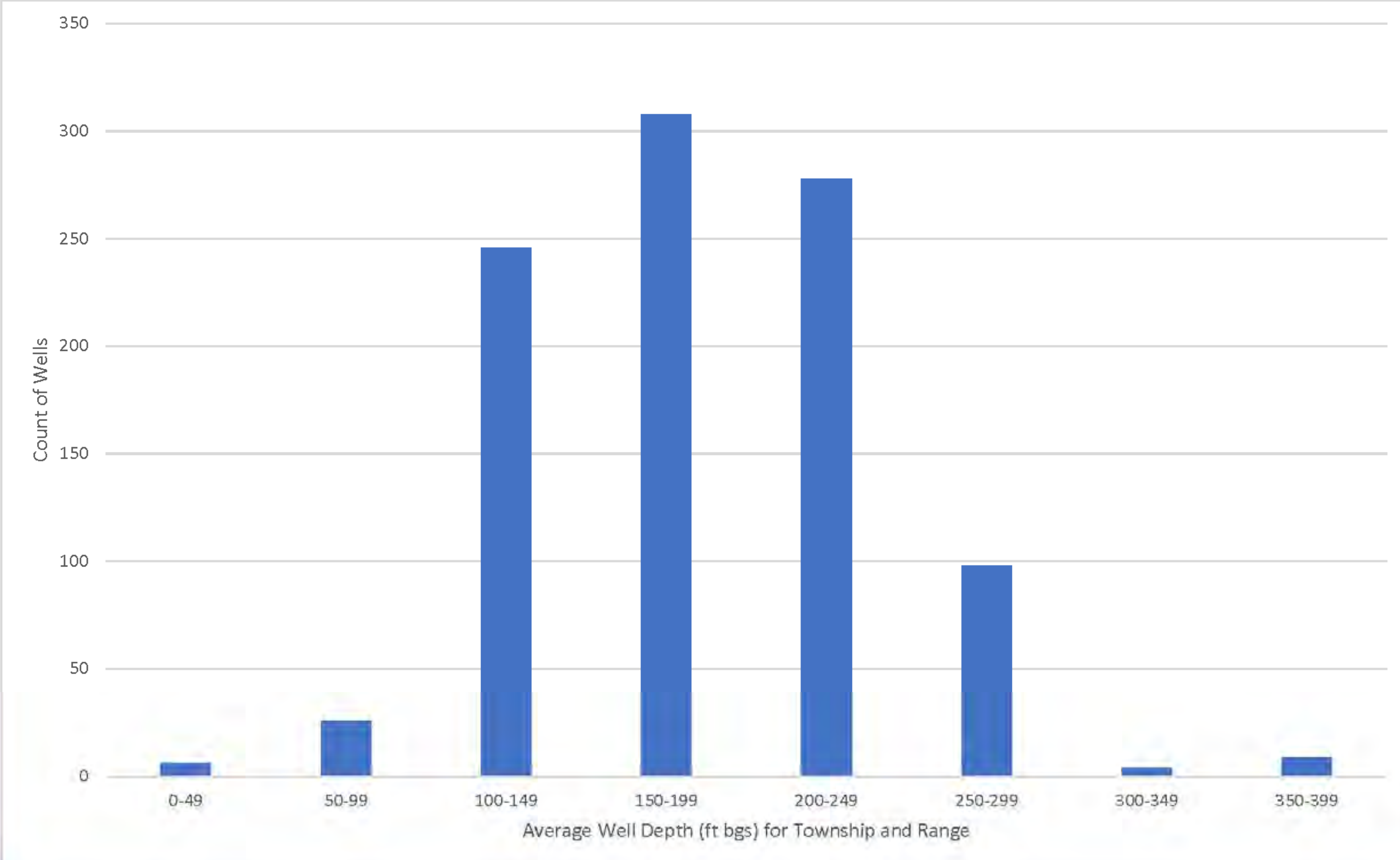
Figure 3-9b



Agricultural Wells - Average Depth

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-9c



Luhdorff & Scalmanini Consulting Engineers

Domestic Well Depths

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-9d

3.2.8 Imported Supplies

Contra Costa Water District draws water from the Delta primarily under a contract with the federal Central Valley Project (CVP). Surface water is diverted at two intake locations within the Subbasin: Rock Slough and Old River (**Figure 2-4**). Two entities in the Subbasin purchase water from CCWD: City of Antioch and Diablo Water District. In addition, CCWD diverts and conveys ECCID surface water for the City of Brentwood.

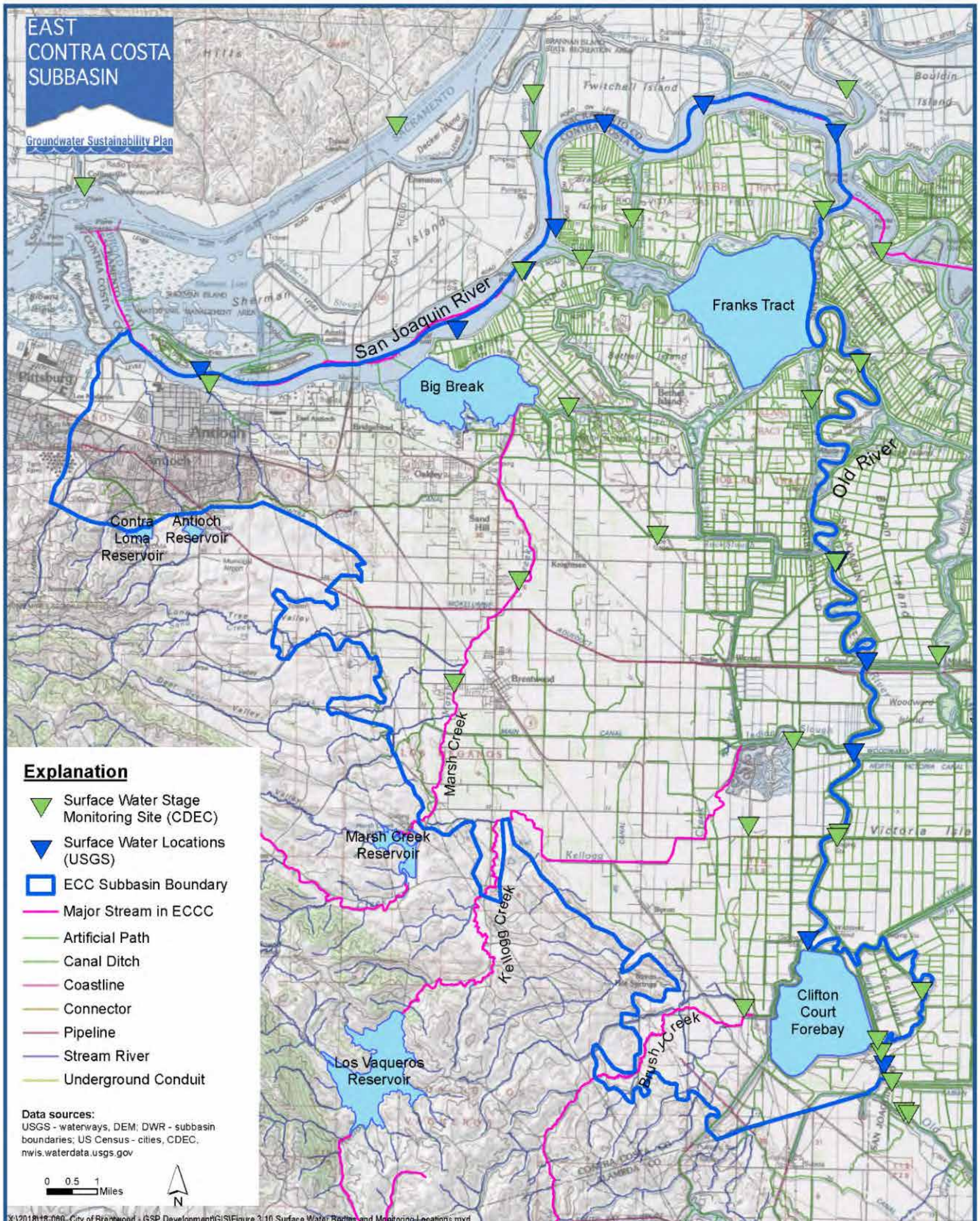
3.2.9 Surface Water Bodies

There are a number of surface water bodies that are significant to the management of the Subbasin (**Figure 3-10**). The Clifton Court Forebay, Franks Tract, and Big Break are large surface water bodies in the Subbasin. Two rivers are the primary natural surface water features in the ECC Subbasin. The San Joaquin River flows from east to west along the northern edge of the Subbasin and Old River flows from north to south on the eastern edge of the Subbasin. Numerous streams from the Coast Range enter the Subbasin from the west and discharge into the Delta (ECC IRWM, 2019). Marsh Creek drains parts of Mt. Diablo and has flows impounded (stored/captured) by the Marsh Creek Reservoir. Kellogg Creek drains the watershed south of Marsh Creek and includes the CCWD operated Los Vaqueros Reservoir. Brushy Creek is south of Kellogg Creek and drains into Old River and Clifton Court Forebay.

3.2.10 Hydrogeologic Conceptual Model Data Gaps and Uncertainty

This section identifies the data gaps and levels of uncertainty of the information for the physical setting and characteristics of the basin and current conditions.

Lithologic, water quality, and water level measurement controls exist for purposes of developing the hydrogeologic conceptual model mostly in the urban areas of Brentwood, Discovery Bay and Oakley. There are large areas in the north near Antioch and Bethel Island and in the south, west of Clifford Court Forebay, that have low well density as a result of a more rural setting. Many wells used for municipal purposes were also primarily screened to less than 500 feet bgs, which leads to uncertainty in the nature of the deeper subsurface materials. Many lithological descriptions come from drillers' logs which are limited in quality as a function of driller's experience and attention to detail. Geophysical logs provide the most consistent and quantitative information, but well control is highly variable as a function of current and historic groundwater use patterns. Expanded monitoring by aquifer for groundwater quality and level measurements and additional lithologic descriptions outside the urban areas would benefit development of the hydrogeologic conceptual model.



Surface Water Bodies and Monitoring Locations

Figure 3-10

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

3.3 Groundwater Conditions

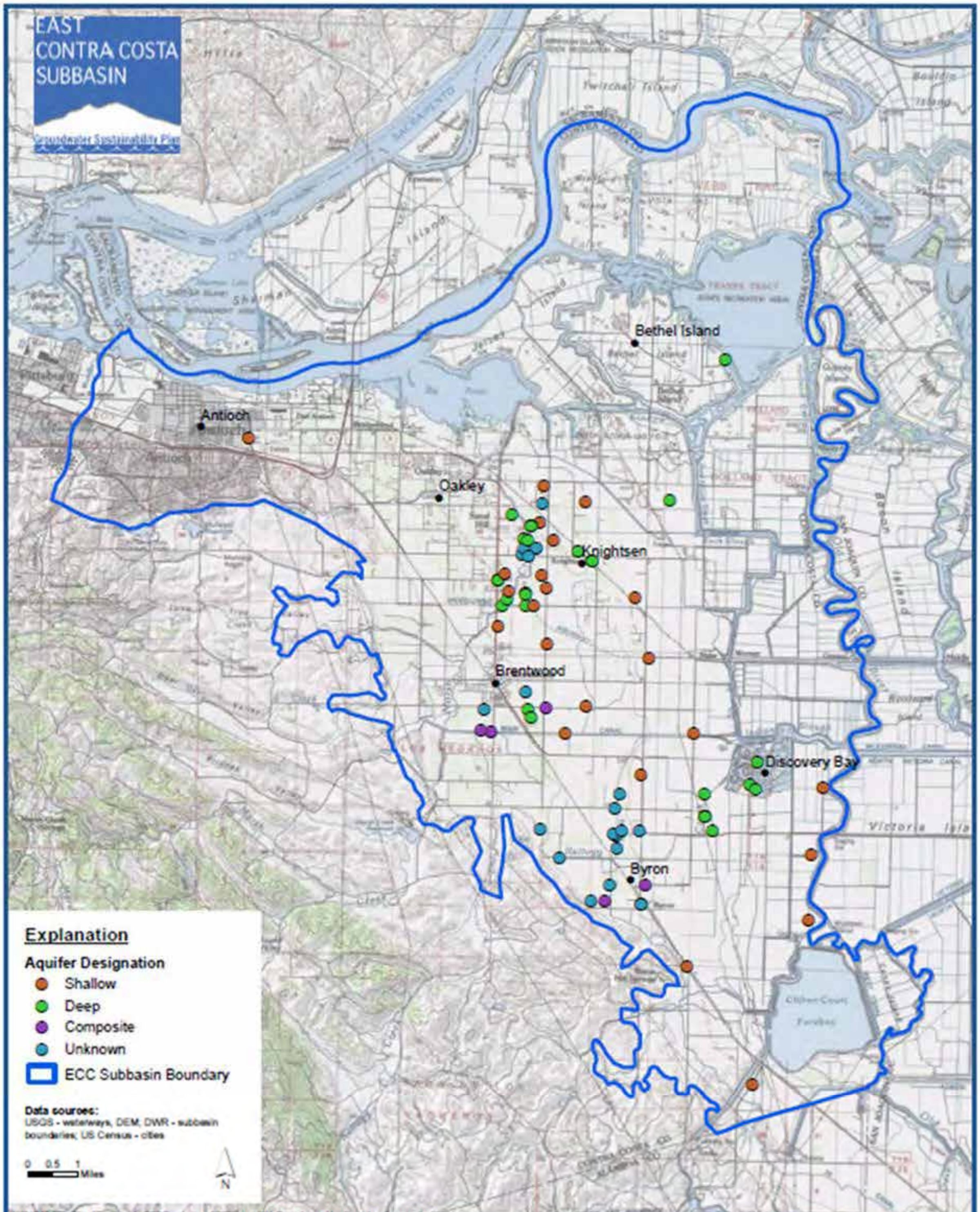
This Groundwater Conditions section describes historical groundwater conditions in the ECC Subbasin through present day. Groundwater levels and storage, seawater intrusion, groundwater and surface water quality, land subsidence, interconnected surface water, and groundwater dependent ecosystems are presented in this section.

3.3.1 Groundwater Levels

Groundwater levels provide useful data for understanding groundwater conditions and trends over time. Groundwater levels are affected by natural recharge and discharge which are in turn governed by variations in climate conditions. Groundwater pumping and water usage such as in agriculture also affect groundwater levels. Groundwater movement, as governed by regional and local gradients and aquifer properties are also reflected in groundwater levels. All factors play a role in changes in groundwater storage over time which is a primary consideration in the HCM.

Groundwater level records were compiled from the various entities in the Subbasin in addition to data from Geotracker, USGS, and DWR. A small subset of wells has a long period of record for water level monitoring, but most data are relatively recent, within the last 15 years. The wells with the longest period of record have over 50 years of data and are primarily concentrated in the ECCID area (**Figure 2-1**). All data were reviewed and compiled in a Data Management System (DMS). Data of similar type was converted to the same units and, if applicable, the method used to gather data was noted (e.g., surveyed reference point elevations versus estimated elevations). A well was assigned an aquifer zone designation (Shallow Zone, Deep Zone, Composite, or Unknown) based on the well screen interval and/or total well depth. This well construction information is presented in **Appendix 3c** for over 1,100 wells in the ECC Subbasin. The contact between the Shallow Zone and Deep Zone ranges in depth from 100 and 150 ft bgs throughout the Subbasin but is generally about 120 ft bgs. Wells with screen intervals in both zones were given the designation Composite. Wells with missing well construction information were designated Unknown. **Figure 3-11** illustrates the groundwater level monitoring well locations in the Subbasin and their assigned aquifer designations (Shallow Zone, Deep Zone, Composite, or Unknown) based on well construction. Selected groundwater level hydrographs are presented for Shallow Zone wells in **Figure 3-12a**, for Deep and Composite Zone wells in **Figure 3-12b,** and all hydrographs are presented in **Appendix 3d**. Overall, water levels are stable for the periods of record.

Figure 3-12a is a panel map with hydrographs from wells completed in the unconfined Shallow Zone. Shallow groundwater level information is concentrated in the Oakley, Brentwood, and Discovery Bay areas. These data indicate that basin-wide Shallow Zone water levels have

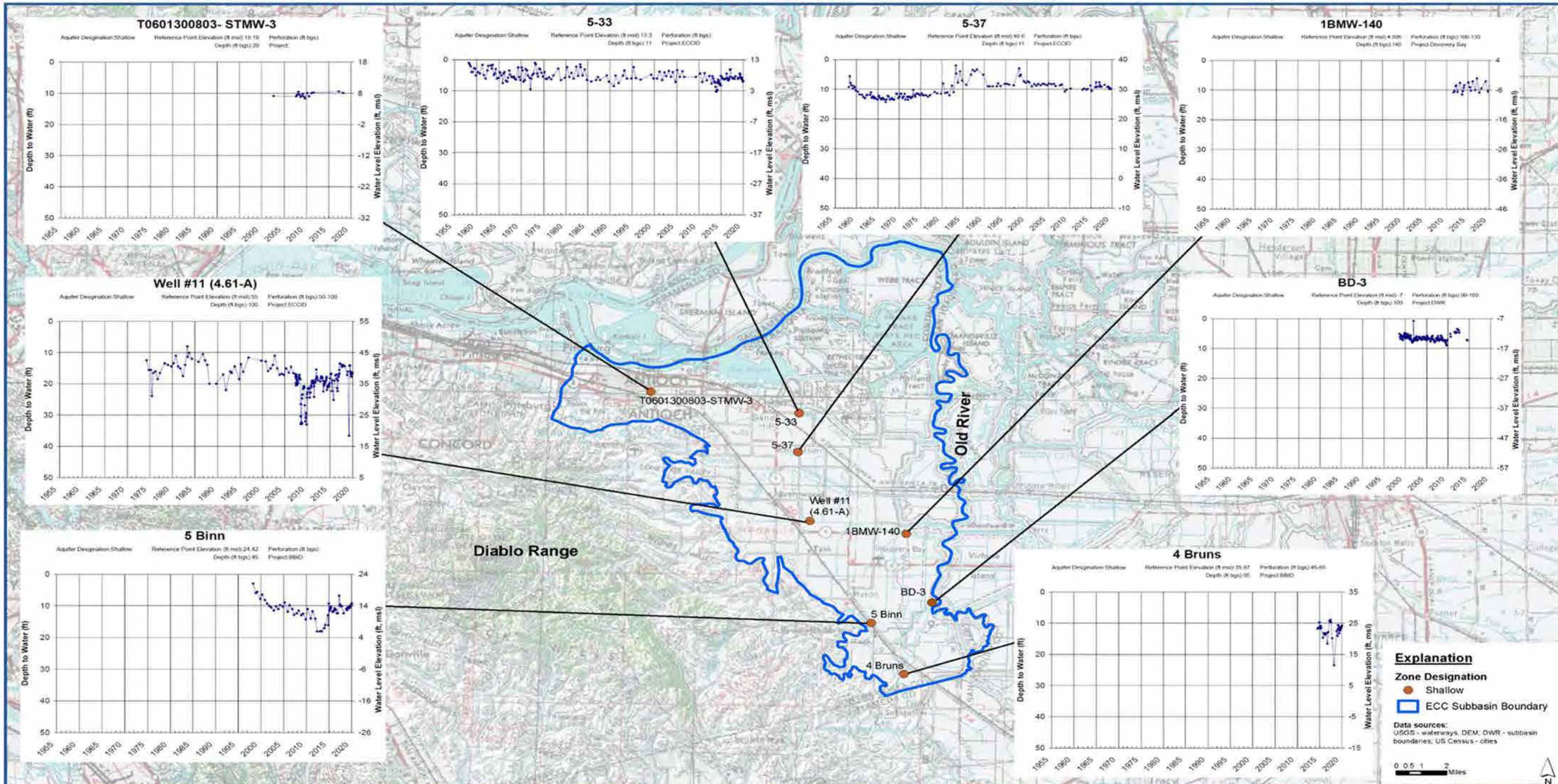


Luhdorff & Scalmanini Consulting Engineers

Groundwater Level Monitoring Locations

Figure 3-11

East Contra Costa Subbasin Groundwater Sustainability Plan
Contro Coasta County, California

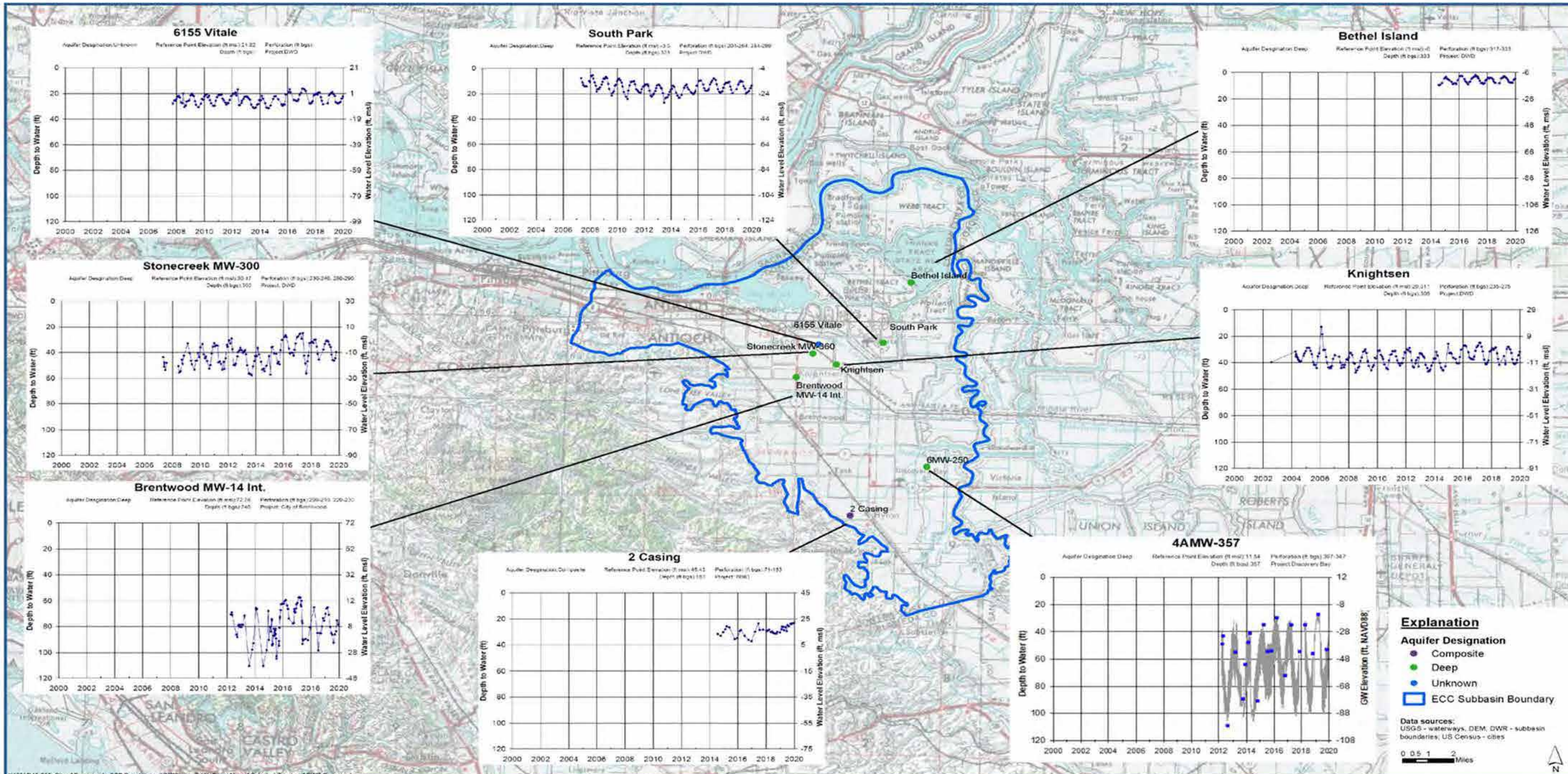


Luhdorff & Scalmanini Consulting Engineers

Selected Graphs of Groundwater Elevations - Shallow Zone

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-12a



Luhdorff & Scalmanini
Consulting Engineers

Selected Graphs of Groundwater Elevations - Deep and Composite Zone

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-12b

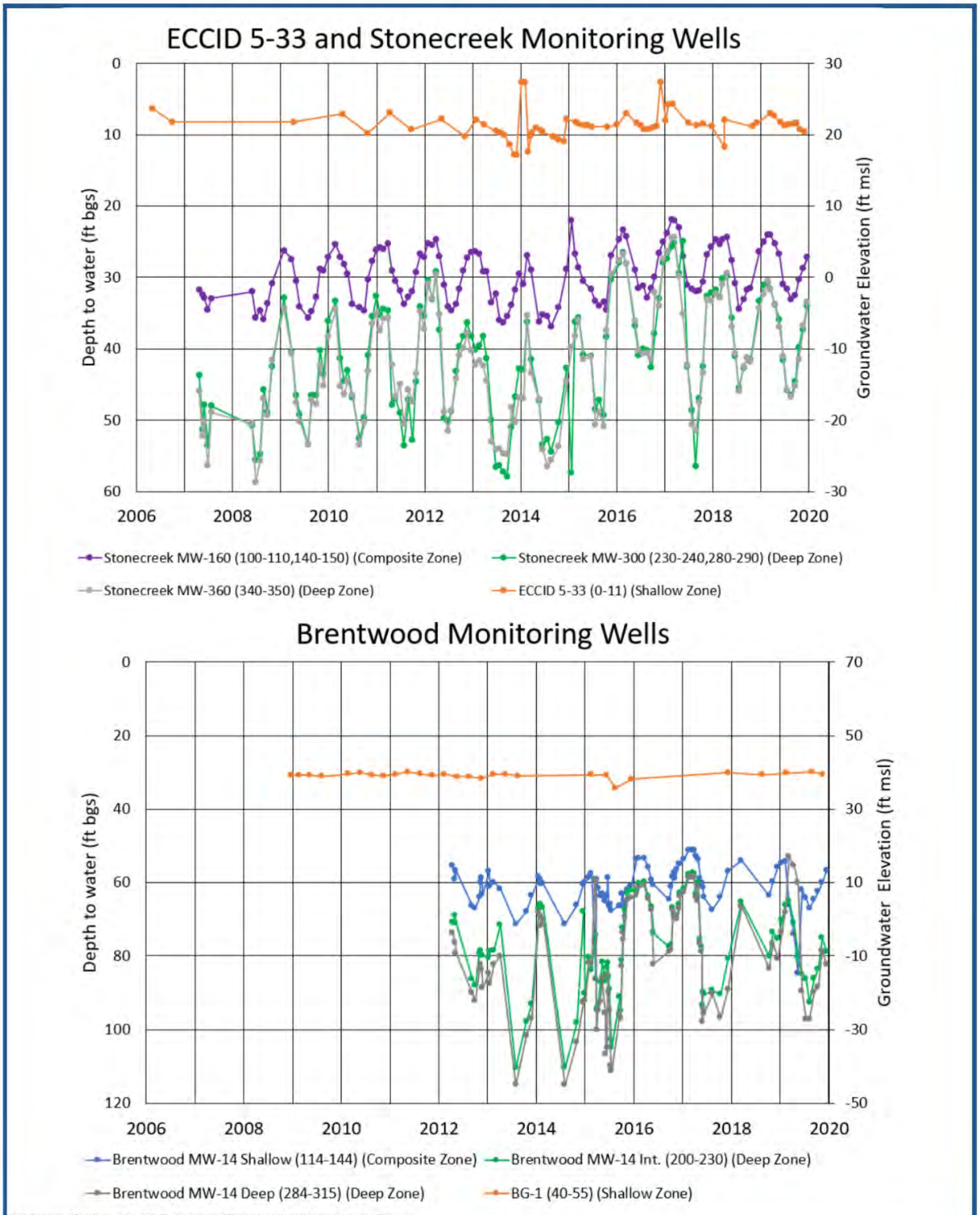
remained fairly stable with no evidence of long-term declines. A minor shift in water level is seen in one well, 5 Binn in the southern portion of the Subbasin, that has dropped five feet over a 22-year period. This is not considered a significant factor to either groundwater quantity or quality in the Subbasin.

Shallow Zone seasonal variations in groundwater levels on a regional basis are very minor (one to three feet). In the Oakley and Brentwood areas, a few Shallow Zone wells with deeper completions (100 to 150 ft bgs) show more variable seasonal trends (10 to 15 feet annual fluctuation in water levels) that suggest a slight increase in confinement (semi-confined) with depth. Shallow monitoring wells in the Discovery Bay area and eastward along Old River (BD-1, 2, 3) do not have pronounced seasonal water level changes (less than five feet annually) that may be attributed to influence by and proximity to the Delta. Shallow wells located in the western portion of the Subbasin (e.g., Well #11 [4.61-A], **Appendix 3d**) have more pronounced seasonal water level changes (about 10 feet annually) that is likely influenced by boundary effects due to proximity to the edge of the groundwater basin (e.g., the Diablo Range). The Delta Islands have a unique shallow groundwater situation unlike the rest of the Subbasin. Depth to water in subsided Delta islands (described in more detail below) is controlled by drainage ditches that convey irrigation water and seepage water from adjacent channels that is then pumped back into Delta channels. Deverel et al. (2016) reports that, due to this drainage system, groundwater levels are generally maintained at about 2-1/2 to 4 feet bgs in the Delta islands area.

Figure 3-12b shows select hydrographs of the confined Deep and Composite Zone wells in the Subbasin. Regional large capacity supply wells target the Deep Zone and are generally over 200 feet in depth (LSCE, 2011). The hydrographs show generally stable conditions with seasonal water level fluctuation from 10 to 30 feet bgs with maximum decline during the summer months. This is followed by a full recovery of water levels during wet months (November to March). Some variation in annual peak water levels according to climatic trends is noted in the period between 2007 and 2010 and 2012 to 2015 when water levels appear to be affected by the state-wide droughts (**Appendix 3d**). There is no evidence of pumping-induced groundwater level declines.

Vertical groundwater gradients can be monitored with nested monitoring wells. When plotted together, the water levels show the variation of groundwater levels in an unconfined, semi-confined and confined aquifer system (**Figures 3-13a and b**). The ECC Subbasin has three locations with nested monitoring wells: Stonecreek Monitoring Wells, Brentwood MW-14 Monitoring Wells, and Discovery Bay (**Figure 3-13c**). The Stonecreek Monitoring Well cluster has three monitoring wells screened between 100 and 350 ft bgs with a local shallow well (ECCID 5-33) that has a well depth of 11 ft bgs. Brentwood MW 14 has three wells screened between 114 and 315 ft bgs and a shallower well (BG-1) screened between 40-55 ft bgs. Discovery Bay MW4A has two wells screened between 122 and 347 ft bgs. All three nested wells show similar trends. In Stonecreek and Brentwood wells, the two deeper screened wells exhibit similar groundwater levels with seasonal variations of up to 30 ft. The shallower wells have higher groundwater levels with less seasonal variation (less than five feet for the ECCID 5-33 well). The Discovery Bay Deep Zone monitoring well (4AMW-357) has up to 60 feet seasonal variation and the Shallow Zone monitoring well (4AMW-152) has less than 5 feet of seasonal variation.

These hydrographs demonstrate that groundwater levels in ECC Subbasin wells are stable and that groundwater conditions in the Subbasin are consistent with sustainable use. The water levels, by virtue of their consistent seasonal recoveries, also indicate that the Subbasin on the whole is full, with no room for additional groundwater recharge.

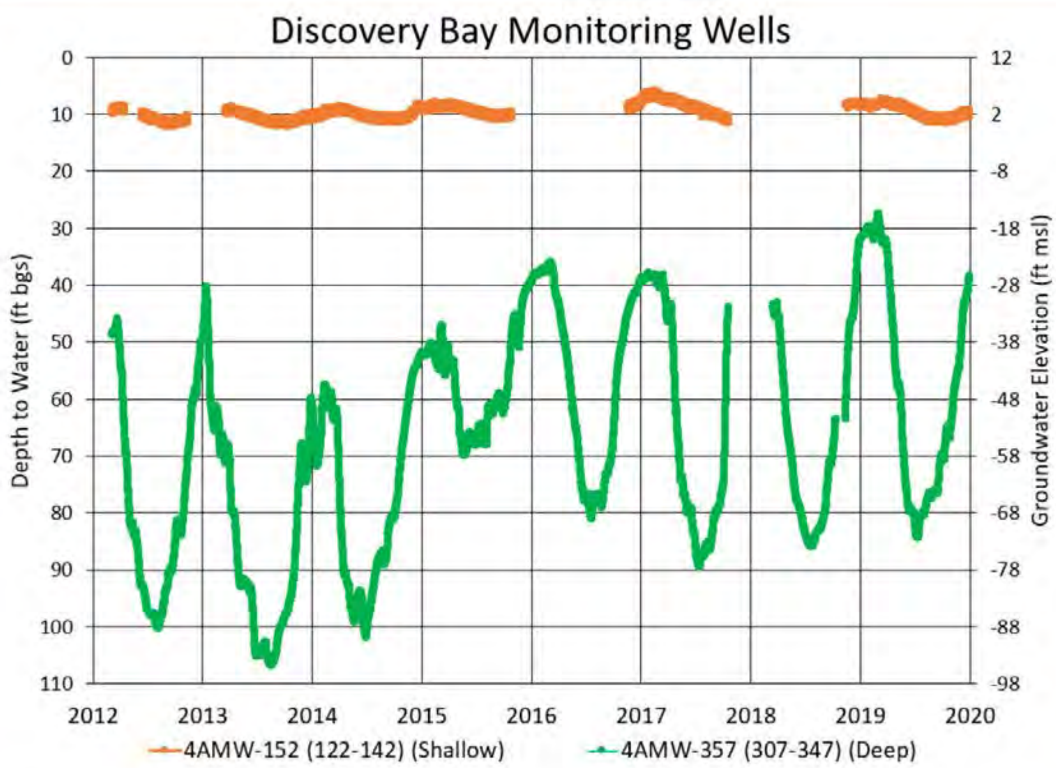


Luhdorff & Scalmanini Consulting Engineers

Vertical Groundwater Gradients

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-13a



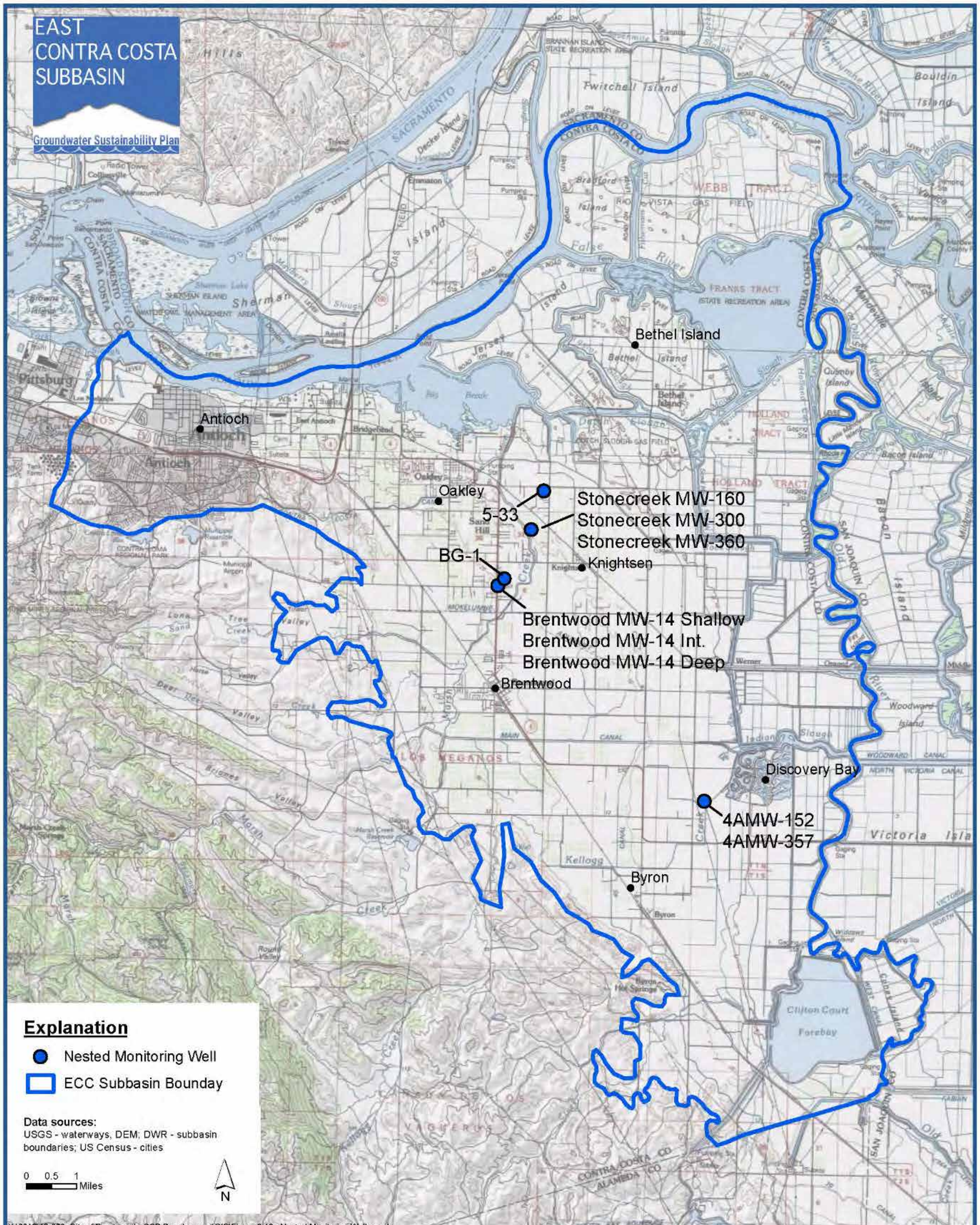
X:\2018\18-060 City of Brentwood - GSP Development\GIS\Figure 3.14b Vertical Groundwater Gradients.mxd

Luhdorff & Scalmanini Consulting Engineers

Vertical Groundwater Gradients

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-13b



Luhdorff & Scalmanini Consulting Engineers

Nested Monitoring Well Locations

East Contra Costa Subbasin Groundwater Sustainability Plan
Contro Coasta County, California

Figure 3-13c

3.3.2 Groundwater Elevation Contours

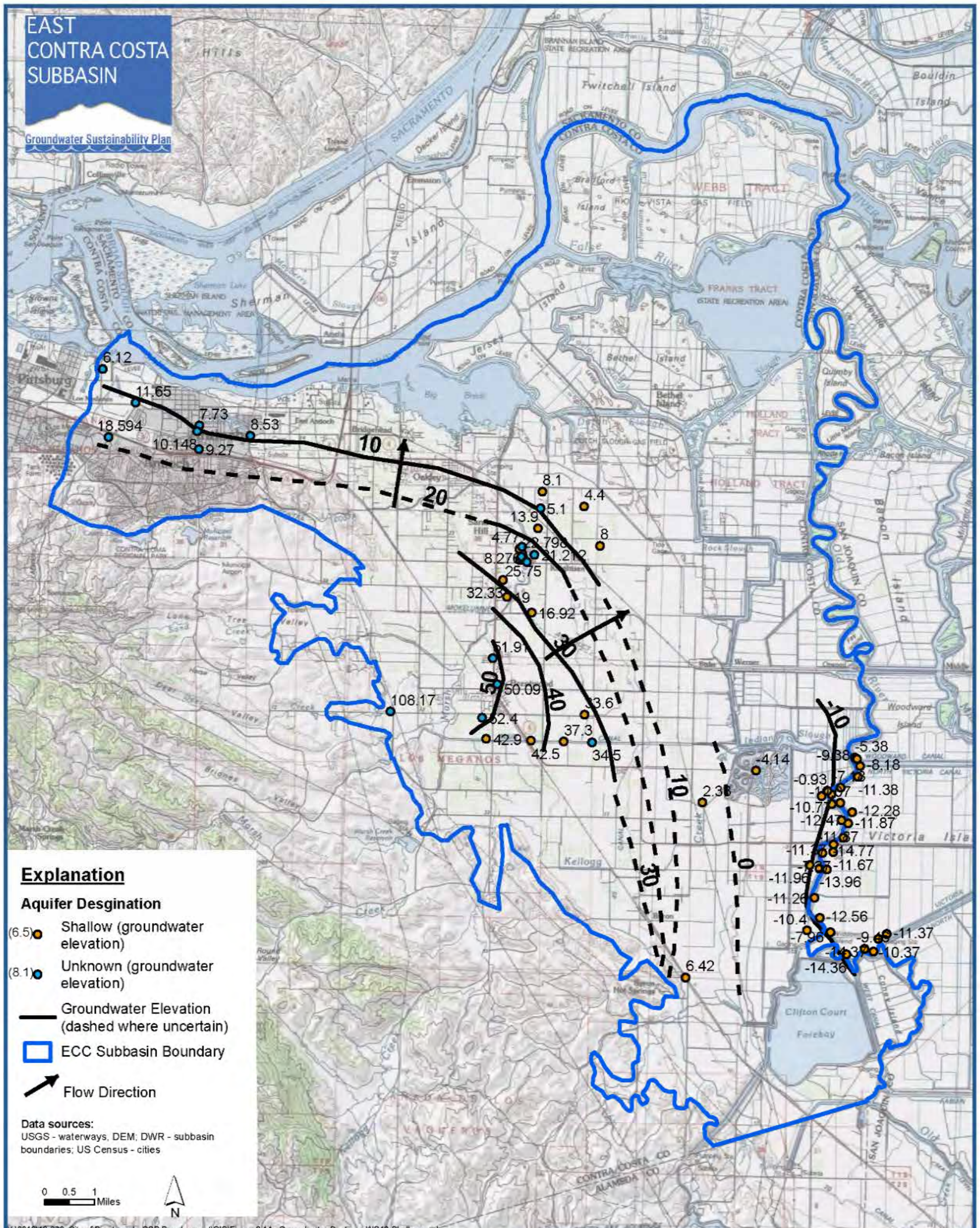
Maps of groundwater elevation from 1958 to present indicate groundwater flow direction is from the Diablo foothills towards the Delta, generally from the southwest to the northeast in the central East Contra Costa Subbasin. Groundwater elevation contour maps developed by LSCE (1999) are available for selected years between 1958 to 1996 (**Appendix 3e**). These maps were developed with water level measurements for wells mostly constructed in the Shallow Zone and are representative of the unconfined aquifer. To evaluate recent groundwater level conditions in the Subbasin, groundwater elevation contour maps were prepared for Spring 2012 and 2018 for both the Shallow and Deep Zones (**Figures 3-14a** to **Figure 3-14d)**.

Shallow Zone

The spring 1958 through spring 2018 groundwater contours for the Shallow Zone exhibit a similar pattern of flow, generally from the southwest to the northeast. In 1958, groundwater elevations ranged from about 55 feet msl in Brentwood to about 5 feet msl near the Delta north of Oakley; however, data is only available in the vicinity of Brentwood and Oakley. In spring 1991 additional data were available for the area south of Brentwood on the basin boundary where the groundwater elevation was as high as 75 feet msl to -15 ft msl around Discovery Bay. In spring 2012 (**Figure 3-14a**), the highest groundwater elevations were south of Brentwood at about 45 ft msl to a low of about -10 ft msl along Old River. In spring 2018 (**Figure 3-14b**) the Shallow Zone high groundwater elevations were again located south of Brentwood at about 40 ft msl to a low of about -5 ft in Discovery Bay. The general groundwater flow directions remained the same (to the northeast) and elevations north of Oakley were still around 5 ft msl.

Deep Zone

Contouring groundwater elevations in the Deep Zone is difficult due to the lack of well control exclusively in the Deep Zone. In contouring groundwater levels in the Deep Zone, water levels were used from wells with known construction in the Deep Zone and composite wells (constructed in both the Deep and Shallow Zones). The composite wells are identified by a different colored symbol on the contour maps and allow contours to tentatively be extended outward. Deep Zone groundwater level data is not available until 2007 around Oakley and 2012 around Brentwood and Discovery Bay. Given the limited data points and spatial representation, two Deep Zone groundwater contour maps were constructed: spring 2012 and spring 2018 (**Figures 3-14c and d**). In spring 2012, the highest Deep Zone groundwater elevations were about 50 ft msl south of Brentwood to a low of less than -20 feet msl around Discovery Bay. The spring 2018 Deep Zone contour map illustrates similar groundwater elevations to spring 2012 with high levels of 52 ft msl south of Brentwood, less than -20 ft msl in Discovery Bay, and about 2 ft msl north of Oakley. The Deep Zone groundwater flow direction is to the northeast which is similar to the Shallow Zone flow direction. Due to the limited spatial coverage of Deep Zone wells, evaluating groundwater flow and gradients within the Subbasin are challenging.

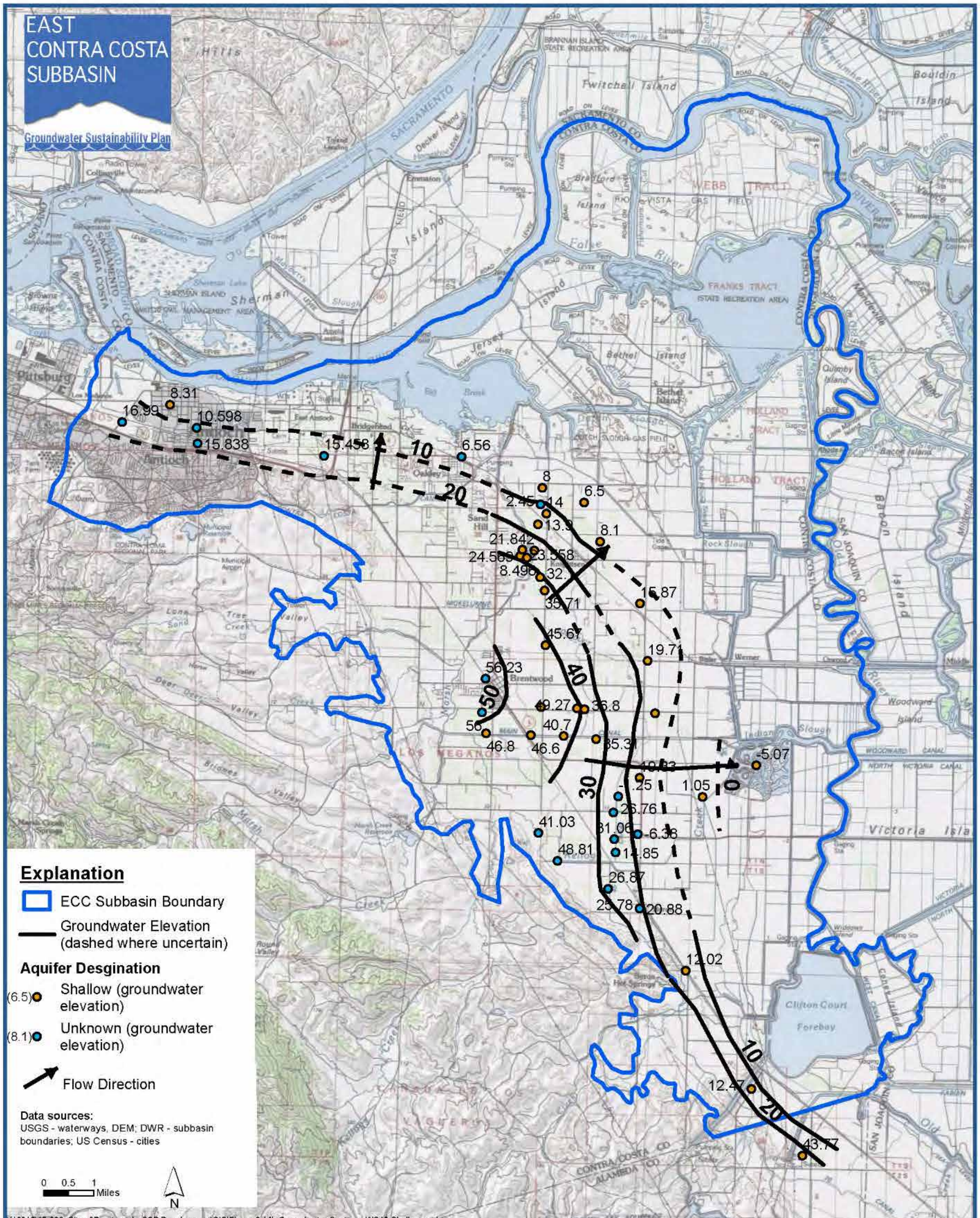


Luhdorff & Scalmanini Consulting Engineers

Groundwater Contours Spring 2012 - Shallow Zone

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-14a

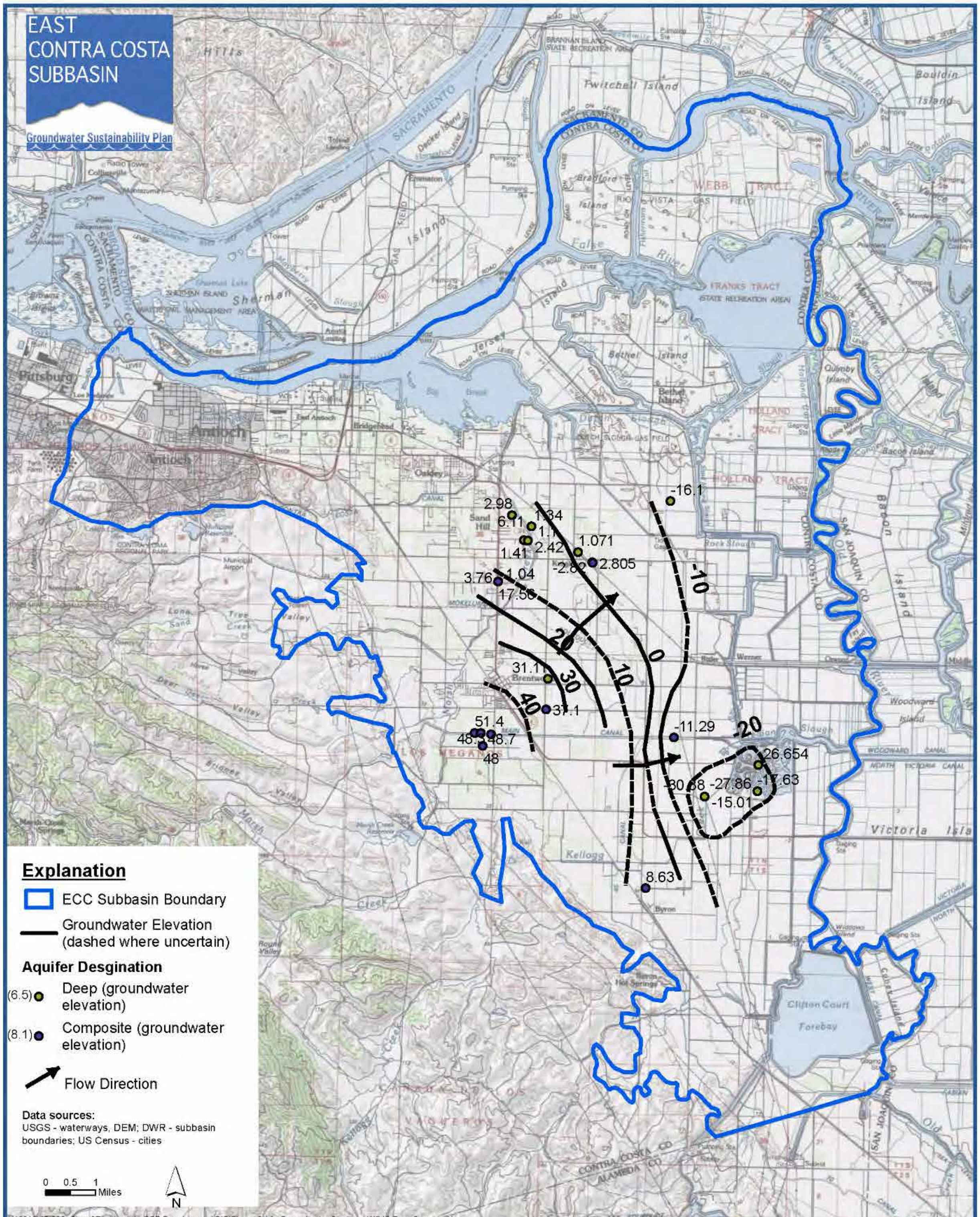


Luhdorff & Scalmanini
Consulting Engineers

Groundwater Contours Spring 2018 - Shallow Zone

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-14b

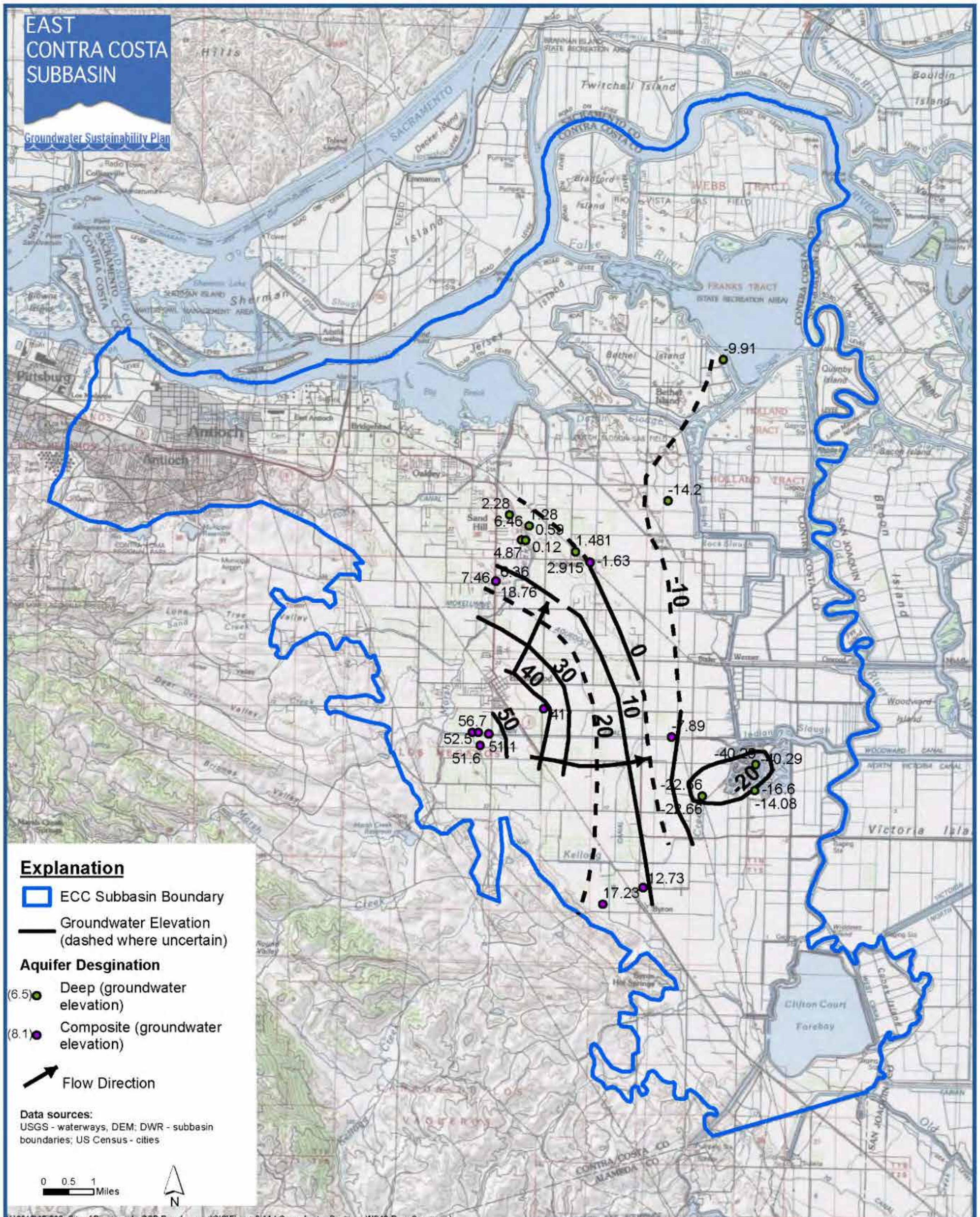


Luhdorff & Scalmanini Consulting Engineers

Groundwater Contours Spring 2012 - Deep Zone and Composite Wells

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-14c



Luhdorff & Scalmanini Consulting Engineers

Groundwater Contours Spring 2018 - Deep Zone and Composite Wells

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-14d

3.3.3 Storage

The total groundwater storage volume within the East Contra Costa Subbasin above the base of freshwater is estimated to be between 4.5 million AF (MAF) and 9.0 MAF based on the specific yield range of 5 to 10 percent and using spring 2018 groundwater level contours. DWR Bulletin 118 (2016 update), did not estimate total groundwater storage in the ECC Subbasin but did provide specific yield value ranges of 7 to 10 percent for the San Joaquin Subbasin and Delta for water bearing deposits. **Table 3-1** summarizes calculations of total groundwater storage in the Subbasin using the 7 and 10 percent specific yield values and a lower value of 5 percent as a sensitivity for lower computed storage. An additional analysis is included in **Table 3-1** ("To Base of Major Production Zone") that estimates groundwater storage for the saturated thickness in the Subbasin from the regional water table (spring 2018) to the base of the major production zone (about 300 feet bgs). The total groundwater storage volume for this subsurface unit is estimated to be between 1.5 MAF and 3.0 MAF. There has not been a change in groundwater storage over time because groundwater levels between 1993 to 2019 have been stable. Sustainable yield[2] refers to conditions under which extraction has not adversely impacted a variety of parameters including groundwater levels, storage, quality, etc. Historical conditions as reflected in the hydrographs and contour maps, where data is available, indicate that groundwater extraction has not impacted groundwater levels and storage and that the Subbasin is operating within its sustainable yield.

[2] "In general, the sustainable yield of a basin is the amount of groundwater that can be withdrawn annually without causing undesirable results. Sustainable yield is referenced in SGMA as part of the estimated basinwide water budget and as the outcome of avoiding undesirable results." DWR, 2017.

Table 3-1: Estimates of Total Groundwater Storage (2018)

Area	ECC Subbasin Volume (acre-feet)	Specific Yield (percent)	Total Groundwater Storage (acre-feet)	Notes on Specific Yield Basis
To Base of Major Production Zone	30,254,373	5%	1,513,000	
		7%	2,118,000	Range of 7 to 10% for water bearing deposits DWR Bull. 118 (2003) Tracy Subbasin
		10%	3,025,000	
To Base of Freshwater	89,839,409	5%	4,493,000	
		7%	6,290,000	Range of 7 to 10% for water bearing deposits DWR Bull. 118 (2003) Tracy Subbasin
		10%	8,986,000	

3.3.4 Seawater Intrusion

The East Contra Costa Subbasin has no coastline, is not bordered by the ocean, and seawater intrusion is not present. The Sacramento-San Joaquin River Delta has historically had brackish tidal water drawn in from the San Francisco Bay; however, levees installed around Delta islands to facilitate agriculture, and development of the Central Valley and State Water Projects, have altered the movement of tidal water through the Delta to maximize freshwater flow. A surface water salinity interface of two parts per thousand near Chipps Island west of the ECC Subbasin, is the State Water Resources Control Board adopted[3] water quality objective to regulate Delta outflow. Though salinity in groundwater is an issue locally in parts of the Subbasin, it is not due to seawater intrusion and is discussed in more detail below.

3.3.5 Groundwater Quality

Groundwater quality in the Subbasin is characterized for this section through a variety of tables, maps and graphs. The entire water quality data set is provided in **Appendix 3f**. Key groundwater quality constituents discussed below include total dissolved solids (TDS), nitrate, chloride, arsenic, boron, and mercury. These constituents were selected because they have the potential to influence sustainability (as opposed to localized, or site-specific contamination). Maps of average and maximum concentration for the selected constituents are displayed in

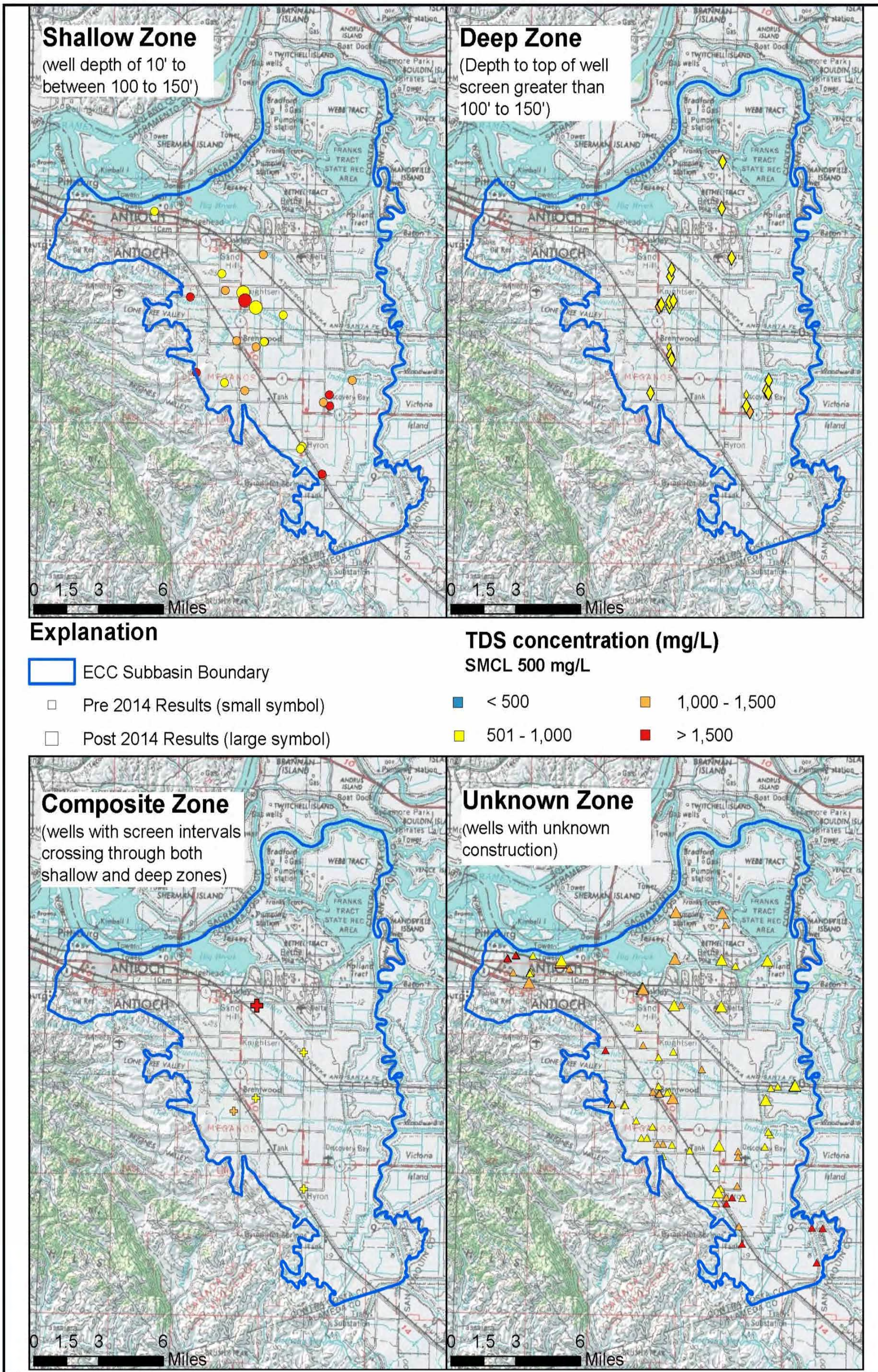
[3] https://www.baydeltalive.com/maps/11634

Figures 3-15a and **b** through **3-18a** and **b.** Recent data (after 2014) are lacking for some constituents so concentrations for wells with results prior to 2014 are included on the map with a smaller symbol. Time series graphs for these same constituents are presented in **Appendix 3g** and can be used to evaluate trends over time (e.g., TDS or chloride increasing or decreasing over time). In general, groundwater quality meets most water quality objectives and serves a variety of domestic and agricultural uses throughout the Subbasin. However, minor restrictions (discussed in more detail below) are caused by naturally occurring salinity levels that are elevated basin wide and nitrate levels that are slightly elevated in the shallow zone (less than 150 ft bgs).

Water quality concentrations in wells are compared for some constituents (nitrate as nitrate, arsenic, and mercury) to the California State Water Quality Control Board (SWQCB) drinking water standards called maximum contaminant levels (MCLs). Not all constituents (e.g., TDS and chloride) have an MCL and are compared to the secondary MCLs (SMCLs) that address esthetics such as taste and odor.

Total Dissolved Solids

TDS is a general measure of salinity and overall water quality. Salinity of groundwater may increase as influenced by land use or may be naturally sourced where subsurface geologic materials are derived from marine sediments. **Figures 3-15a** and **b** illustrate the average and maximum TDS concentrations for Shallow, Deep, and Composite Zones and for wells where the zone is unknown. TDS varies widely across the Subbasin, although it is characteristically high, ranging between 500 and 1,500 mg/L, in all areas. The Secondary maximum contaminant level (SMCL) for TDS is 500 mg/L (Recommended), 1,000 mg/l (Upper Limit), and 1,500 (Short-Term Limit). The SMCL is established for aesthetic reasons such as taste and odor and is not based on public health concerns. In the Shallow Zone, only three wells in Brentwood have recent results (since 2014) with TDS concentrations ranging between 500 and over 1,500 mg/L and older data indicate similar values. The lack of data for Shallow Zone wells is noted as a data gap. A lower portion of the Shallow Zone (between 80 and 140 ft bgs) in the vicinity of Discovery Bay contains brackish to saline water with EC levels between 2,000 and 6,500 uS/cm (Wells 1B, 4A, and 7, spring 2013). To prevent cross contamination of aquifer units, production wells are constructed with a deep cement seal below 140 ft bgs. The Deep Zone has many wells with TDS concentrations between 500 and 1,000 mg/L. The Deep Zone Discovery Bay wells have TDS concentrations generally below 600 mg/L and three City of Brentwood wells (wells 6, 7, and 8) increased from 600 mg/L and have stabilized with TDS concentrations around 1,000 mg/L (the upper secondary MCL) (**Appendix 3g**). The areas around Antioch and Byron have elevated TDS concentrations compared to the rest of the Subbasin, with some average results over 2,000 mg/L.

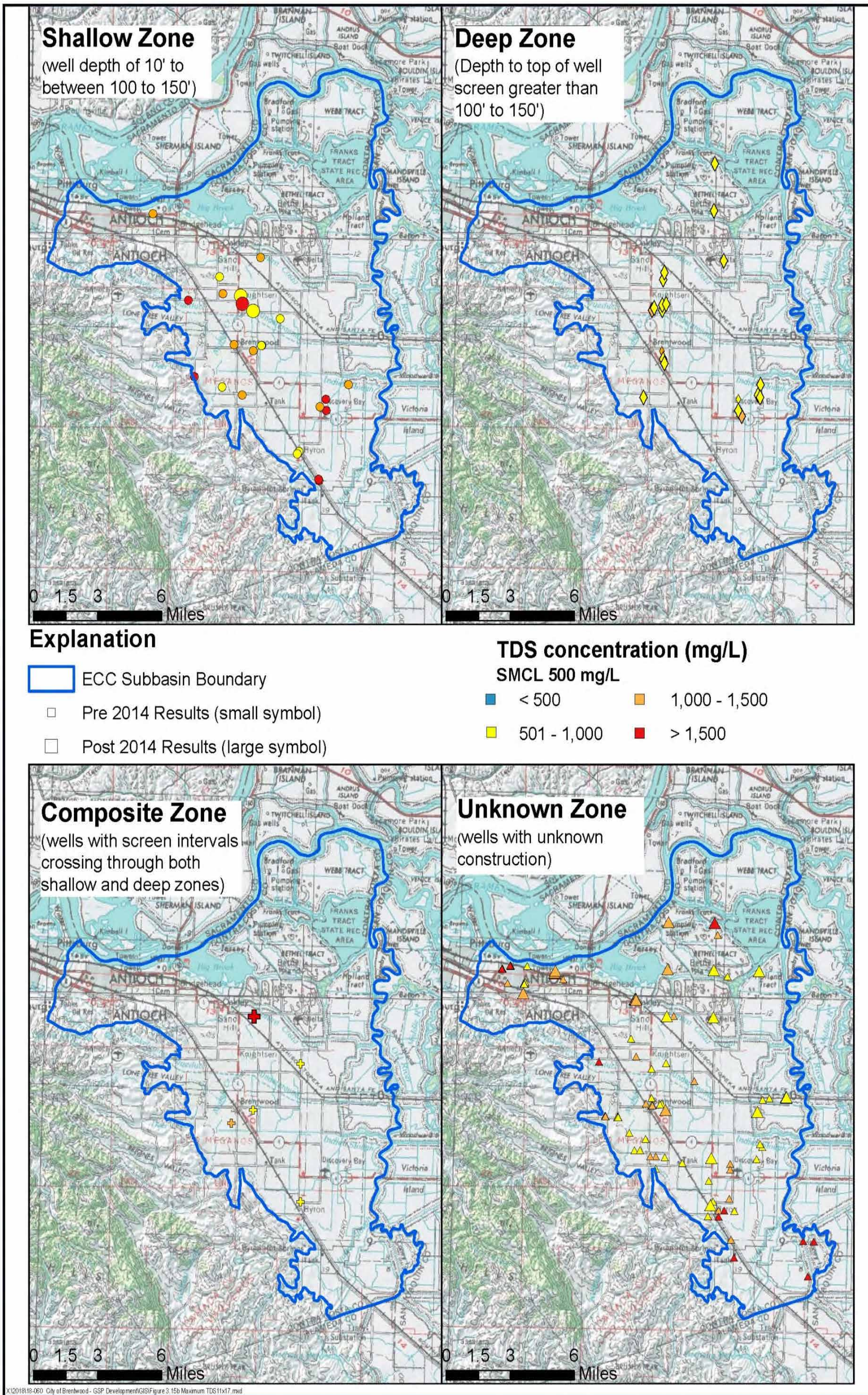


Luhdorff & Scalmanini Consulting Engineers

Average Total Dissolved Solids

East Contra Costa County Groundwater Sustainability Plan
Contra Costa County, California

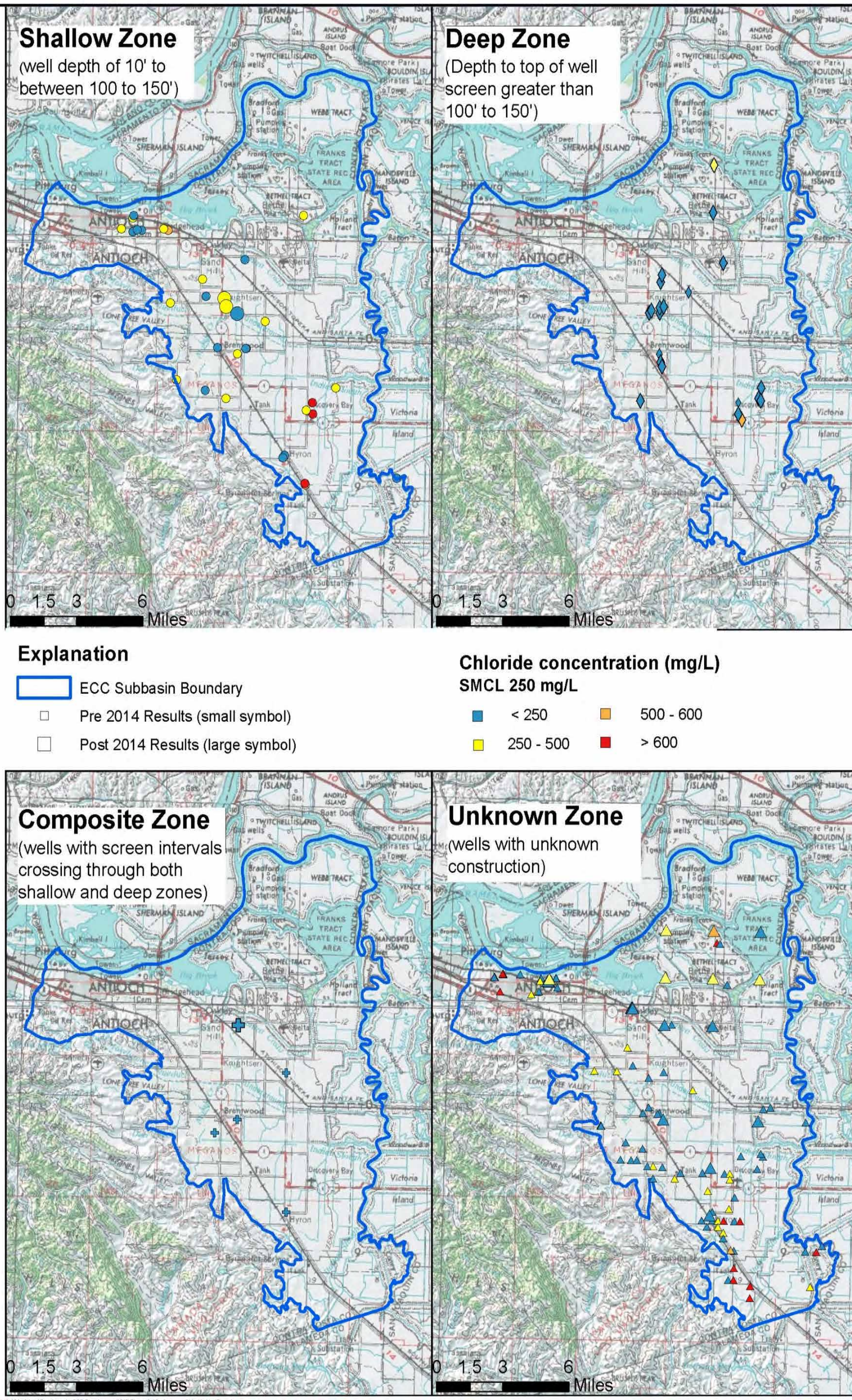
Figure 3-15a



Maximum Total Dissolved Solids

East Contra Costa County Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-15b



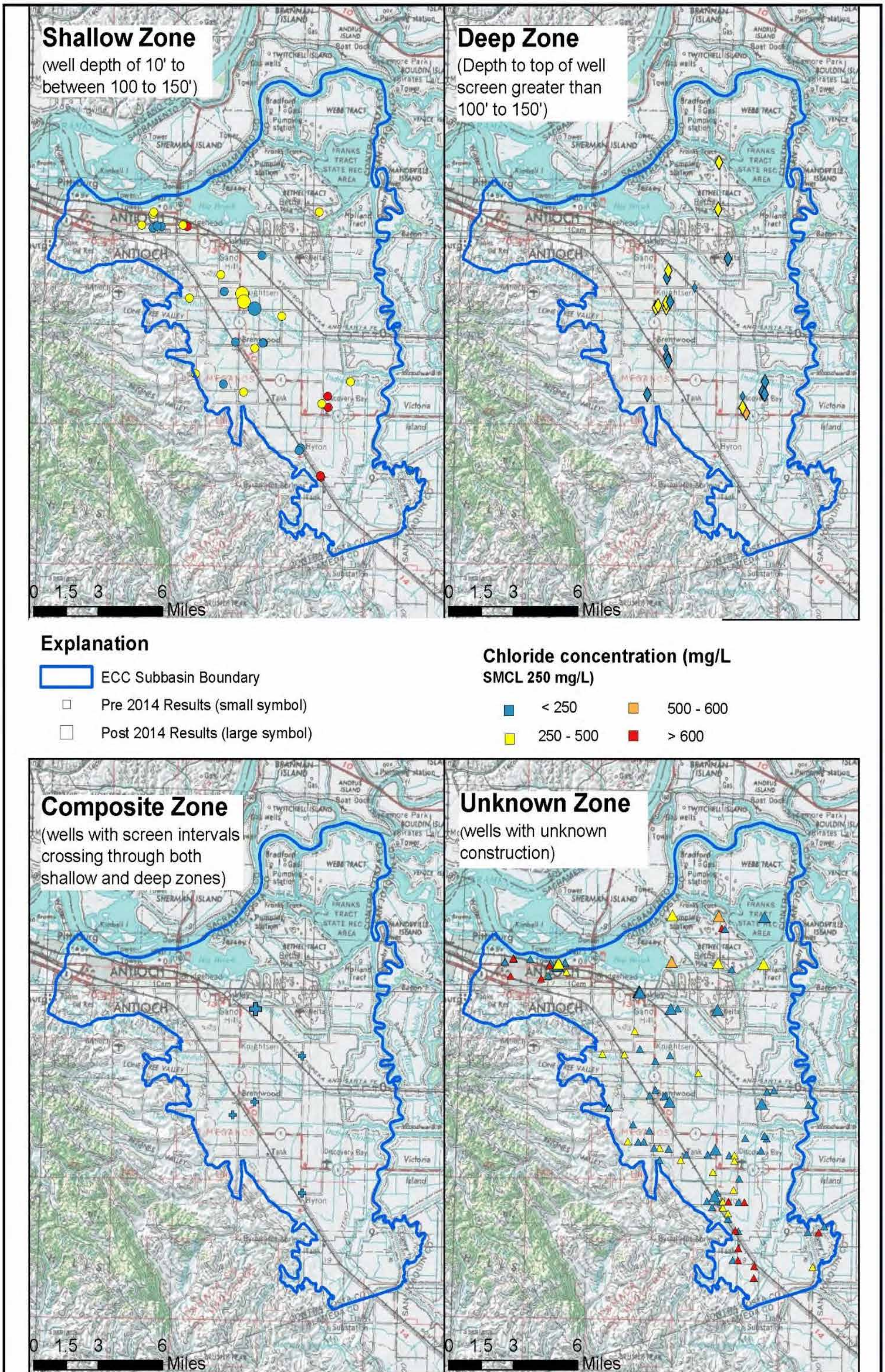
X:\2018\18-060 City of Brentwood - GSP Development\GIS\Figure 3-16a Average Chloride11x17.mxd

Luhdorff & Scalmanini Consulting Engineers

Average Chloride

East Contra Costa County Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-16a

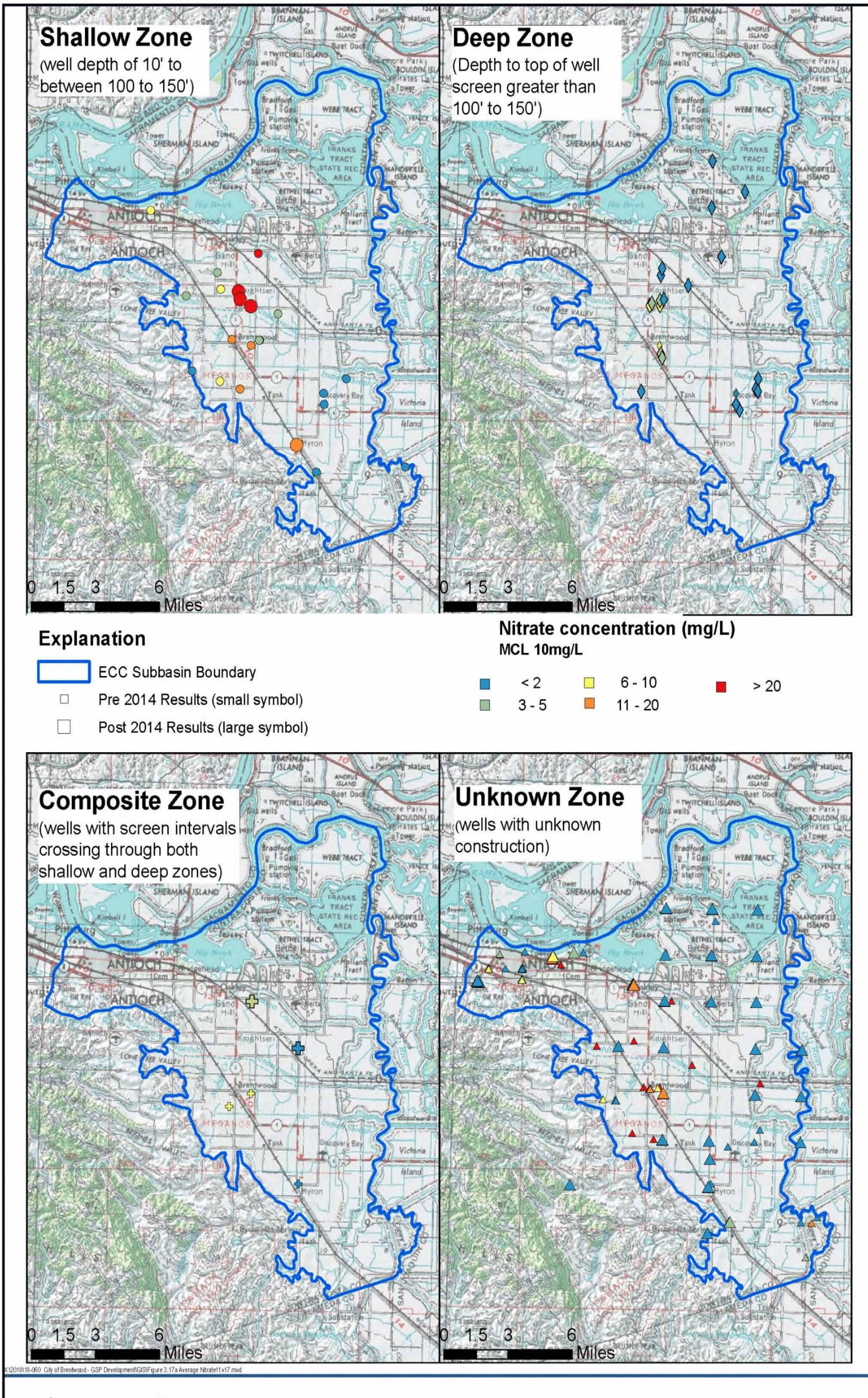


Luhdorff & Scalmanini Consulting Engineers

Maximum Chloride

East Contra Costa County Groundwater Sustainability Plan
Contra Costa County, California

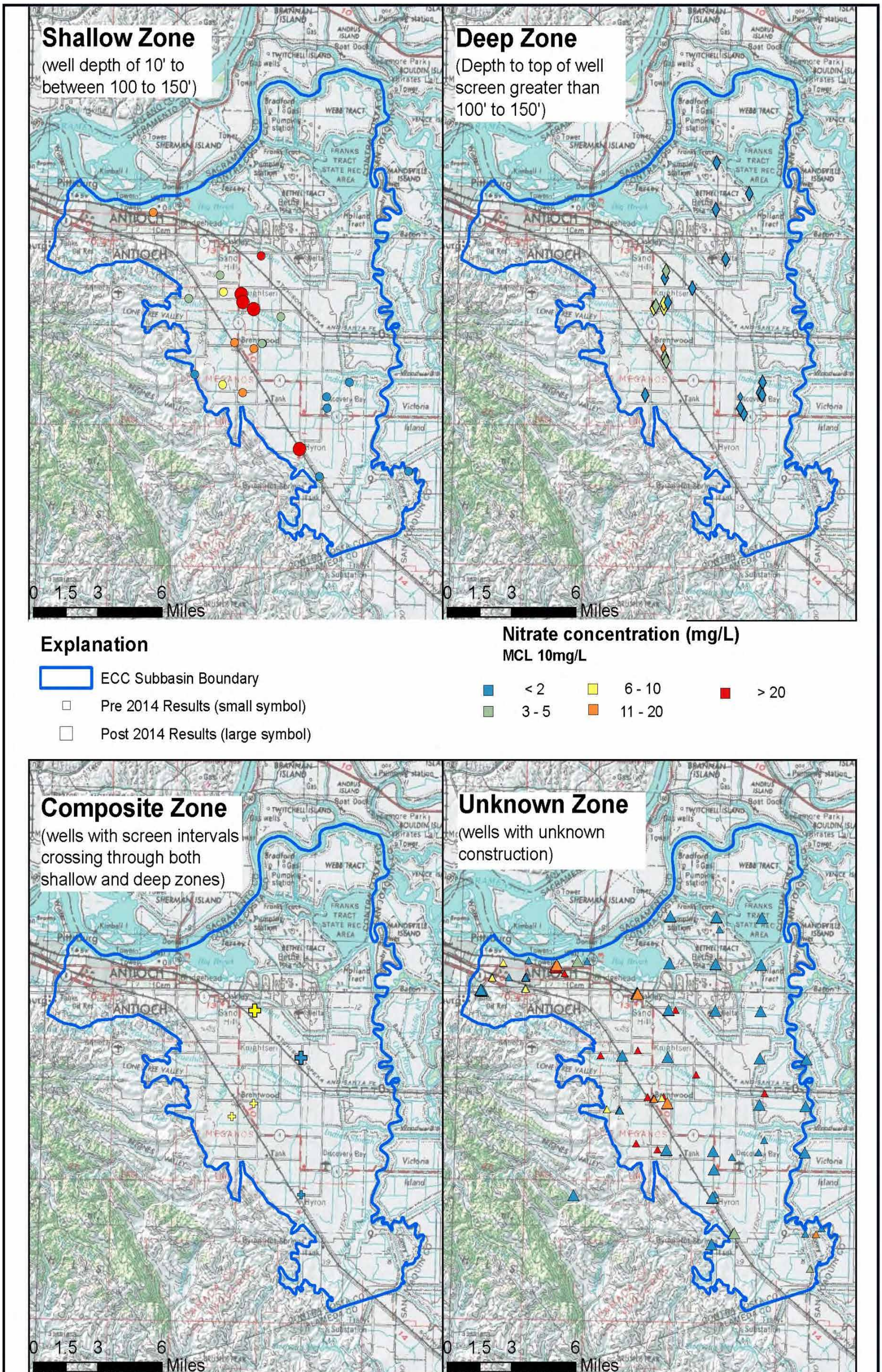
Figure 3-16b



Average Nitrate

East Contra Costa County Groundwater Sustainability Plan
Contra Costa County, California

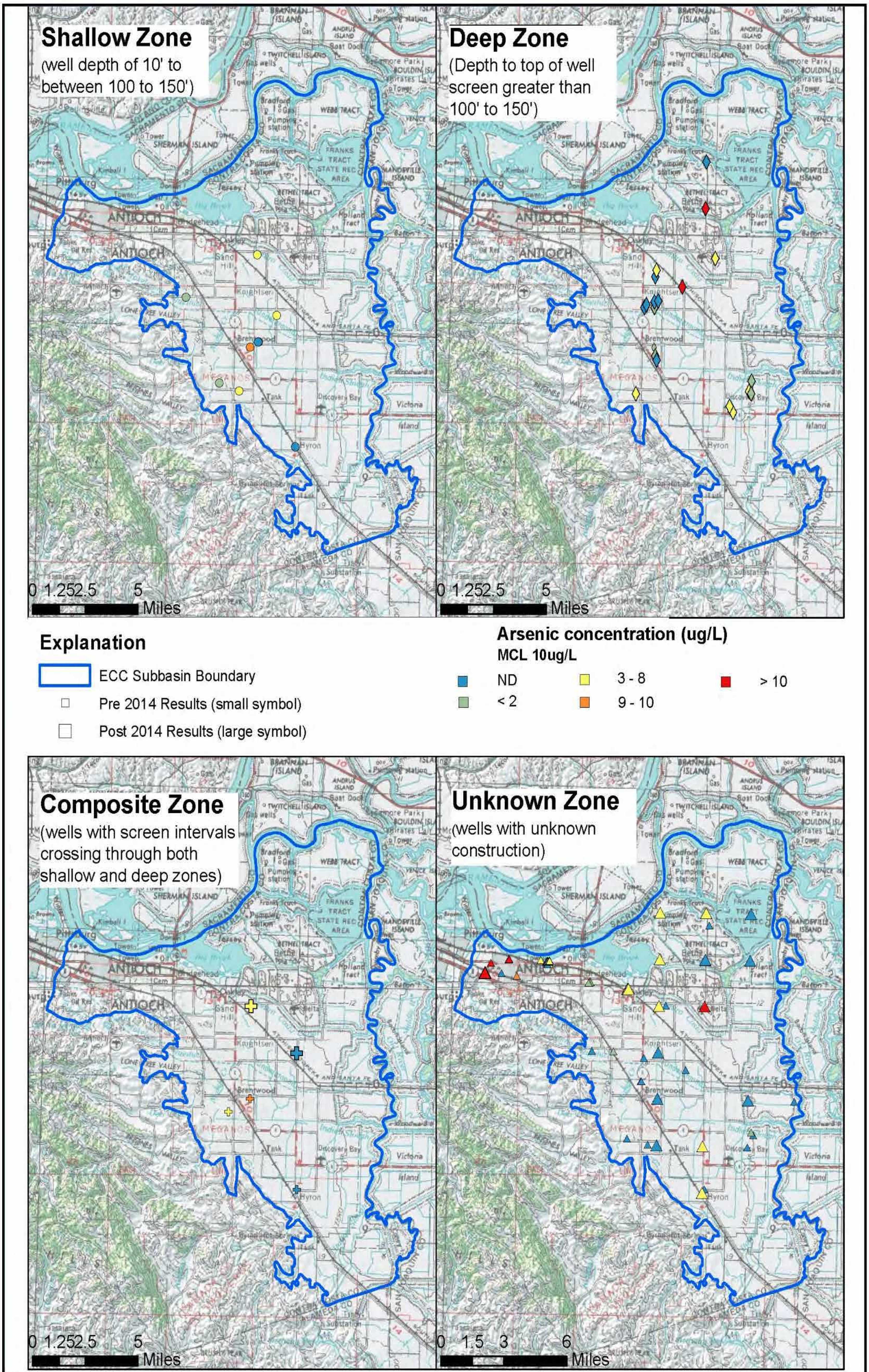
Figure 3-17a



Maximum Nitrate

East Contra Costa County Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-17b

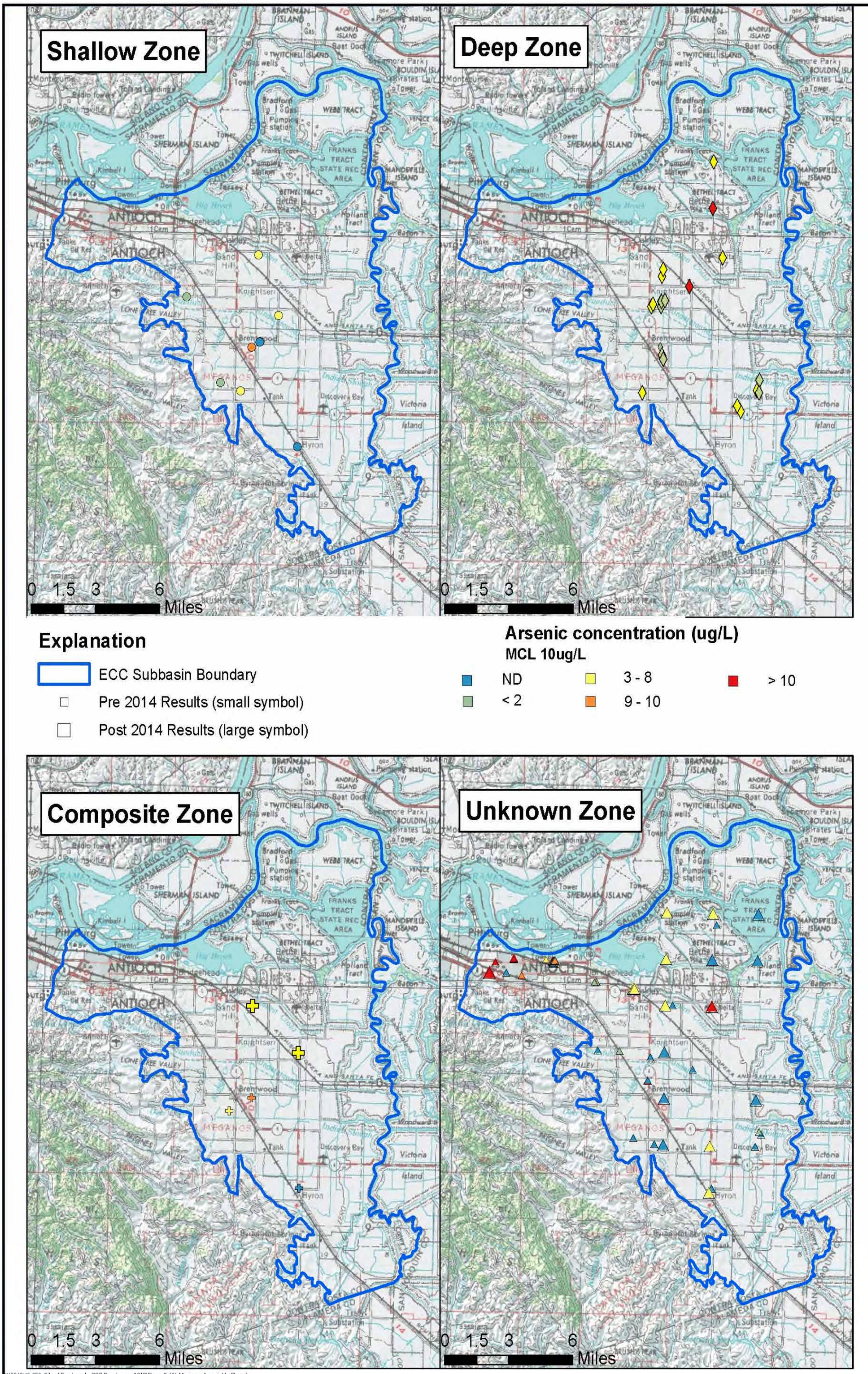


Luhdorff & Scalmanini Consulting Engineers

Average Arsenic

East Contra Costa County Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-18a



Luhdorff & Scalmanini Consulting Engineers

Maximum Arsenic

East Contra Costa County Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-18b

In summary, TDS concentrations in groundwater in the Subbasin exceed or are near the recommended SMCL (500 mg/L) in most wells (**Table 3-2**) suggesting that water concentrations are naturally higher for TDS (LSCE 1999).

Table 3-2: Water Quality Concentrations for Key Constituents

Consti-uent (Units)	Date Range	Number of Wells					No. of Meas-urments	Concentration			
		DDW	DWR	Geo-tracker	USGS	Total		Range	Median	Average	St Dev
TDS (mg/L)	1957-2019	87	46	73	22	228	802	86 - 20,400	885	1,098	1,431
Chloride (mg/L)	1957-2019	97	67	80	36	280	1562	11 - 4,900	168	231	310
NO3-N (mg/L)	1957-2019	135	23	125	30	313	2360	ND - 1,400	0.5	4.7	30.5
Arsenic (ug/L)	1957-2019	88	12	81	9	190	959	ND - 750	3	8	29

Chloride

Chloride is also a common way to indicate salinity. **Figures 3-16a** and **b** illustrate the average and maximum chloride results for the Shallow, Deep, and Composite Zones and the wells where the zone is unknown. Where zones are known, chloride concentrations generally decrease with depth to under 200 mg/L. Shallow Zone wells have higher chloride concentrations in the vicinity of Brentwood (230 to 280 mg/L) and Discovery Bay (360 to 2,000 mg/L) than the Deep Zone wells. Deep Zone wells (Wells 6, 7, and 8) in Brentwood have increased from less than 100 mg/L to over 200 mg/L) and Discovery Bay wells are stable and generally <100 mg/L. All results in the two zones (Shallow and Deep) are generally under 500 mg/. The areas around Antioch and Byron have elevated chloride concentrations compared to the rest of the Subbasin, with average results up to over 1,800 mg/L. The SMCL for chloride is 250 mg/L (Recommended), 500 mg/L (Upper Limit), and 600 mg/L (Short-Term).

In summary, chloride concentrations in groundwater in the Subbasin exceed or are near the recommended SMCL for chloride (250 mg/l) in most wells (**Table 3-2**) suggesting that water concentrations are naturally higher for chloride (LSCE 1999).

Nitrate

Nitrate is both naturally occurring and can be a result of human activity (e.g., fertilizers, septic systems, and animal waste). The MCL for nitrate as nitrogen (N) is 10 mg/L for drinking water. **Figures 3-17a** and **b** illustrate the average and maximum nitrate concentrations as N for the Shallow, Deep, and Composite Zones and for wells with an unknown aquifer zone. Wells with average nitrate as N concentrations that exceed the MCL are Shallow Zone wells in the Brentwood area (24 to 121 mg/L) and Unknown Zone wells scattered in the central western portion of the Subbasin. A few City of Brentwood composite production wells have been taken out of service due to high nitrate concentrations. In previous work, the higher Shallow Zone concentrations have been attributed to agricultural influences in the area and lack of confining clay units between soil horizons and shallow aquifer materials. Continued monitoring of Brentwood Deep Zone wells (currently all below 10 mg/L) will monitor whether nitrate is migrating from the Shallow Zone. Deep Zone production wells in the Discovery Bay and Oakley area have nitrate concentrations less than 2 mg/L. Wells in the Delta Island area in the northern and eastern portion of the Subbasin generally have very low nitrate as N concentrations.

In summary, nitrate is observed in some Shallow Zone areas of the Subbasin (i.e., Brentwood), with concentrations exceeding the MCL (10 mg/L) that may be linked to historical agricultural influences in the area.

Arsenic

Arsenic is a naturally occurring constituent and is commonly found in groundwater throughout California. An MCL was established at 10 ug/L in California in 2008. **Figures 3-18a** and **b** illustrate the average and maximum arsenic concentrations for the Shallow, Deep, and Composite Zones and the wells where the zone is unknown. For wells in the Shallow and Deep Zones, all have average and maximum arsenic concentrations at or below 10 µg/L with four exceptions: Knightsen, two public water systems on Sandmound Blvd., and Bethel Island. Near Discovery Bay, there have been detections of 10 µg/L; but, on average, the Discovery Bay area has concentrations less than 8 µg/L. For Unknown Zones, most of the wells are less than 8 µg/L. An exception is in the Antioch area which has higher concentrations of arsenic with average results over 100 µg/L.

In summary, arsenic concentrations are less than the MCL (10 ug/L) basin wide.

Boron

Boron is a naturally occurring constituent in groundwater and particularly in Contra Costa County[4]. The most common sources of boron in drinking water are from leaching of rocks and soils, wastewater, and fertilizers/pesticides. Boron concentrations in the Subbasin range from 500 ug/L to over 4,000 ug/L with the majority over 1,000 (**Appendix 3f**). MCLs for boron have

[4] The SWQCB Division of Water Quality GAMA Program "Groundwater Information Sheet for Boron (B), revised November 2017. Contra Costa County was identified on one of the top three counties in the state for boron detection from a study of public water supply wells from 2007 to 2017.

not been established but there is an agricultural goal (700 ug/L) where some crops may become sensitive, a state notification level (SNL)l[5] (1,000 ug/L), and a US EPA Health Advisory for non-cancer health effect (5,000 ug/L). Boron concentrations in groundwater in the Subbasin exceed the agricultural and SNL (1,000 ug/L) in most wells but are less than the EPA Health Advisory (5,000 ug/L) suggesting that water concentrations are naturally higher.

Mercury

Marsh Creek runs from Mt. Diablo through Brentwood and out to the San Joaquin River and drains water from the Mt. Diablo Mercury Mine operated from 1849 to 1971. There is potential for rainwater to leach mercury from mine tailings and to flow into the Marsh Creek watershed. However, there is no evidence that mercury has contaminated groundwater in the Subbasin and no wells in the ECC Subbasin tested for mercury have exceeded the MCL (2 ug/L).

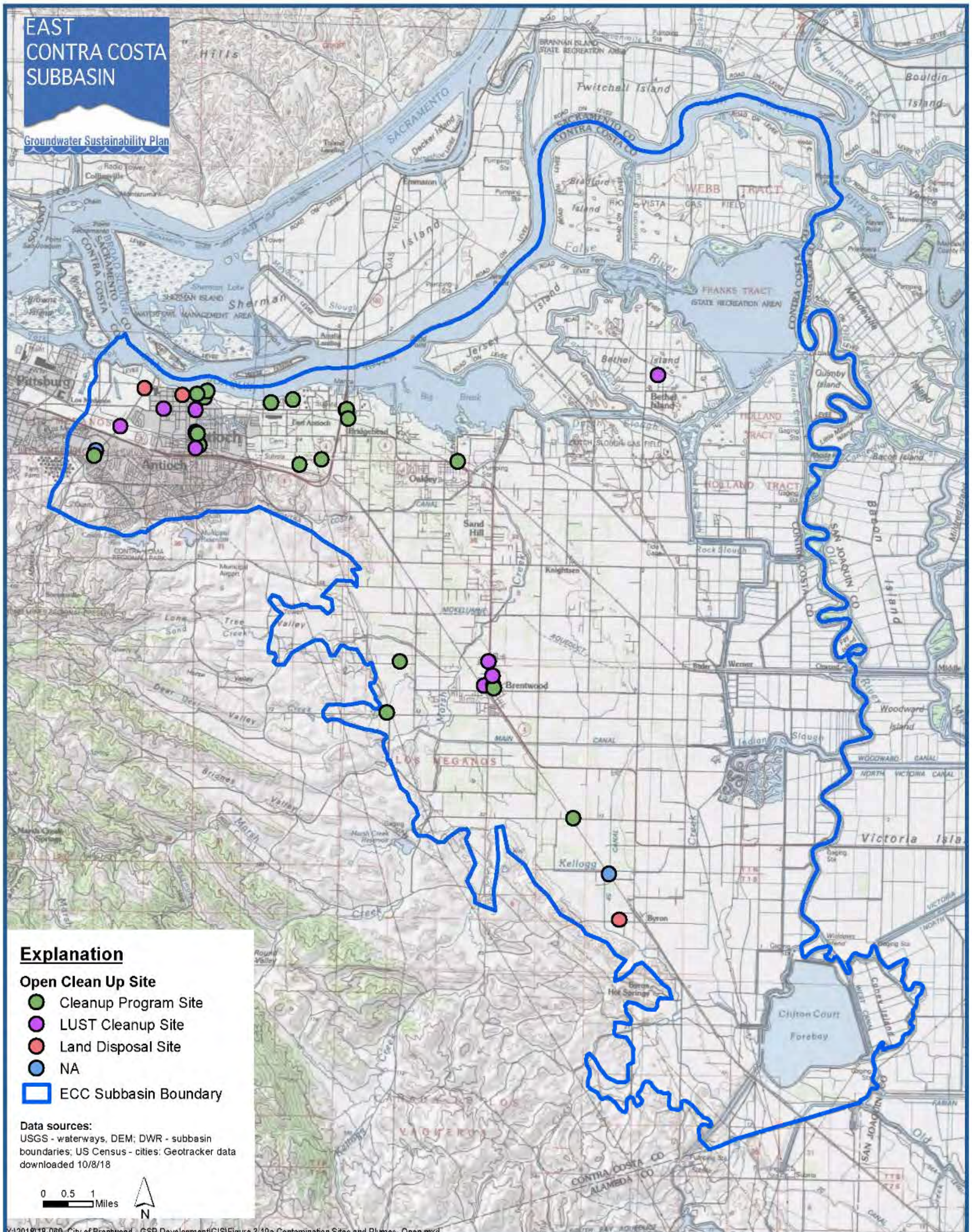
Appendix 3f is a table of all groundwater quality (general minerals and trace elements) in the Subbasin, by zone. Most of the wells in the Subbasin are missing construction information so water quality for the Shallow and Deep Zones is limited.

In summary, groundwater in the Subbasin generally exceeds or is near the recommended SMCL for TDS (500 mg/L) and chloride (250 mg/l) (**Table 3-2**). The observed concentrations may reflect a naturally higher baseline for these constituents (LSCE 1999). Nitrate is observed in some Shallow Zone areas (i.e., Brentwood) in the Subbasin, with concentrations generally exceeding the MCL (10 mg/L) that may be linked to past agricultural influences in the area. Arsenic concentrations are generally less than the MCL (10 ug/L) basin wide. Boron concentrations are high in most wells and are attributed to a naturally elevated baseline. Groundwater serves a variety of domestic and agricultural uses throughout the Subbasin with limited restrictions due to natural (salinity and boron) and anthropogenic (nitrate) causes. The availability of surface water gives the opportunity to mitigate these issues when necessary. Depending on local groundwater quality, the stringent municipal standards for drinking water are met by a mix of water sources: City of Antioch uses surface water only, DWD and Brentwood blend groundwater with surface water, and TODB uses groundwater only. The ECC Subbasin's groundwater quality is generally stable which indicates that groundwater extraction is not degrading water quality and the Subbasin is being operated within its sustainable yield

[5] Notification levels are non-regulatory health-based advisory levels establish by the SWRCB for chemicals with not established MCL.

3.3.6 Groundwater Contamination Sites

Figures 3-19a and **b** illustrate the open and closed groundwater contamination sites in the ECC Subbasin. Contaminated sites can pose a hazard to human health through the contamination of aquifers if the area is using groundwater. Contamination site data were obtained from GeoTracker (online resource) and are divided into cleanup program sites, leaky underground storage tank (LUST) sites, and land disposal sites. **Appendix 3h** lists the 35 open sites and 105 closed sites including the potential contaminants of concern for each site. The majority of sites are in Antioch followed by Brentwood. The most common contaminant is hydrocarbon for both open and closed sites.

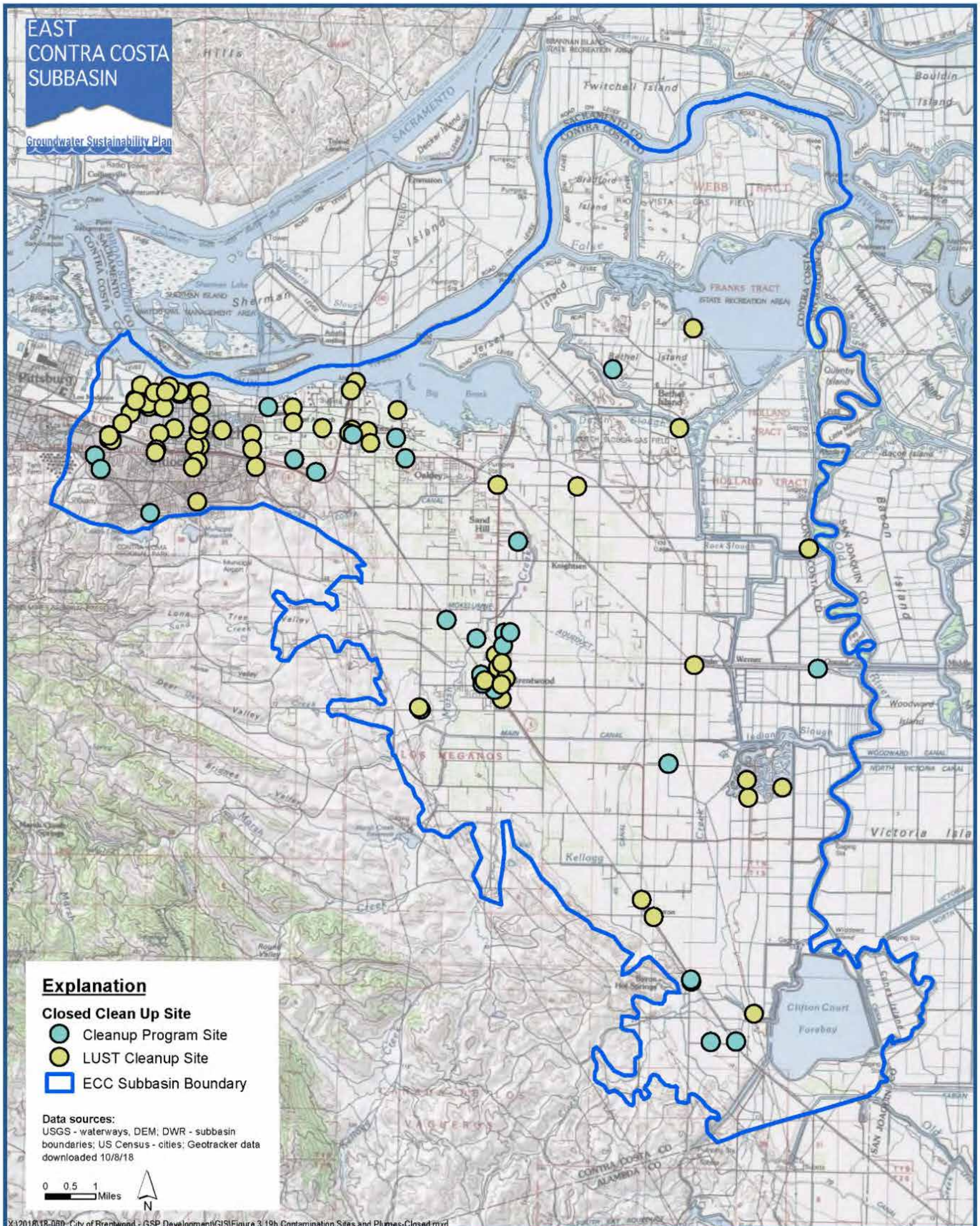


Luhdorff & Scalmanini Consulting Engineers

Groundwater Contamination Sites and Plumes - Open Sites

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-19a



Luhdorff & Scalmanini Consulting Engineers

Groundwater Contamination Sites and Plumes - Closed Sites

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-19b

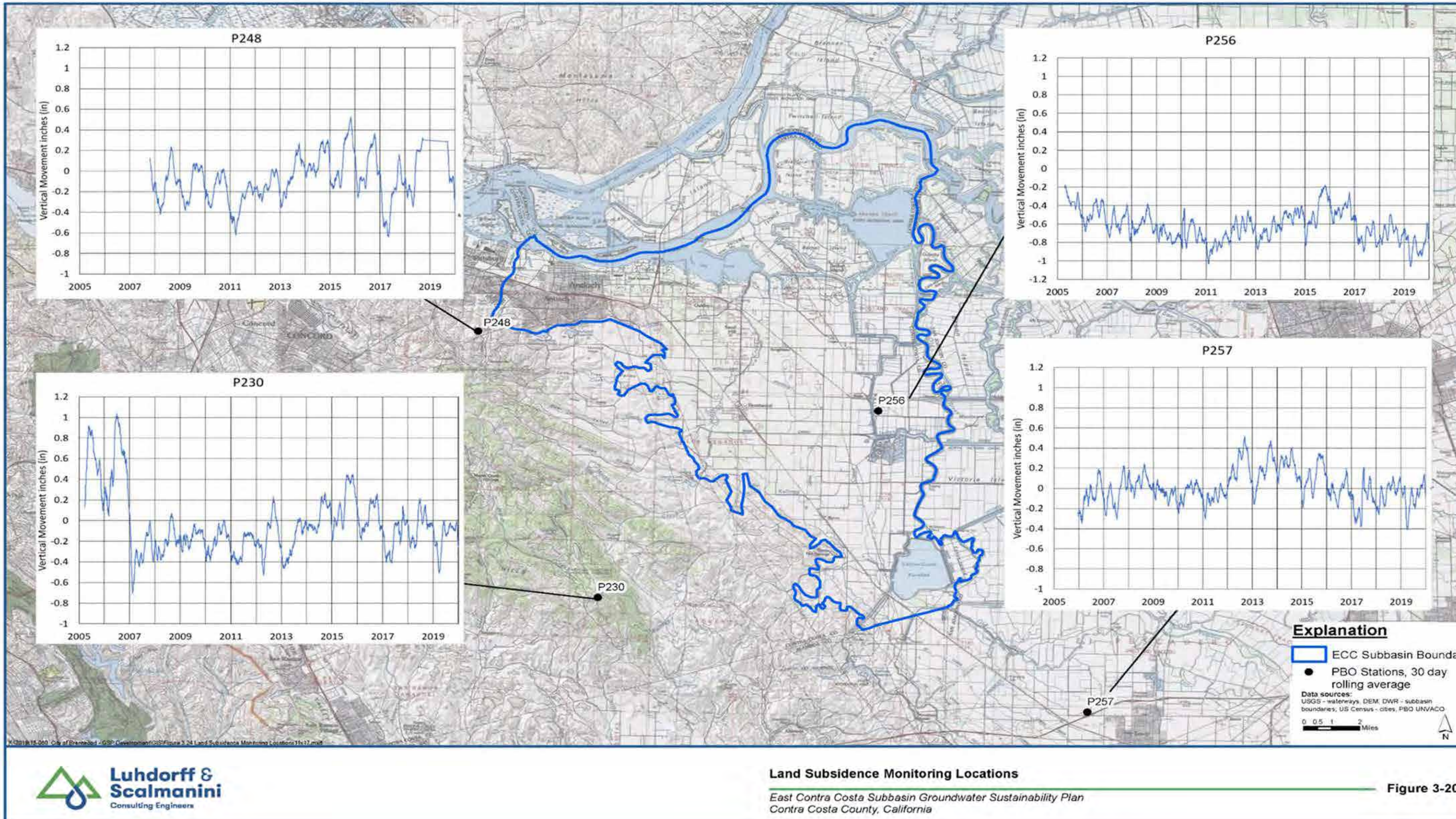
3.3.7 Land Subsidence

There are no historical records of impacts from subsidence due to groundwater withdrawal in the ECC Subbasin. Land subsidence in the Subbasin is continuously monitored by the Plate Boundary Observatory (PBO) monitoring network managed by University NAVSTAR Consortium (UNVACO). The PBO's main task is to "quantify three-dimensional deformation and its temporal variability across the active boundary zone between the Pacific and North American plates." The PBO stations can be used to monitor for land subsidence using vertical land surface measurements. PBO stations are used to measure centimeter to millimeter-scale movement on the Earth's surface. Four stations located in or near the Subbasin (**Figure 3-20**) all show minor displacements. PBO stations take measurement once per day, to mitigate erroneous data a 30-day rolling average was applied to the data. PBO Station 256 (P256), located inside the Subbasin, has shown a vertical displacement from 2005 to 2019 of -0.01096 inches per year. PBO Station 230 (P230) west in the Diablo Mountains also has a slight downward displacement of -0.01461 inches per year. Two stations near Antioch and Tracy (P248 and P257) have a slight upward displacement of the land surface. **Table 3-3** below provides the estimated rate of land surface change. Trends do not indicate inelastic downward displacement in the land surface.

Table 3-3: Land Surface Displacement Rates at PBO Sites

Monitoring Location	Location Relative to Subbasin	Period of Record	Rate of Land Surface Displacement (inches per year)	Rate of Land Surface Displacement (feet per year)
Inside East Contra Costa Subbasin				
P256	East of Center of Subbasin	2005-2019	-0.0093	-0.00077
Outside East Contra Costa Subbasin				
P230	South West of Subbasin	2005-2019	-0.01487	-0.00124
P248	North West of Subbasin	2007-2019	.01092	0.00091
P257	South East of Subbasin	2006-2019	.001461	0.00122

In the late 1800s to the early 1900s levees were built along stream channels in the delta and the rich land was converted to agriculture (discussed in more detail in **Section 2.1**). However, this caused ongoing land subsidence associated with drainage for agriculture, called hydrocompaction, on islands in the Delta including parts of the ECC Subbasin specifically.



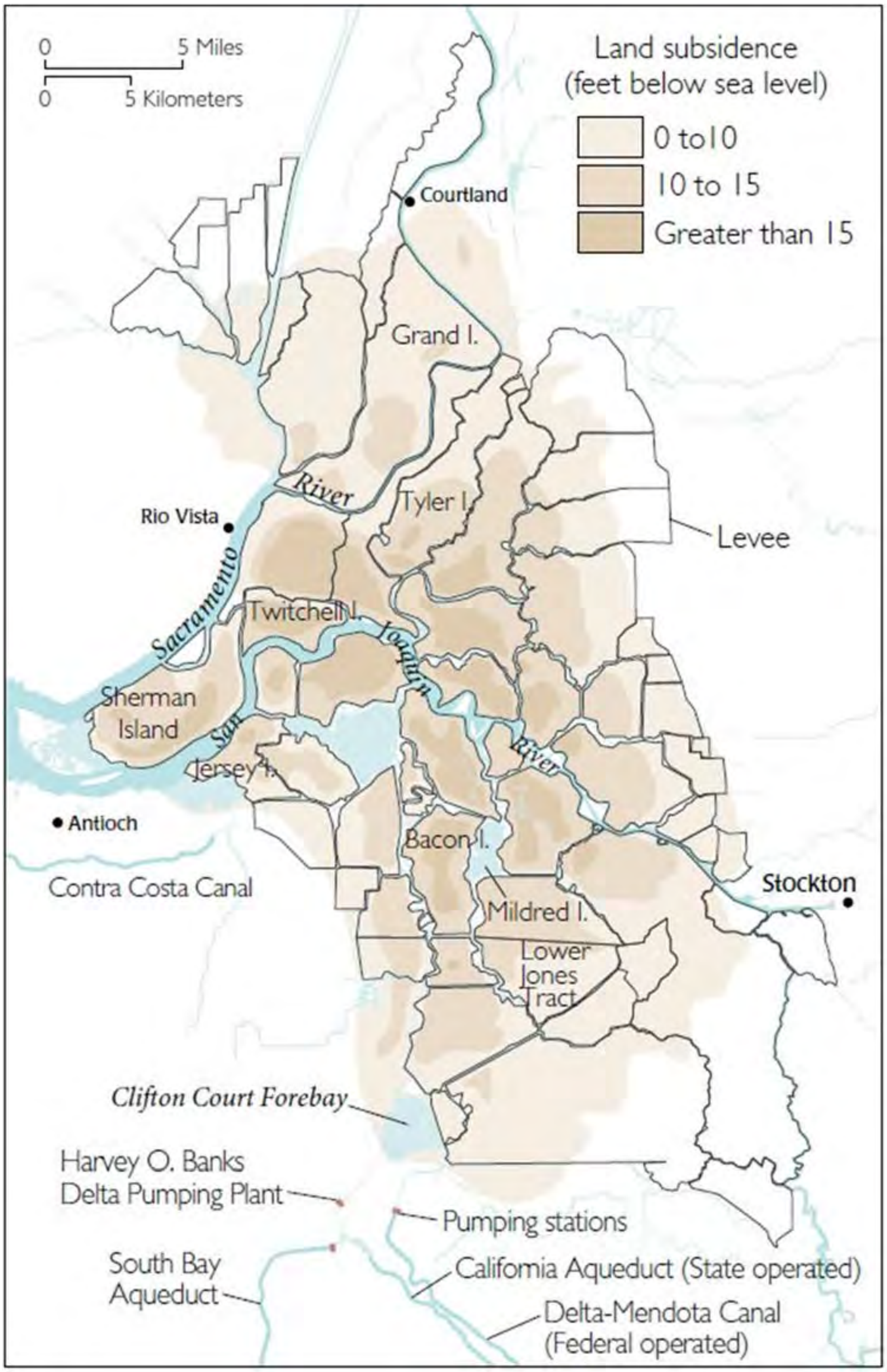
Land Subsidence Monitoring Locations

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-20

Hydrocompaction is due to dewatering of peat soil that dries out and compresses[6] as a result of land reclamation. This caused many central Delta islands to drop 10 to nearly 25 feet below sea level (USGS, 1999, **Figure 3-21a).** The Delta soils are composed of 1) coarser sediments concentrated near the natural waterways of the Delta and 2) peat from decaying marsh vegetation concentrated near the centers of the islands (up to 60 feet thick in the western Delta). **Figure 3-21b** illustrates the late 1880's freshwater tidal marsh land surface profile (upper diagram) and the current configuration of many islands (lower diagram) that is saucer-shaped due to compacted peat soils in the interior and mineral sediments at their edge. Currently, groundwater levels are maintained on the islands by a network of drains at three to six feet bgs with drainage water pumped back into the stream channels (**Figure 3-21b**). Though this GSP is only required to discuss subsidence due to groundwater withdrawal, understanding of how these Delta islands are constructed improves understanding of interactions between surface water and groundwater in the Delta area.

[6] Source: Water Education Foundation, 2020. Can Carbon Credits Save Sacramento-San Joaquin Delta Islands and Protect California's Vital Water Hub? Gary Pitzer, February 27, 2020.



(California Department of Water Resources)

Figure 3-21a Subsidence on Delta Islands (source: https://www.usgs.gov/centers/ca-water-ls/science/subsidence-sacramento-san-joaquin-delta?qt-science_center_objects=0#qt-science_center_objects)

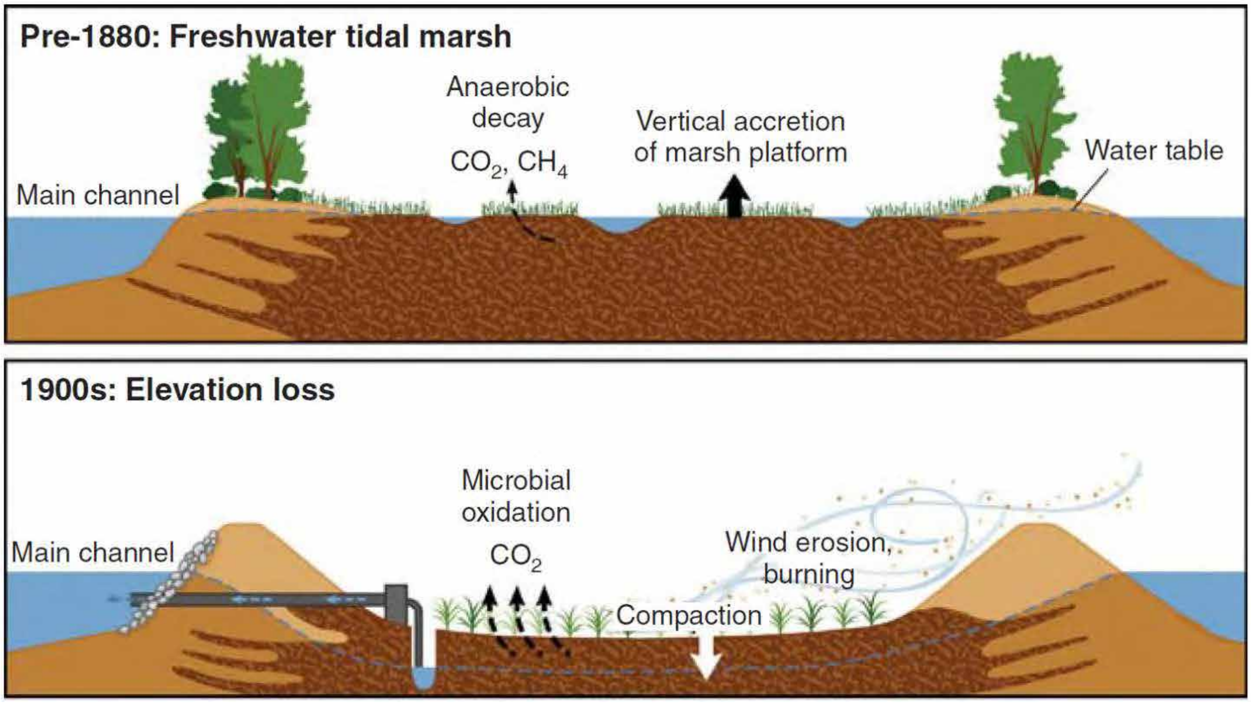


Figure 3-21b Cross-section of Subsidence and Drains on Delta Island. Source: Mount and Twiss (2005)

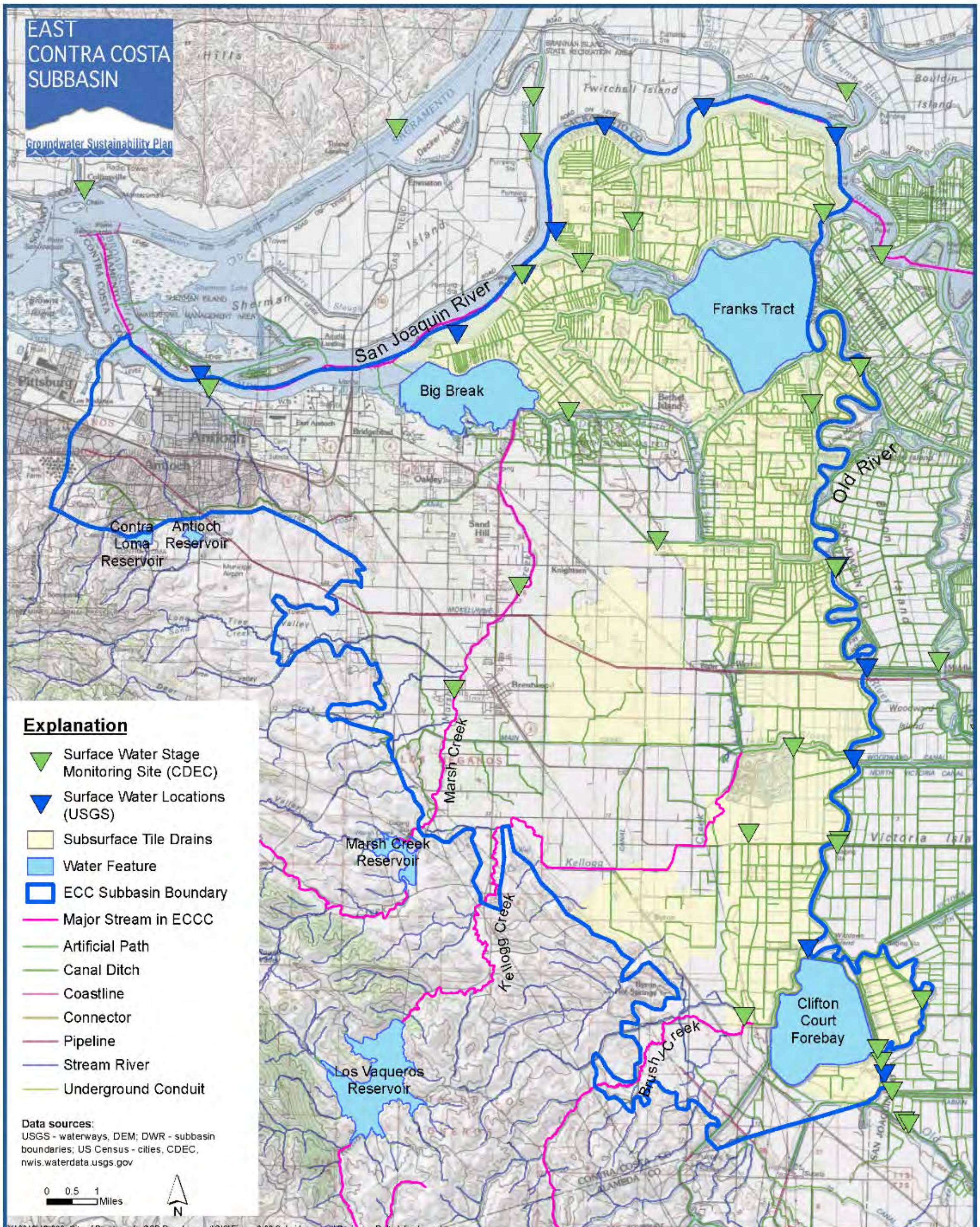
3.3.8 Interconnected Surface Water Systems

Interconnected surface water systems are the locations where groundwater and surface water are hydrologically connected. It is important to know where these systems are located in order to minimize impacts of groundwater pumping on the surface water bodies and biological communities that rely on the interconnected water system. The ECC Subbasin is bounded by the San Joaquin River to the north and Old River to the east with an extensive network of canals installed (**Figure 3-10**). Delta islands located in the northern and eastern portion of the Subbasin, as described above, are protected by levees and require excess water that collects in subsurface drains to be discharged to the Delta. **Figure 3-22** identifies the surface water features in the Subbasin and vicinity and illustrates coverage of subsurface tile drains installed at between 5 and 8[7] feet bgs to provide drainage of water to the river. Given this unusual configuration, Old River and the San Joaquin River are considered interconnected rivers and currently or historically, surface water depletions have not occurred along these rivers.

[7] As communicated by individual water districts.

In the western portion of the Subbasin a few creeks are present that are considered a natural source of recharge to the Subbasin (**Figure 3-22**) and have the potential to be considered interconnected systems. Marsh Creek, the most prominent, is earthen lined and channelized, and is adjacent to both the City of Brentwood and DWD pumping wells. It may be vulnerable to impacts from the loss of interconnected surface water due to groundwater pumping and groundwater level declines. Both the Marsh Creek and Kellogg Creek have dams with required releases. Currently there is an incomplete understanding of the ECC Subbasin surface water/groundwater connection, but this is expected to be remedied through installation of multiple completion monitoring wells and future monitoring efforts related to this GSP.

Figure 3-23 is a map illustrating the spring 2018 depth to shallow groundwater in the ECC Subbasin. There is not complete coverage of the Subbasin, but it does present the 30 ft depth to water contour that may represent the point when a stream is no longer considered interconnected to groundwater. Review of the depth to water figure indicates that the majority of the Subbasin may have interconnected surface water and groundwater. Specifically, the San Joaquin River, Old River, and portions of western creeks are likely connected to the groundwater system and there is then potential for regional groundwater pumping to impact groundwater dependent ecosystems (GDEs).

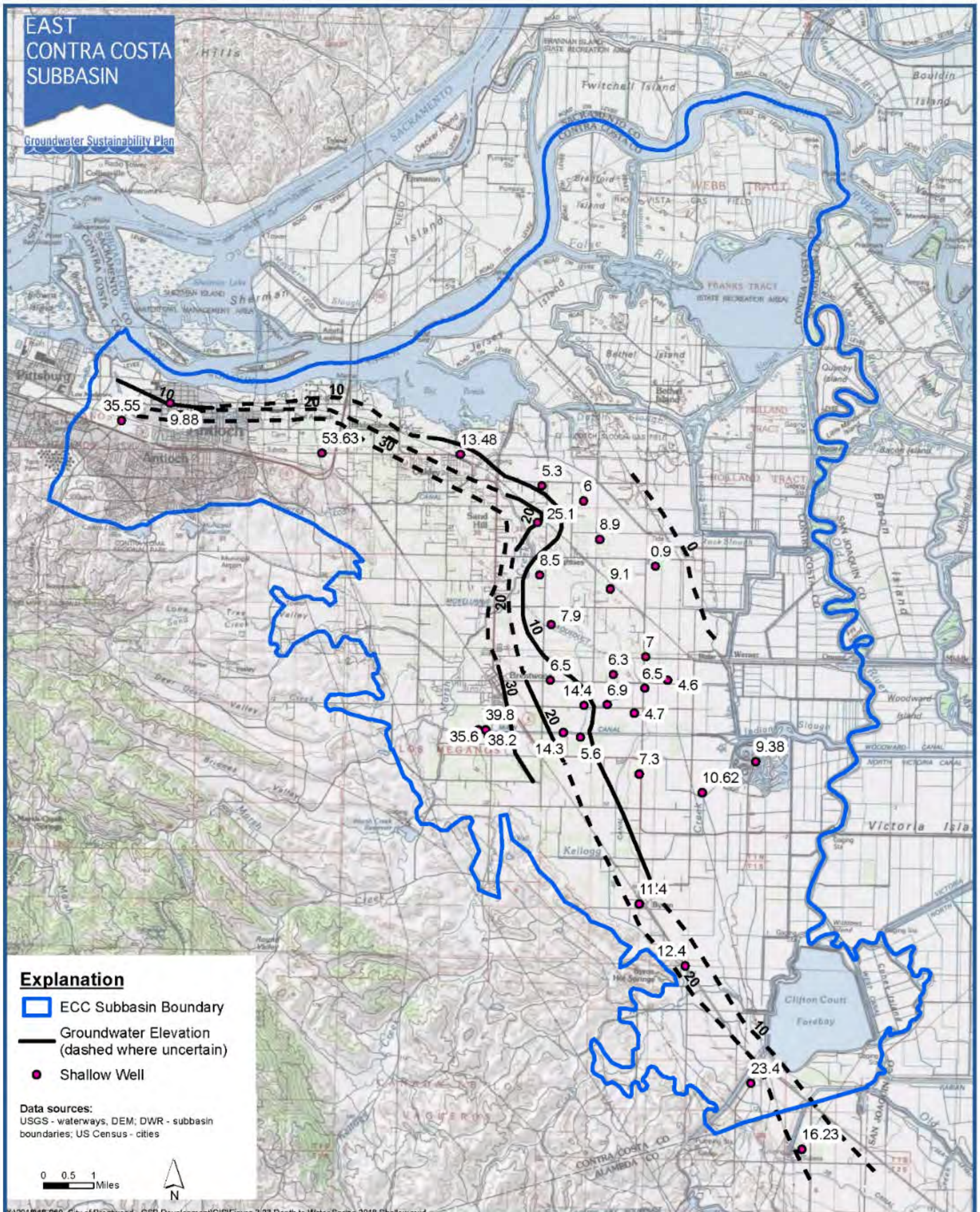


Luhdorff & Scalmanini Consulting Engineers

Surface Water Features and Subsurface Drains

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-22



Luhdorff & Scalmanini Consulting Engineers

Depth to Shallow Groundwater - Spring 2018

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

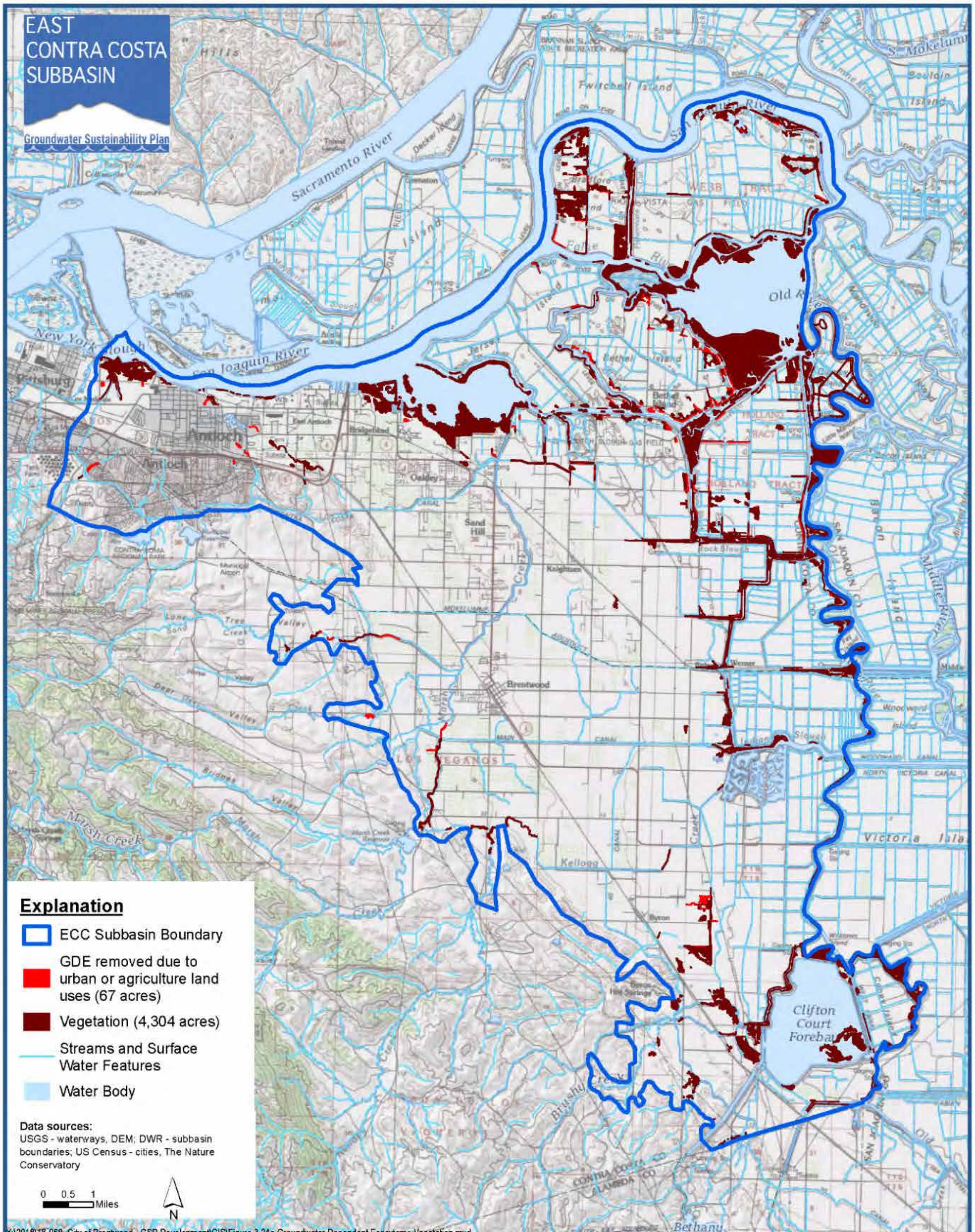
Figure 3-23

3.3.9 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) “refers to ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface” outlined in the GSP Emergency Regulations. Each plan is required to identify groundwater dependent ecosystems within the basin, utilizing data available from DWR or the best available information. GSAs are only responsible for impacts to GDEs resulting from changing groundwater conditions resulting from pumping or groundwater management in the Subbasin (TNC, 2019). For example, if groundwater conditions stay the same but GDEs lose access to water due to surface water diversions/depletions, this is not the GSA’s responsibility.

GDEs are similarly defined as “the plants, animals, and natural communities that rely on groundwater to sustain all or a portion of their water needs” by The Nature Conservancy (TNC) in the Guidance for preparing Groundwater Sustainability Plans (Rohde et al, 2018). GDEs are an important aspect of the diverse California landscape and are found in nearly all subbasins. The GDEs are diminishing rapidly and largely due to human interference and unsustainable groundwater extraction (Rohde et al, 2018). Water Code Section 10723.2 requires the GSP to identify GDEs and determine how groundwater does or does not affect them. The following section describes the process for identifying the GDEs within the ECC Subbasin and mapping their location.

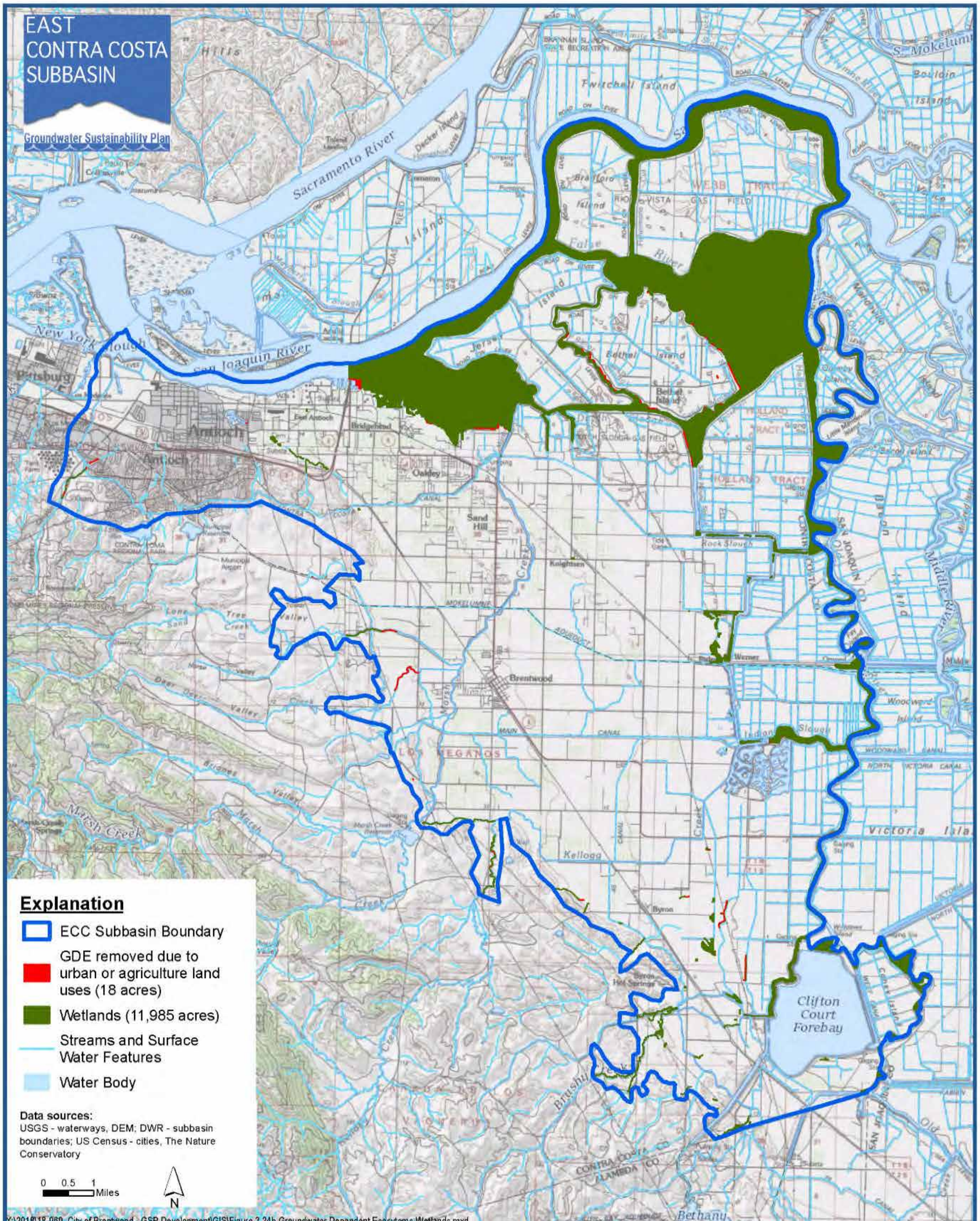
The Natural Communities Commonly Associated with Groundwater (NCCAG) Dataset was used as a starting point to identify GDEs within the Subbasin. This dataset is compiled from 48 publicly available agencies datasets and was then reviewed by a working group comprised of DWR, TNC, and the California Fish and Wildlife **(Figures 3-24a** and **b)**. The Subbasin GDEs exhibited in **Figures 3-24a** and **b** were compared by the county with local information and it was concluded that these are the best available data. Further analysis of GDEs in ECC was conducted by identifying areas where depth to groundwater is greater than 30 feet, the general vegetation maximum rooting depth. The assumption was that those areas could be eliminated however, groundwater level monitoring is lacking in some of the western areas of the Subbasin so no changes to Wetland or Vegetation NCCAG Datasets were made. Current land use was also analyzed to determine if the parcel was still a GDE. Using DWR’s 2016 Land use data set it was found that 67 acres of vegetation and 18 acres of wetland were no longer classified as native materials and the corresponding GDEs were removed. A total of 13,970 potential GDE acres (11,985 wetlands and 4,304 vegetation with some areas of overlap in the ECC Subbasin) were identified by the NCCAG database and retained for this GSP. Most of these areas are located in the Delta with a few occurring along western creeks. **Table 3-4** includes all species in the ECC Subbasin as identified by TNC. TNC has identified 22 vegetation species and additional category of Not Applicable. The majority of species represent a small percentage of the total



Groundwater Dependent Ecosytems-Vegetation

Figure 3-24a

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California



Luhdorff & Scalmanini
Consulting Engineers

Groundwater Dependent Ecosytems- Wetlands

East Contra Costa Subbasin Groundwater Sustainability Plan
Contra Costa County, California

Figure 3-24b

GDEs; the largest designation is Not Applicable. **Figure 3-25** identifies critical habitat for species in the ECC Subbasin: Steelhead (threatened), Delta smelt (threatened), and vernal pool fairy shrimp (threatened).

The Subbasin has multiple GDE areas, mostly in the Delta in the north along the San Joaquin River and the east along the Old River in addition to various canals located in the east. However, these areas have minimum groundwater pumping from mostly domestic wells (**Figure 2-3a**). TODB is wholly reliant on groundwater and has GDEs noted around the town; a shallow zone groundwater monitoring well has been identified as a Data Gap and will be installed as part of this GSP. Brentwood also uses groundwater but no GDEs are noted in the area; however, three shallow zone monitoring wells are part of the monitoring network. Bethel Island has a groundwater production well that is located near GDEs for both wetlands and vegetation and this also has been identified as a Shallow Zone monitoring well Data Gap. The southern portion of the Subbasin has small areas of GDEs but with no municipal groundwater production; however, this area is also identified as a Shallow Zone monitoring well Data Gap for this GSP.

New projects that include construction of wetlands are in the planning and/or constructions phase and will be added to the GDE maps when completed. They include Dutch Slough Tidal Restoration Project[8] located at the intersection of Marsh Creek and the Delta (managed marsh and tidal), Three Creeks Parkway Project[9] located in Brentwood, and Franks Track State Park[10]. Municipal Water District of Southern California (MWD) owns all or parts of two islands[11] in the Delta area of the ECC Subbasin: Webb Tract (100% MWD owned) and Holland Tract (75% MWD owned). Originally Webb Tract was slated to be a Reservoir Island to store available water in winter and discharged in summer or fall and 845 acres of Holland Tract was to be wetlands and a dedicated Habitat Island. However, as of September 2020 the islands are projected to continue as farms for at least the next 5 years with no major land use change and MWD is reportedly not pursuing the island storage project[12]. Future updates to the GSP will include refinement of GDE locations in the Subbasin as land use changes.

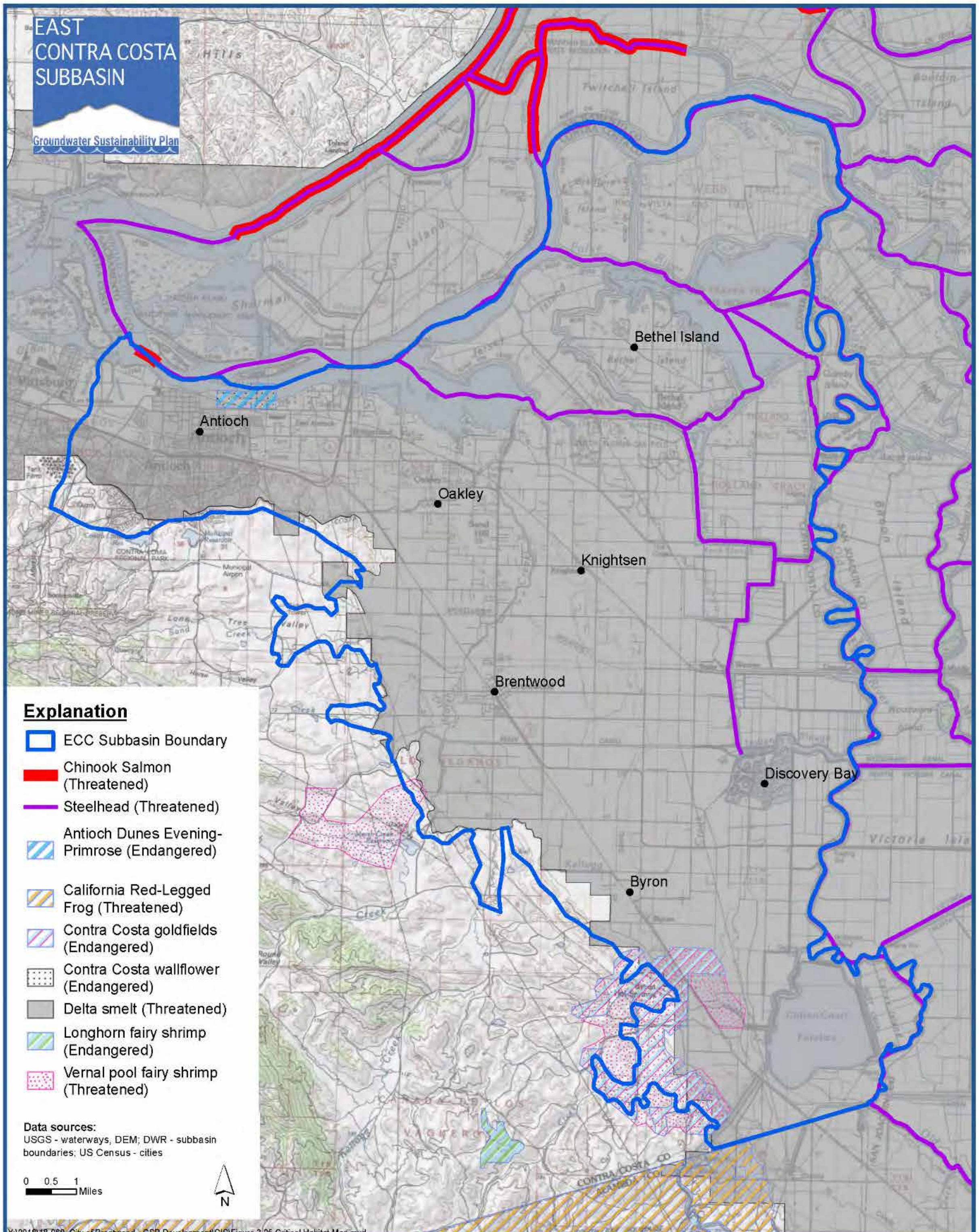
[8] Information can be access here: https://water.ca.gov/Programs/Integrated-Regional-Water-Management/Delta-Ecosystem-Enhancement-Program/Dutch-Slough-Tidal-Restoration-Project. Construction to restore 1,200 acres launched in 2018, planting occurred in 2020 and a levee breach is planned for 2021.

[9] Information can be accessed here: https://www.contracosta.ca.gov/5814/Three-Creeks-Parkway-Project

[10] Information can be accessed on Franks Tract Futures here: https://franks-tract-futures-ucdavis.hub.arcgis.com/

[11] Holland and Webb Tracts are owned by Municipal Water District (MWD) that are part of the proposed water storage project call Delta Wetlands Project. Information can be accessed here: https://www.spk.usace.army.mil/Portals/12/documents/regulatory/eis/190109804-eis/190109804-SDEIS/AppendixJ.pdf

[12] Delta Protection Commission meeting, September 17, 2020, report by Stephen Arakawa, MWD, on Delta Islands.



Luhdorff & Scalmanini
Consulting Engineers

Critical Habitat Map

East Contra Costa Subbasin Groundwater Sustainability Plan
Contro Coasta County, California

Figure 3-25

Table 3-4 Vegetation Species in Subbasin

Dominate Species	Percentage of Total Vegetation	Dominant Species	Percentage of Total Vegetation
Arctic Rush	< 1%	**Iodine Bush**	4%
Arroyo Willow	9%	**Narrowleaf Cattail**	< 1%
Broadleaf Cattail	1%	**Narrowleaf Willow**	2%
Broadleaf Pepper-grass	4%	**Northern California Black Walnut**	< 1%
California Bulrush	7%	**Not applicable**	37%
California Rose	< 1%	**Red Willow**	0%
Common Reed	1%	**Shrubby Seepweed**	1%
Fremont Cottonwood	1%	**Three-square Bulrush**	< 1%
Giant Reed	< 1%	**Tree-of-Heaven**	< 1%
Gooding's Willow	10%	**Valley Oak**	< 1%
Hardstem Bulrush	16%	**White Alder**	< 1%
Himalayan blackberry	5%	**--**	--

Summary

Basin Setting

- ECC Subbasin is bounded on the north, east, and south by the Contra Costa County line, which is contiguous with the San Joaquin River (north) and Old River (east). In the west, the Subbasin is bounded by marine sediments of the Coast Range.
- Topography and geological formations gently slope to the northwest. The upper 400 feet of Subbasin sediments is comprised of alluvial deposits with discontinuous clay layers interspersed with more permeable coarse-grained units.
- The ECC Subbasin aquifer system is divided into the upper unconfined Shallow Zone (to about 150 ft bgs) and a lower semi-confined to confined Deep Zone (the Corcoran Clay is not present in the Subbasin). Most water wells are constructed within the upper 400 feet.

Groundwater Conditions

- Groundwater levels in the ECC Subbasin are stable which indicates that the Subbasin is being operated within its sustainable yield. This is due to surface water being the major supply source for agricultural and urban uses. Groundwater flow direction is generally from the southwest to the northeast toward the Delta.

- Groundwater quality is generally good with no restrictions for agricultural or urban uses in the Subbasin. Constituents of concern are TDS, chloride, nitrate as N, and boron which all have natural sources with the exception of nitrate. TDS concentrations in both the Shallow Zone and Deep Zone are generally stable and average 1,100 mg/L, around the SMCL of 1,000 mg/L. Chloride is another indicator of salinity and averages around 230 mg/L which is near the SMCL of 250 mg/L. Nitrate levels are primarily below the MCL of 10 mg/L, with slightly elevated concentrations in the Shallow Zone around Brentwood due to past land uses. Boron does not have a drinking water standard, but the agricultural goal is 700 ug/L where some crops may become sensitive to it. Boron concentrations in ECC wells are generally over 1,000 ug/L.
- Groundwater Storage: the total volume of groundwater in storage in the Subbasin was estimated to be between 4.5 MAF and 9 MAF when measuring to the base of fresh water (to over 1,000 ft bgs) and between 1.5 MAF to 3 MAF when measuring the current production zone (to average of 300 ft bgs). There has not been a change in groundwater storage overtime because groundwater levels between 1993 to 2019 have been stable.
- Land Subsidence: there are no historical records of inelastic subsidence due to groundwater withdrawal in the ECC Subbasin.
- Seawater Intrusion: the East Contra Costa Subbasin has no coastline, is not bordered by the ocean, and seawater intrusion is not present.
- Interconnected Surface Water: are locations where groundwater and surface water are hydrologically connected. The San Joaquin River and Old River are considered interconnected rivers in this Subbasin. Impacts on these surface water bodies due to groundwater pumping will be managed under this GSP to minimize stream depletion.
- Groundwater Dependent Ecosystems: potential GDEs are identified and will be studied further throughout the GSP process.

3.4 References

Anderton, R. 1985. Geological Society, London, Special Publications, 18, 31-47, 1 January 1985, https://doi.org/10.1144/GSL.SP.1985.018.01.03

Bartow, J.A. 1985. Map showing Tertiary stratigraphy and structure of the Northern San Joaquin Valley, California, Field Studies Map MF-1761, Scale 1:250,000.

Bartow, J.A. 1991. The Cenozoic Evaluation of the San Joaquin Valley, California. U.S. Geological Survey, Professional Paper 1501.

Berkstresser, C.F., Jr. 1973, Map showing base of fresh ground-water, approximately 3,000 micromhos, in the Sacramento Valley and Sacramento-San Joaquin Delta, California: U.S. Geological Survey Water-Resources Investigations Report 40-73, 1 sheet.

Bertoldi, G., Johnston, R., and Evenson, K.D., 1991, Regional Aquifer-System Analysis-Central Valley, California: U.S. Geological Survey Professional Paper 1401-A.

Davis, T.A., Bennett, G.L., Metzger, L.F., Kjos, A.R., Peterson, M.F., Johnson, J., Johnson, T.D., Brilmyer, C.A., and Dillon, D.B., 2018, Data analyzed for the preliminary prioritization of California oil and gas fields for regional groundwater monitoring: U.S. Geological Survey data release, https://doi.org/10.5066/F7FJ2DV3.

Deverel, S.J., Ingrum, T. Leighton, D. (2016). Present-day oxidative subsidence of organic soils and mitigation in the Sacramento-San Joaquin Delta, California, USA. Hydrogeology Journal. Distributed under the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/).

Department of Water Resources (DWR). 2003. Bulletin 118: California's Groundwater.

DWR. 2016. Bulletin 118: California's Groundwater, Interim Update 2016.

DWR. 2017. Draft Best Magement Practices for the Sustainable Management of Groundwater, Sustainable Management Criteria BMP. November 2017.

GeoTracker. 2018. GeoTracker Cleanup Sites. https://geotracker.waterboards.ca.gov/datadownload

ECCC IRWM. 2019. https://www.eccc-irwm.org/east-county-irwm

Luhdorff and Scalmanini, Consulting Engineers. 1999. Investigation of Ground-Water Resources in the East Contra Costa Area. Prepared for East County water entities. March 1999.

Luhdorff and Scalmanini, Consulting Engineers. 2016. An Evaluation of Geologic Conditions East Contra Costa County. Prepared for East Contra Costa County Agencies. March 2016.

Page, R.W.,1973b, Base of fresh ground water (approximately 3,000 micro mhos) in the San Joaquin Valley, California: U.S. Geological Survey Hydrologic Investigations Atlas HA-489.

Rohde, M. M., S. Matsumoto, J. Howard, S. Liu, L. Riege, and E. J. Remson. 2018. Groundwater Dependent Ecosystems under the Sustainable Groundwater Management Act: Guidance for Preparing Groundwater Sustainability Plans. The Nature Conservancy, San Francisco, California.

Town of Discovery Bay Community Services District and Luhdorff and Scalmanini, Consulting Engineers. 2017. 2015 Urban Water Management Plan. Adopted June 21, 2017.

UNAVCO. 2019. UNAVCO's Monitoring Network Map database. https://www.unavco.org/instrumentation/networks/map/map.html#/. Accessed on April 2019.

University of California, Davis (UCD) Department of Agriculture and Natural Resources. n.d. Soil Resource Lab. Soil Agricultural Groundwater Banking Index (SAGBI). https://casoilresource.lawr.ucdavis.edu/sagbi/. Accessed May 2019.

U.S. Geological Survey. 1999. Land subsidence in the United States: Sacramento-San Joaquin Delta. Circular 1182. Pages 83-94.

Williamson, A. K., Prudic, D.E., and Swain, L.A., 1989, Ground-water flow in the Central Valley, California, U.S. Geological Survey Professional Paper 1401-D, 127p.