Merced Subbasin Groundwater Sustainability Plan Current and Historical Groundwater Conditions

Draft for Stakeholder Committee and Coordinating Committee Review

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ACRONYMS

µg/L	Microgram per liter
AF	Acre-Feet
As	arsenic
bgs	Below ground surface
CASGEM	California Statewide Groundwater Elevation Monitoring Program
CDPH	California Department of Public Health
Cl	chloride
Cr^6	Hexavalent Chromium
CV-SALTS	Central Valley Salinity Alternatives for Long Term Sustainability
DBCP	Dibromochloropropane
DLR	Detection Limit for Purposes of Reporting
DTSC	Department of Toxic Substances Control
DWR	Department of Water Resources
EDP	Ethylene Dibromide
Fe	iron
GAMA	Groundwater Ambient Monitoring Assessment
GSP	Groundwater Sustainability Plan
HCM	Hydrogeologic Conceptual Model
IRWM	Integrated Regional Water Management
LUST	Leaking Underground Storage Tank
MAF	Million Acre-Feet
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
Mn	manganese
MTBE	Methyl Tertiary Butyl Ether
NO_3	nitrate
NWIS	National Water Information System
OWTS	onsite wastewater treatment systems
PCE	Tetrachloroethylene
PFOA	Perfluorooctantoic acid
PFOS	Perfluorooctanesulfonic acid
RWQCB	Regional Water Quality Control Board
SGMA	Sustainable Groundwater Management Act
SJRRP	San Joaquin River Restoration Program
SNMP	Salt and Nutrient Management Plan
SWRCB	State Water Resources Control Board
TCA	1,1,1-Trichloroethane
TCE	Trichloroethylene
TCP	1,2,3-Trichloropropane
TDS	Total Dissolved Solids
USBR	United States Bureau of Reclamation
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	volatile organic compound

This document includes the Current and Historical Groundwater Conditions Section that will be included as part of a report section in the Merced Subbasin Groundwater Sustainability Plan (GSP) that satisfies § 354.8 of the Sustainable Groundwater Management Act (SGMA) Regulations. The Current Conditions section is a portion of the Basin Settings portion of a GSP. The Basin Settings contains three main subsections:

- Hydrogeologic Conceptual Model (HCM) **–** This section, presented here, provides the geologic information needed to understand the framework that water moves through in the basin. It focuses on geologic formations, aquifers, structural features, and topography.
- Groundwater Conditions **–** This section describes and presents groundwater trends, levels, hydrographs and level contour maps, estimates changes in groundwater storage, identifies groundwater quality issues, and addresses subsidence and surface water interconnection.
- Water Budget **–** This section provides the data used in water budget development, discusses how the budget was calculated, and provides water budget estimates for historical conditions, current conditions and projected conditions.

The draft HCM and Water Budget sections have already been released for review and comment.

1. BASIN SETTING

1.1 CURRENT AND HISTORICAL GROUNDWATER CONDITIONS

This section describes the current and historical groundwater conditions in the Merced Subbasin. As defined by the GSP regulations by the Department of Water Resources (DWR), the Groundwater Conditions section is intended to:

- Define current groundwater conditions in the Subbasin
- Describe historical groundwater conditions in the Subbasin
- Describe the distribution, availability, and quality of groundwater
- Identify interactions between groundwater, surface water, dependent ecosystems, and subsidence
- Establish a baseline of quality and quantity conditions that will be used to monitor changes in the groundwater conditions relative to measurable objectives and minimum thresholds
- Inform development measurable objectives to maintain or improve specified groundwater conditions
- Support monitoring to demonstrate that the GSP is achieving sustainability goals of the Basin

The groundwater conditions described in this section are intended to convey the present and historical availability, quality, and distribution of groundwater. These conditions are used elsewhere in the GSP to define measurable objectives, identify sustainability indicators, and establish undesirable results.

1.1.1 Groundwater Elevation

1.1.1.1 Historical Groundwater Elevations

To visually show long-term trends in groundwater elevations in the Merced Subbasin, 13 wells with long periods of record and that are relatively evenly distributed across the Subbasin were selected from the larger available dataset (see Figure 1-1). Across all three Principal Aquifers, this includes four wells screened above the Corcoran Clay, five wells screened from below the Corcoran Clay, and four wells located outside the extent of the Corcoran Clay. Long-term hydrographs prepared for these wells show that, throughout most of the Merced Subbasin, groundwater elevations are declining with time (see Figure 1-1).

Average groundwater level decline per Principal Aquifer was quantified for 1996-2015. In Section X – Water Budgets, the Historical Water Budget uses 1996-2015 as a representative hydrologic period which includes an average annual precipitation of 11.6 inches, nearly the same as the long-term average of 12.2 inches. The 1996-2015 period also includes the recent 2012-2015 drought, the wet years of 1996-1998, and periods of normal precipitation. This was calculated using all CASGEM and Voluntary wells with groundwater level data available for 1996-2015 (totaling 51 wells).

Based on data from 11 wells in the Above Corcoran Clay Principal Aquifer, average groundwater level decline was -1.3 ft/yr from 1996-2015. Based on data from 15 wells in the Below Corcoran Clay Principal Aquifer, average groundwater level decline was -2.4 ft/yr from 1996-2015. Based on data from 25 wells in the Outside Corcoran Clay Principal Aquifer, average groundwater level decline was -1.2 ft/yr from 1996-2015. Note that most of the CASGEM wells for the Outside Corcoran Clay Principal Aquifer were Voluntary wells that did not report beyond 2012. It is possible that some portion of additional groundwater level decline during the 2012-2015 drought is missing from the overall 1996-2015 average for the Outside Corcoran Clay Principal Aquifer. Voluntary wells provide important long-term historical information about groundwater levels, but since they do not meet the full CASGEM program standards, they are not included in the future monitoring program for this GSP.

Figure 1-1: Hydrographs for Selected Wells in the Merced Subbasin

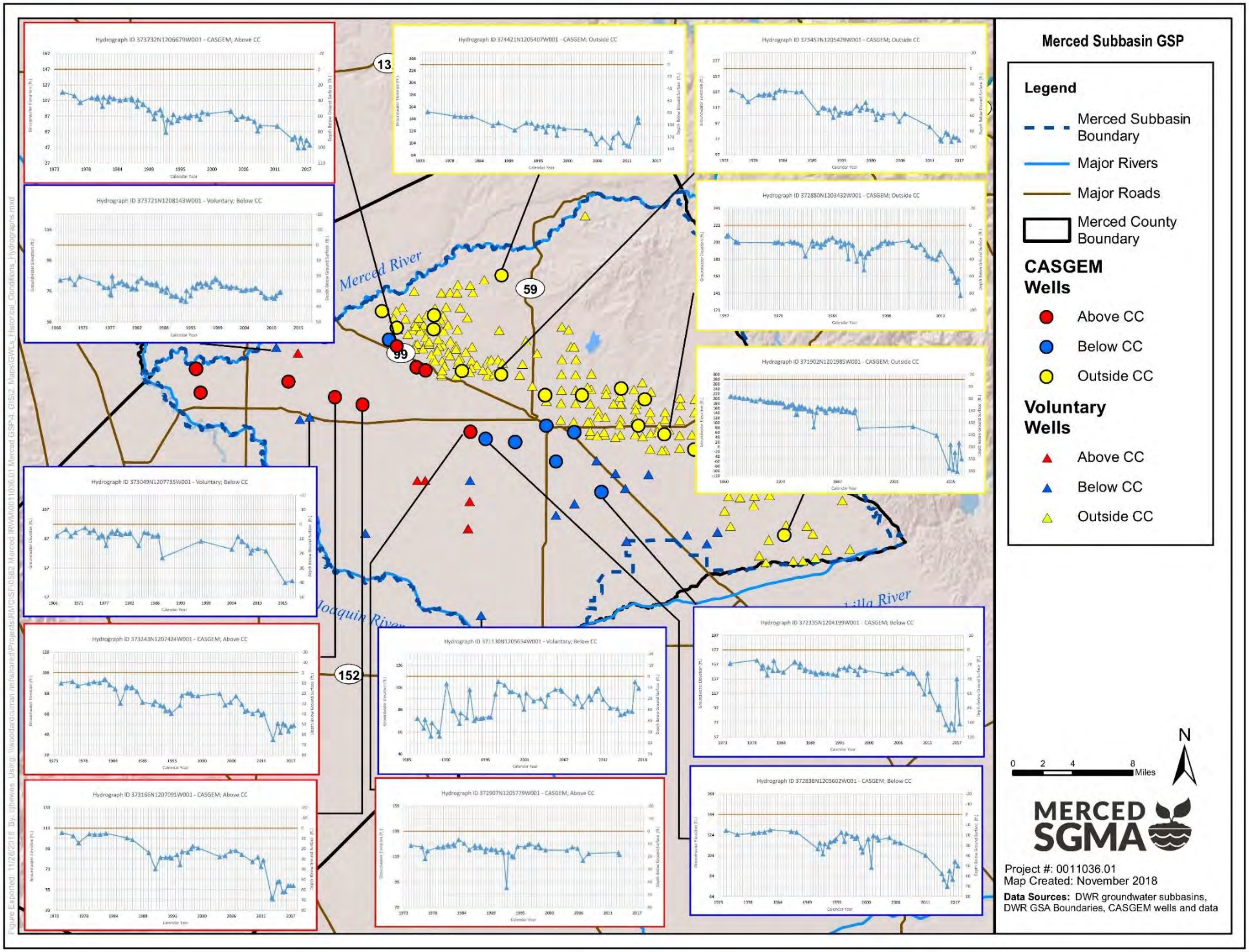


Figure 1-2 through Figure 1-4 show groundwater elevations (in feet above sea level, datum NAVD88) in Fall 2014 based on measurements recorded at California Statewide Groundwater Elevation Monitoring (CASGEM) wells, including voluntary wells where data was available. Fall 2014 is the closest season of available CASGEM data to display conditions as of January 1, 2015, representing conditions when SGMA became law. Groundwater elevations are mapped separately for the three principle aquifers: Above, Below, and Outside of the Corcoran Clay.

Figure 1-2: Fall 2014 Groundwater Elevation, Principal Aquifer: Above Corcoran Clay

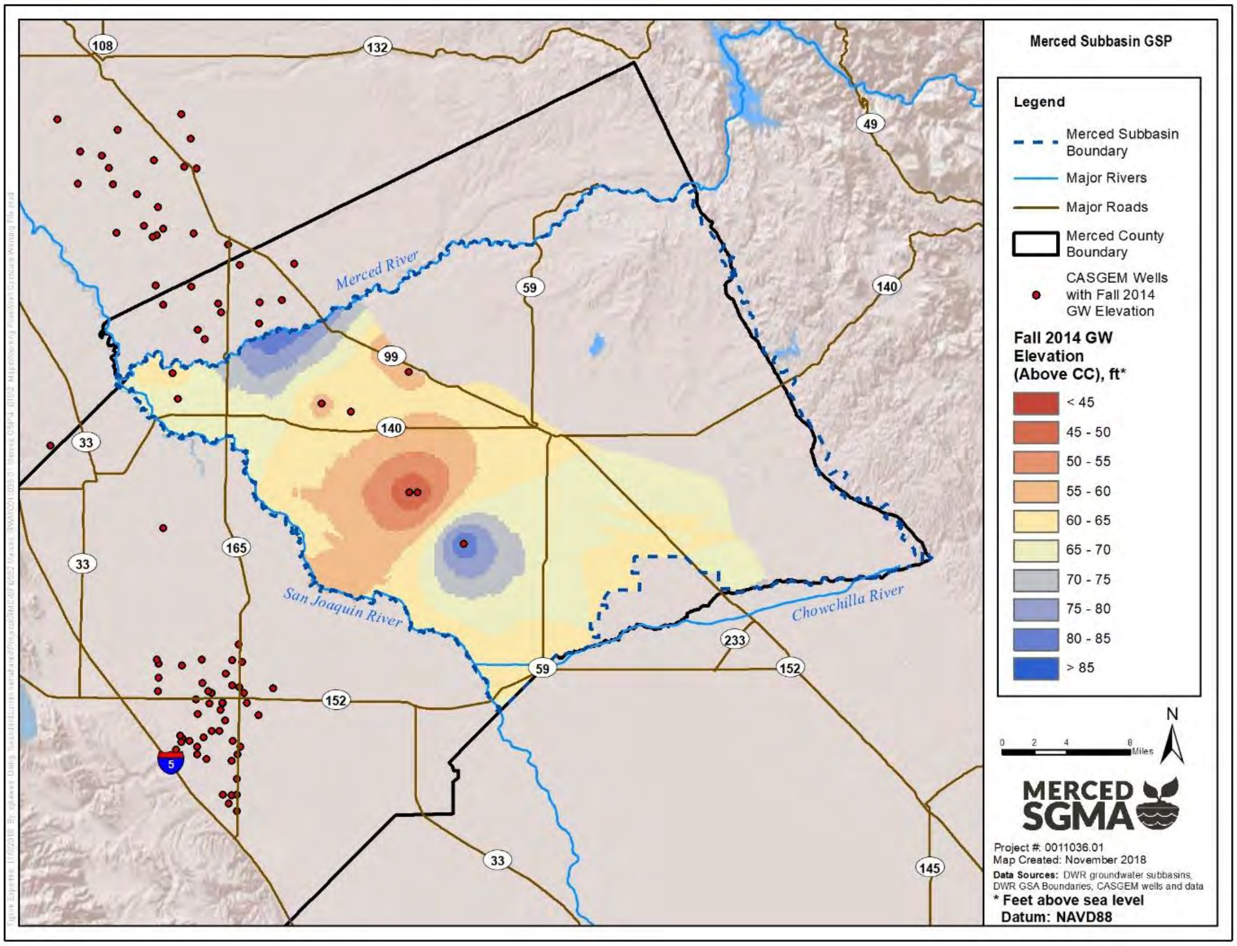


Figure 1-3: Fall 2014 Groundwater Elevation, Principal Aquifer: Below Corcoran Clay

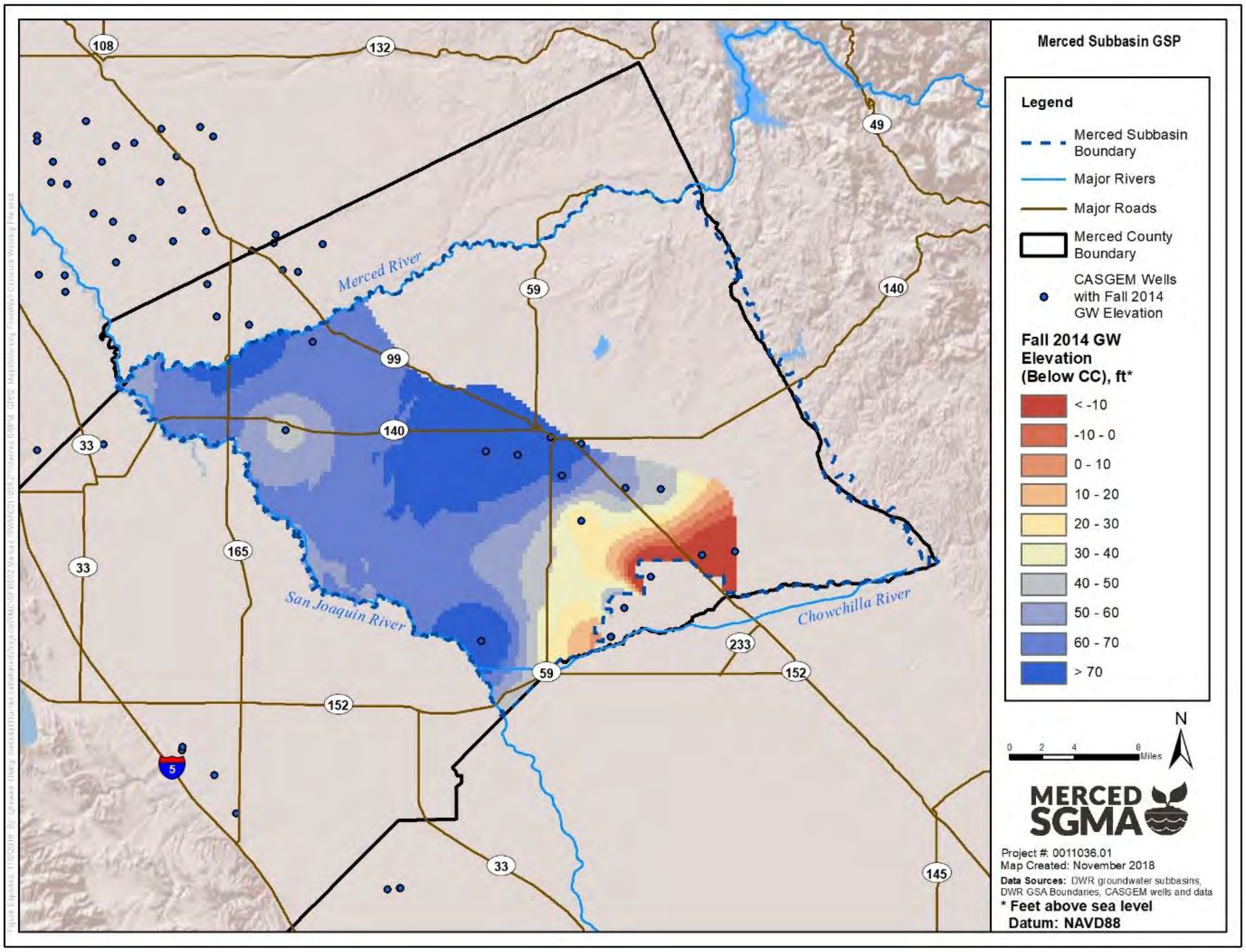
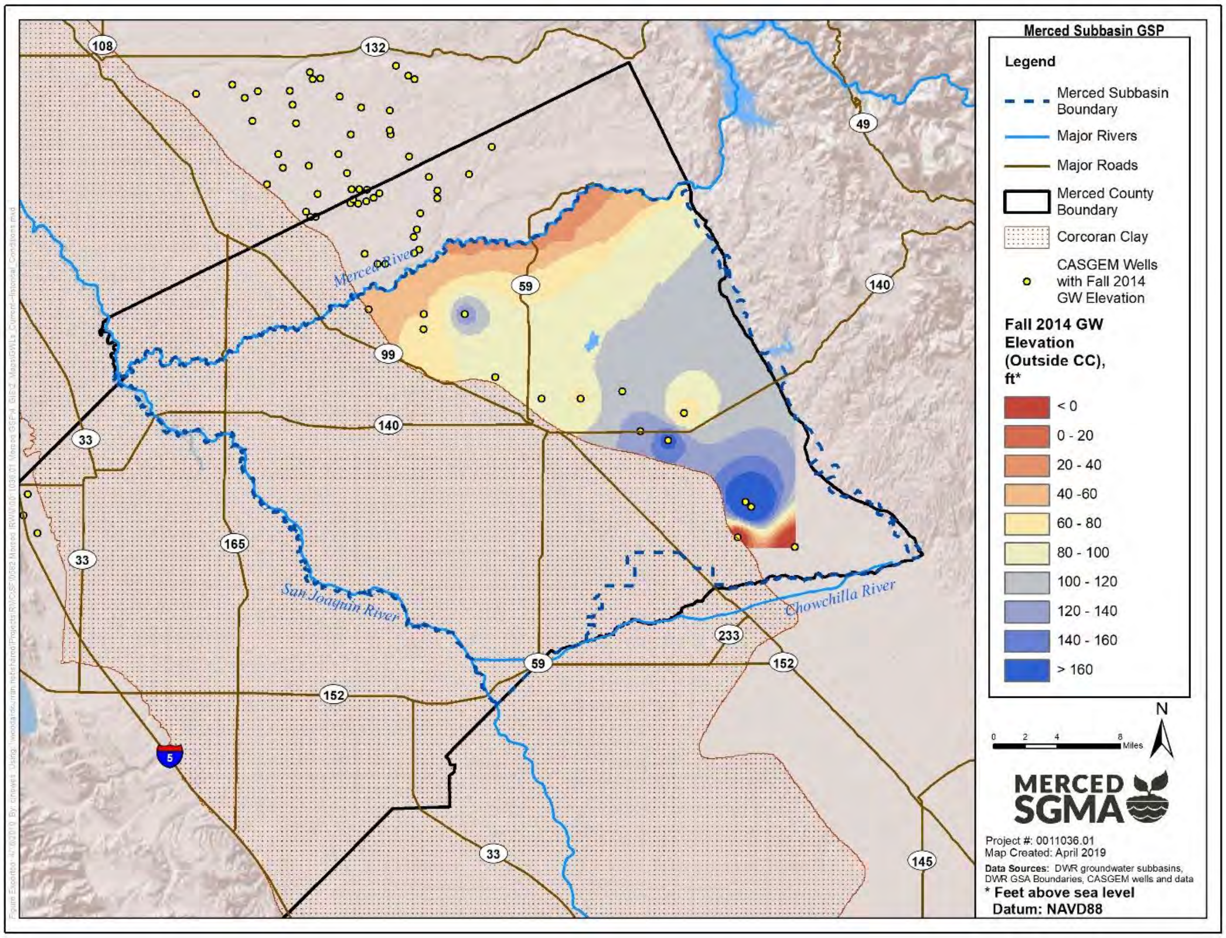


Figure 1-4: Fall 2014 Groundwater Elevation, Principal Aquifer: Outside Corcoran Clay[1]



[1] Groundwater elevations are missing for the southeast corner of the Outside Corcoran Clay Principal Aquifer due to a lack of data in this corner of the Subbasin from Fall 2014.

1.1.1.2 Current Groundwater Conditions

Figure 1-5 through Figure 1-7 show groundwater elevations in Spring 2017 (most recent seasonal high), while Figure 1-8 through Figure 1-10 show groundwater elevations in Fall 2017 (most recent seasonal low). Groundwater elevations are mapped for CASGEM wells (including voluntary wells) separately for the three principle aquifers: Above, Below, and Outside of the Corcoran Clay.

Above the Corcoran Clay, groundwater generally flows northerly from the southern portion of the aquifer boundary and southerly from the northern portion of the aquifer boundary, meeting at a low point in the middle. The lateral gradient is fairly shallow at approximately 4 ft/mi.

Below the Corcoran Clay, groundwater generally flows in an easterly or southeasterly direction towards the Chowchilla Subbasin. The lateral gradient is approximately 7 ft/mi.

Outside of the Corcoran Clay, groundwater generally flows from the center of the aquifer region to the north. There also appears to be localized highs and depressions without a dominant lateral gradient to the southern end of the aquifer region, possibly due to pumping or stream influences. The lateral gradient is approximately 5.2 ft/mi.

Figure 1-5: Spring 2017 Groundwater Elevation, Principal Aquifer: Above Corcoran Clay

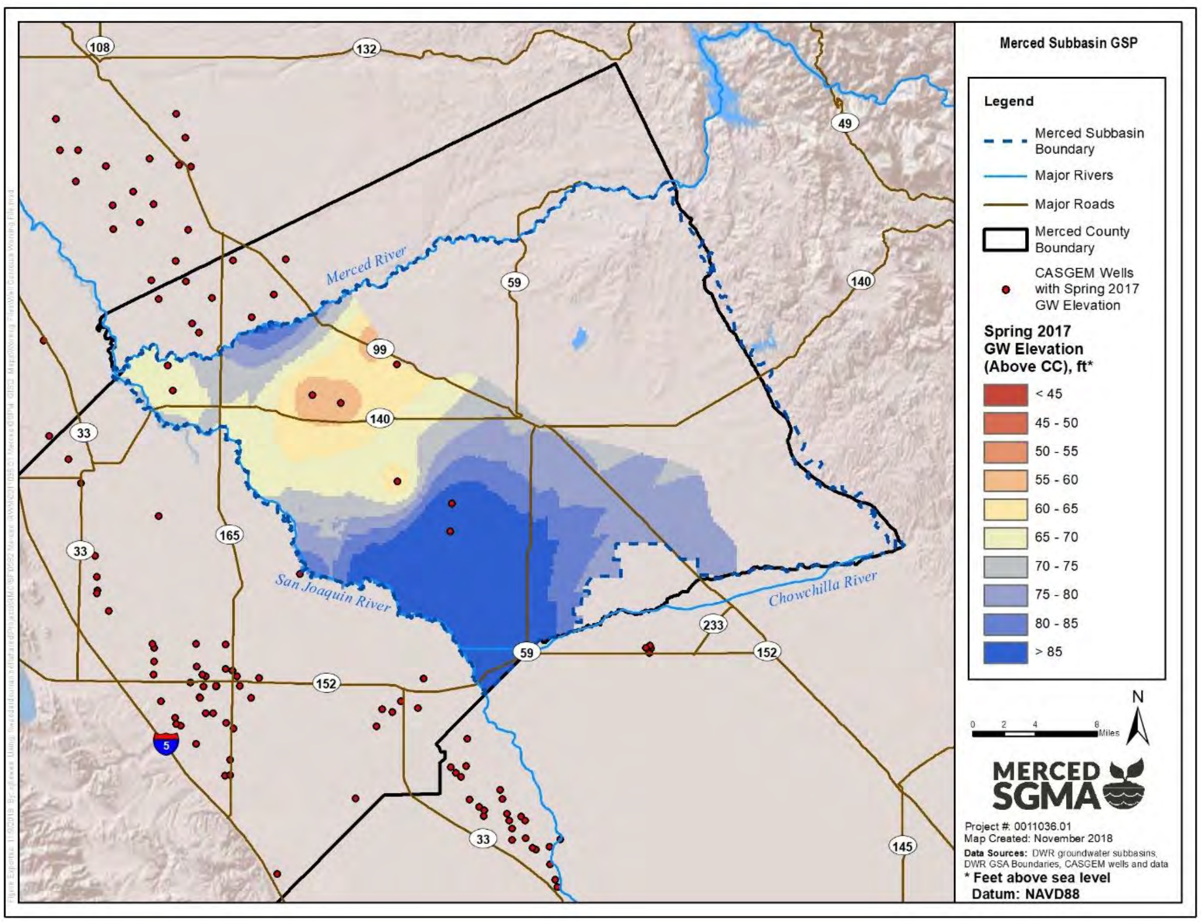


Figure 1-6: Spring 2017 Groundwater Elevation, Principal Aquifer: Below Corcoran Clay

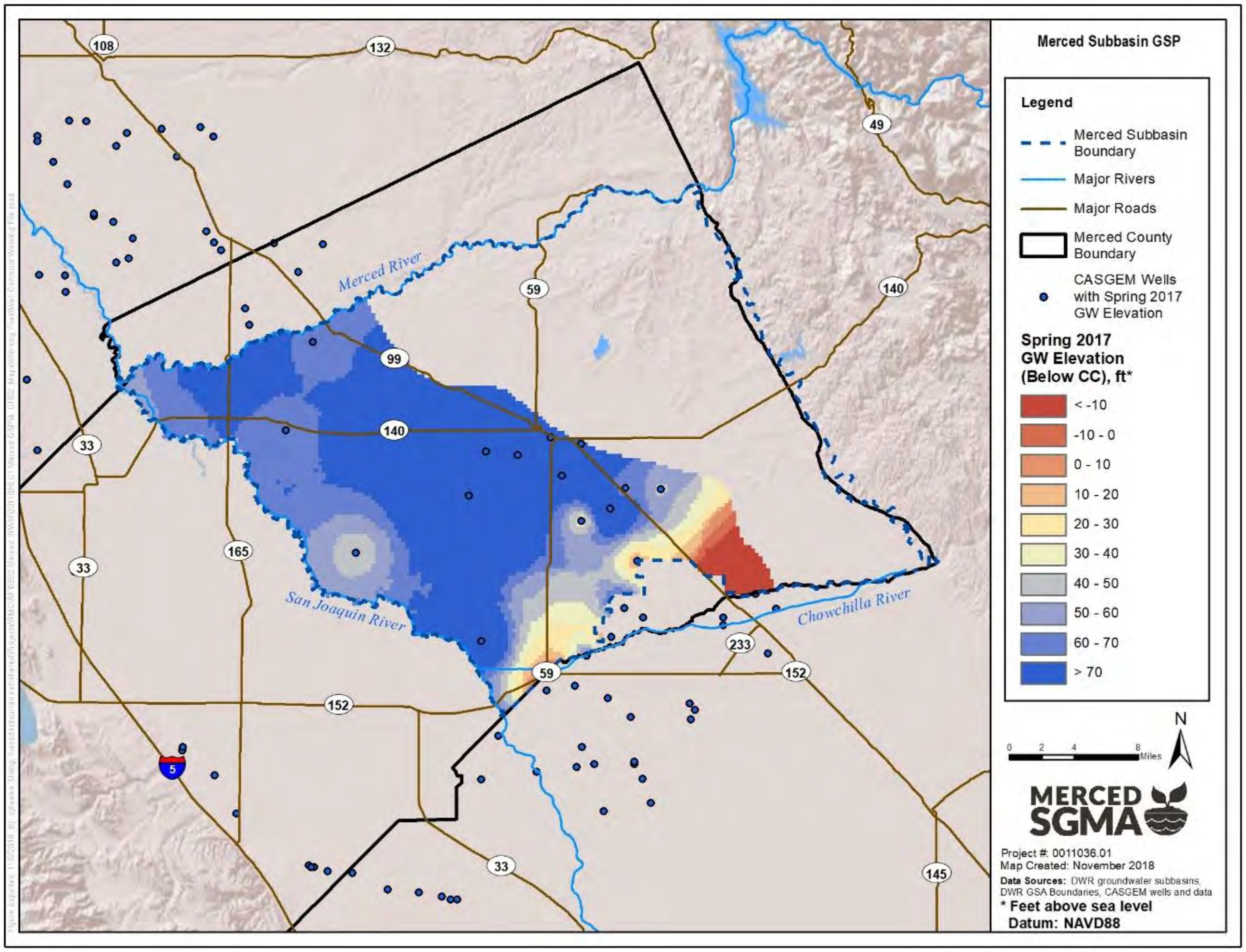


Figure 1-7: Spring 2017 Groundwater Elevation, Principal Aquifer: Outside Corcoran Clay

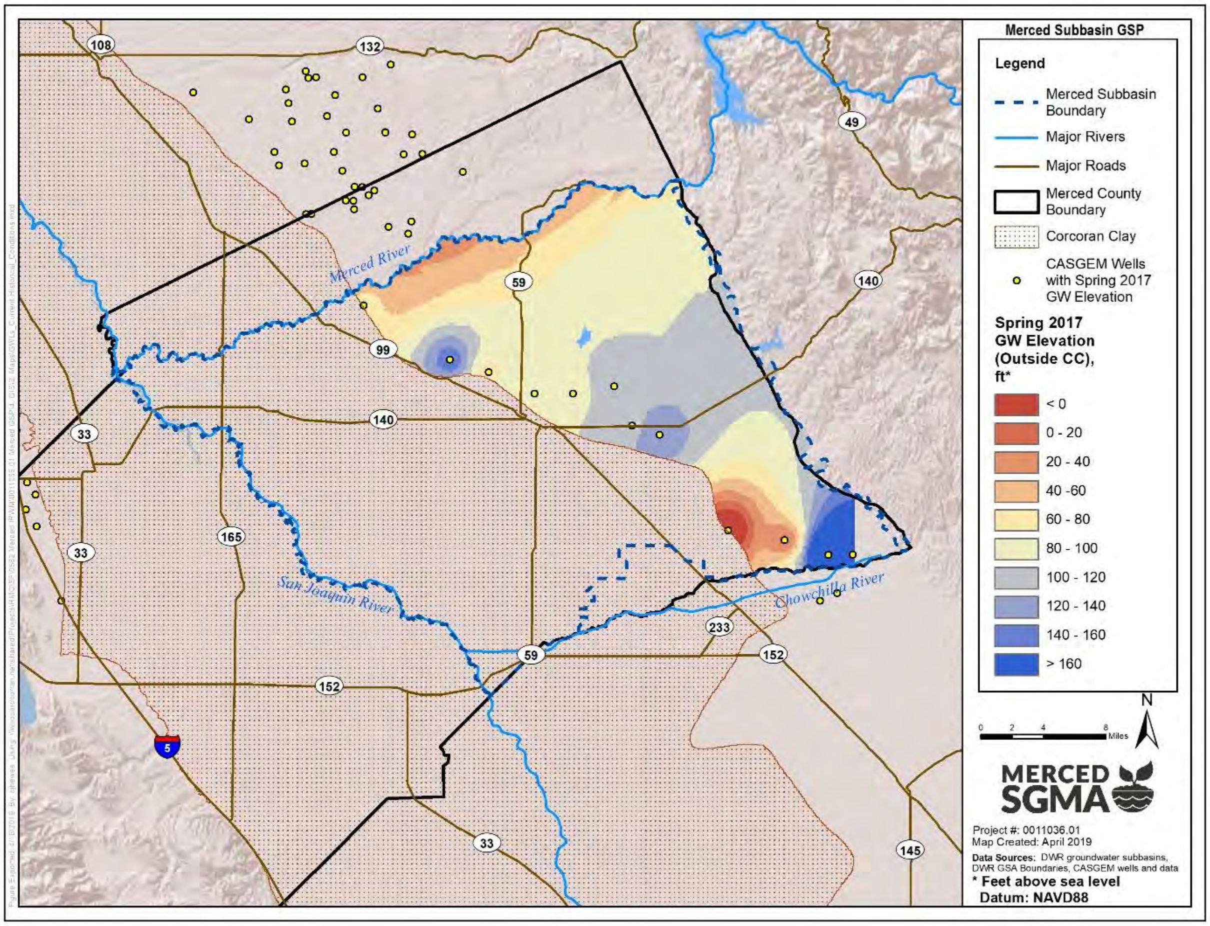


Figure 1-8: Fall 2017 Groundwater Elevation, Principal Aquifer: Above Corcoran Clay

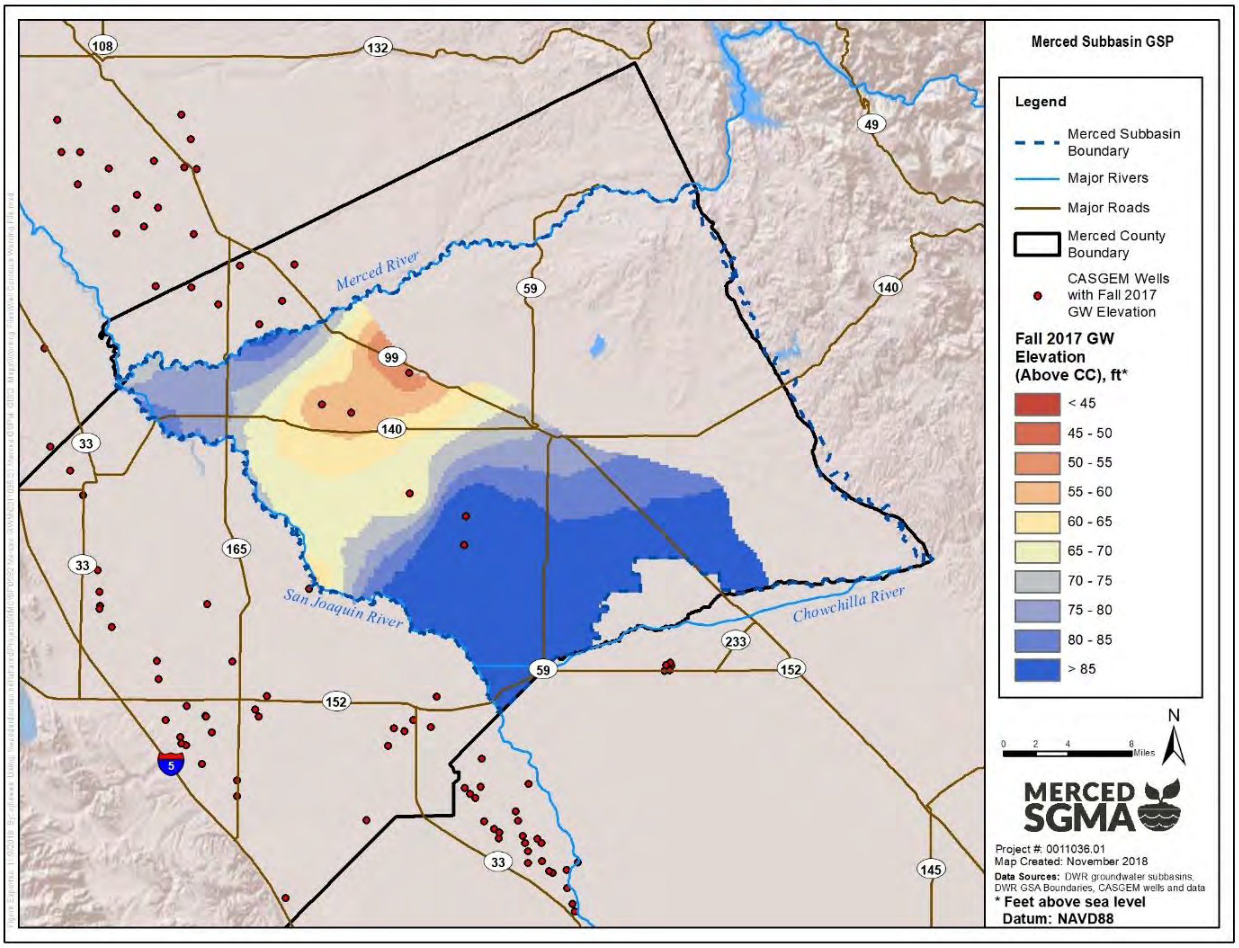


Figure 1-9: Fall 2017 Groundwater Elevation, Principal Aquifer: Below Corcoran Clay

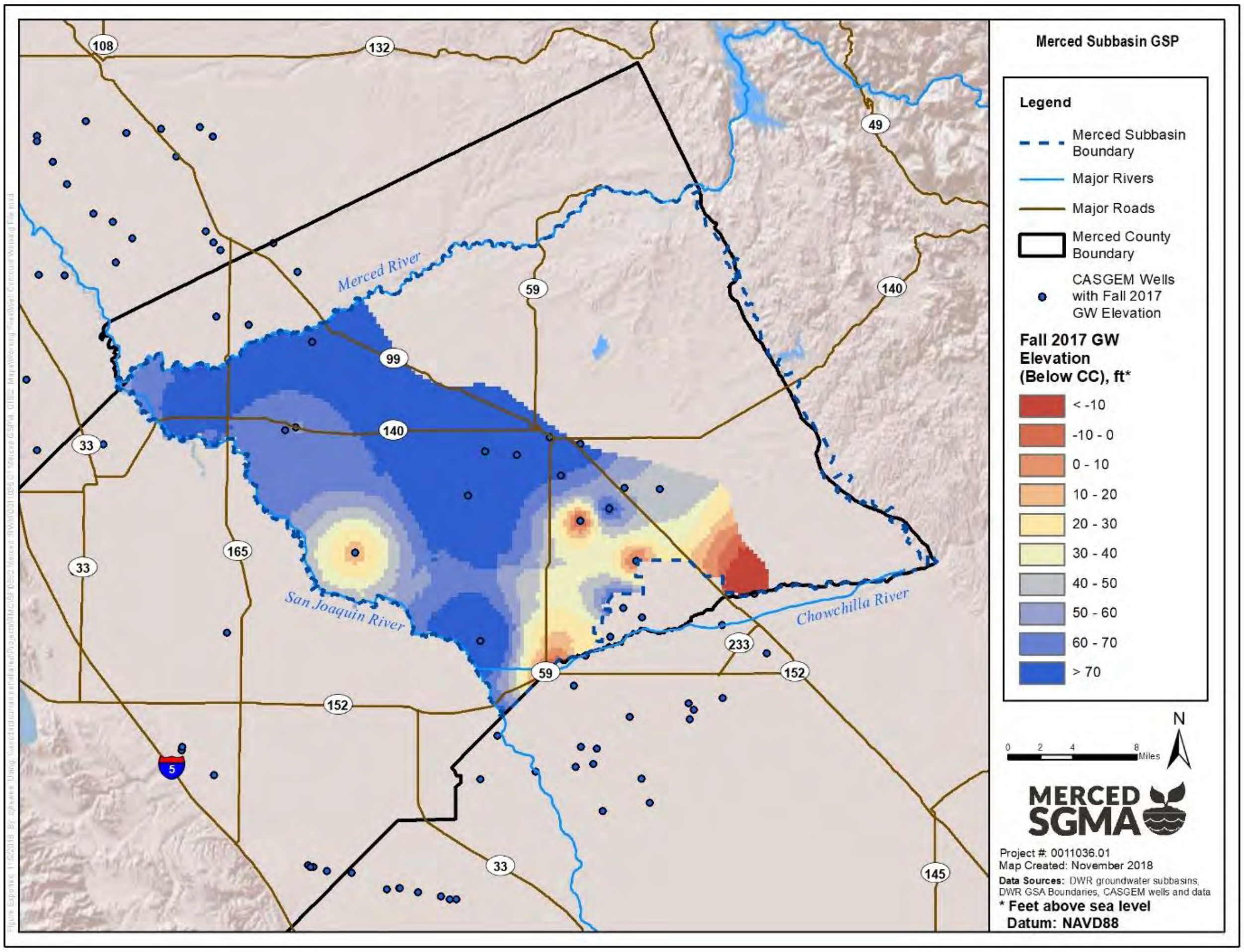
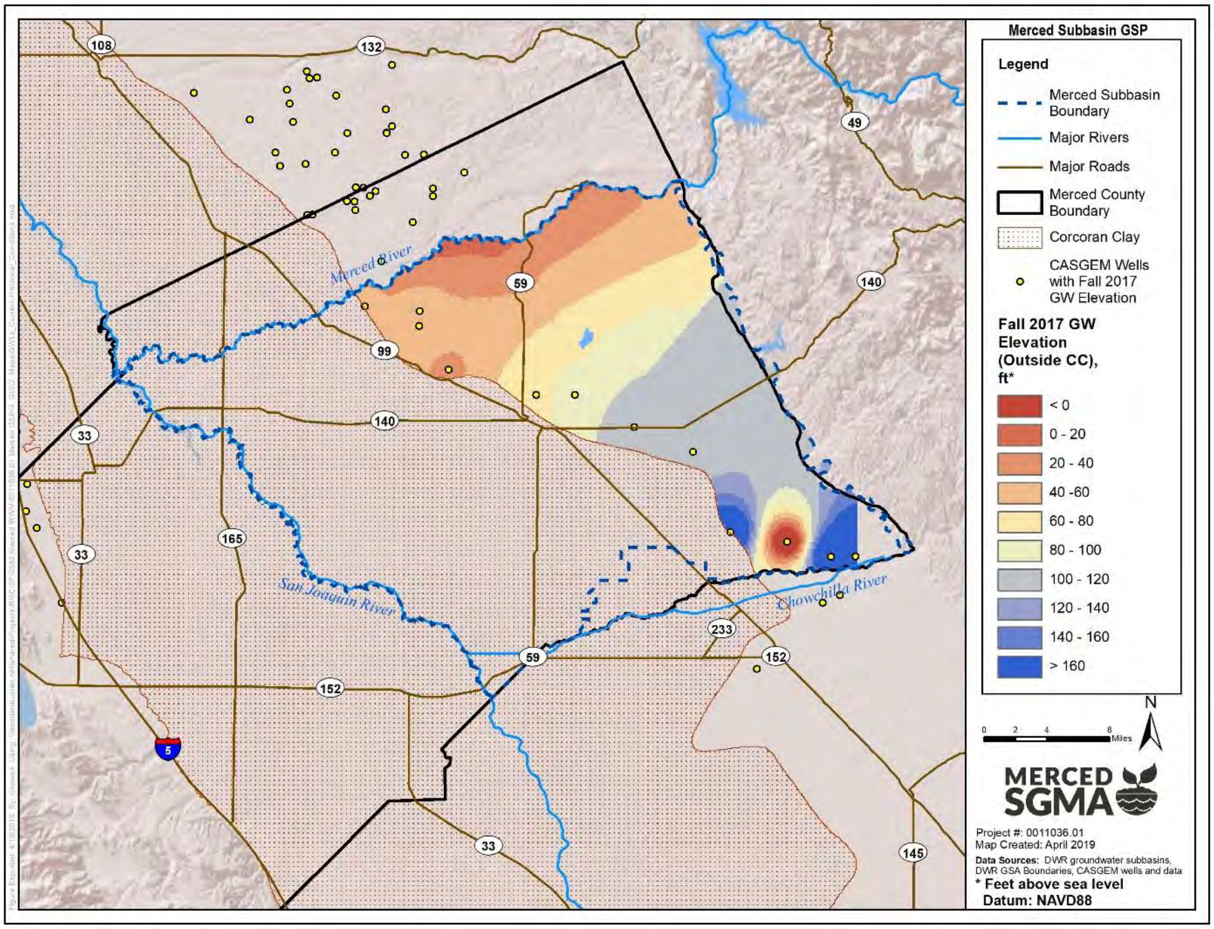


Figure 1-10: Fall 2017 Groundwater Elevation, Principal Aquifer: Outside Corcoran Clay



1.1.1.3 Vertical Gradients

A vertical gradient describes the movement of groundwater perpendicular to the ground surface and is typically measured by comparing the elevations of groundwater in a well with multiple completions that are of different depths. If groundwater piezometric elevations in the shallower completions are higher than in the deeper completions, the gradient is identified as a downward gradient. A downward gradient is one where groundwater is moving downward through the subsurface. If groundwater piezometric elevations in the shallower completions are lower than in the deeper completions, the gradient is identified as an upward gradient. An upward gradient is one where groundwater is moving upward through the subsurface. If groundwater elevations are the same throughout the completions, there is no vertical gradient. Knowledge about vertical gradients is required by regulation and is useful for understanding how groundwater moves in the Subbasin.

There are four multiple completion wells located in the Merced Subbasin, all of which are monitored through the CASGEM program. The locations of the multiple completion wells are shown in Figure 1-11. Hydrographs with groundwater elevations for each respective set of completion wells are shown in Figure 1-12 through Figure 1-15. The four sets of multiple completion wells are owned and operated by the City of Merced primarily for municipal water quality monitoring.There are no known recent studies dedicated to vertical gradients using groundwater elevations recorded at these wells.

One of the two sets of multiple completion wells in the Below Corcoran Clay Principal Aquifer shows an upward gradient (see Figure 1-13). The other shows a slight indication of an upward gradient but is not significant across all screened intervals (see Figure 1-12). These wells are located right at the edge of the extent of the Corcoran Clay where it is most shallow and thin and the level of confinement is not as well understood. The top of the Corcoran Clay is approximately 55 feet below ground surface (bgs) and 15 feet thick (extending to a depth of approximately 70 feet bgs), while the shallowest wells have screened intervals 60-110 feet or 89-170 feet bgs.

One of the two sets of multiple completion wells in the Outside Corcoran Clay Principal Aquifer shows evidence of a downward gradient (see Figure 1-15) which is consistent with previous studies (Elliott, 1984), as referenced by (AMEC, 2008). The other set of wells shows a slight indication of a downward gradient (see Figure 1-13: Vertical Gradient at Wells with Site Code Beginning 372904N1204207 or 372904N1204529 (Below Corcoran Clay)

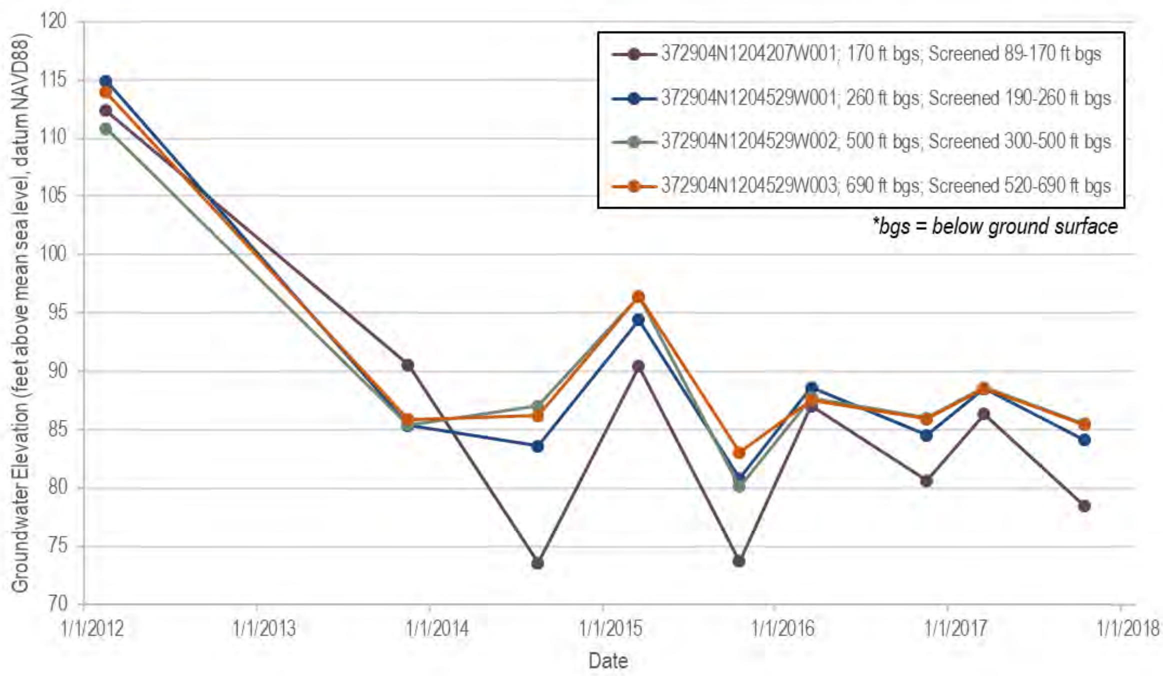


Figure 1-14) but is not significant across all screened intervals. Consequently, in the Outside Corcoran Clay, degradation of shallow groundwater can potentially affect deeper water supply wells if downward flow is significant and if dilution and chemical/biological processes are insufficient to adequately reduce the concentrations of constituents of concern (AMEC, 2008).

Figure 1-11: CASGEM Multiple Completion Wells

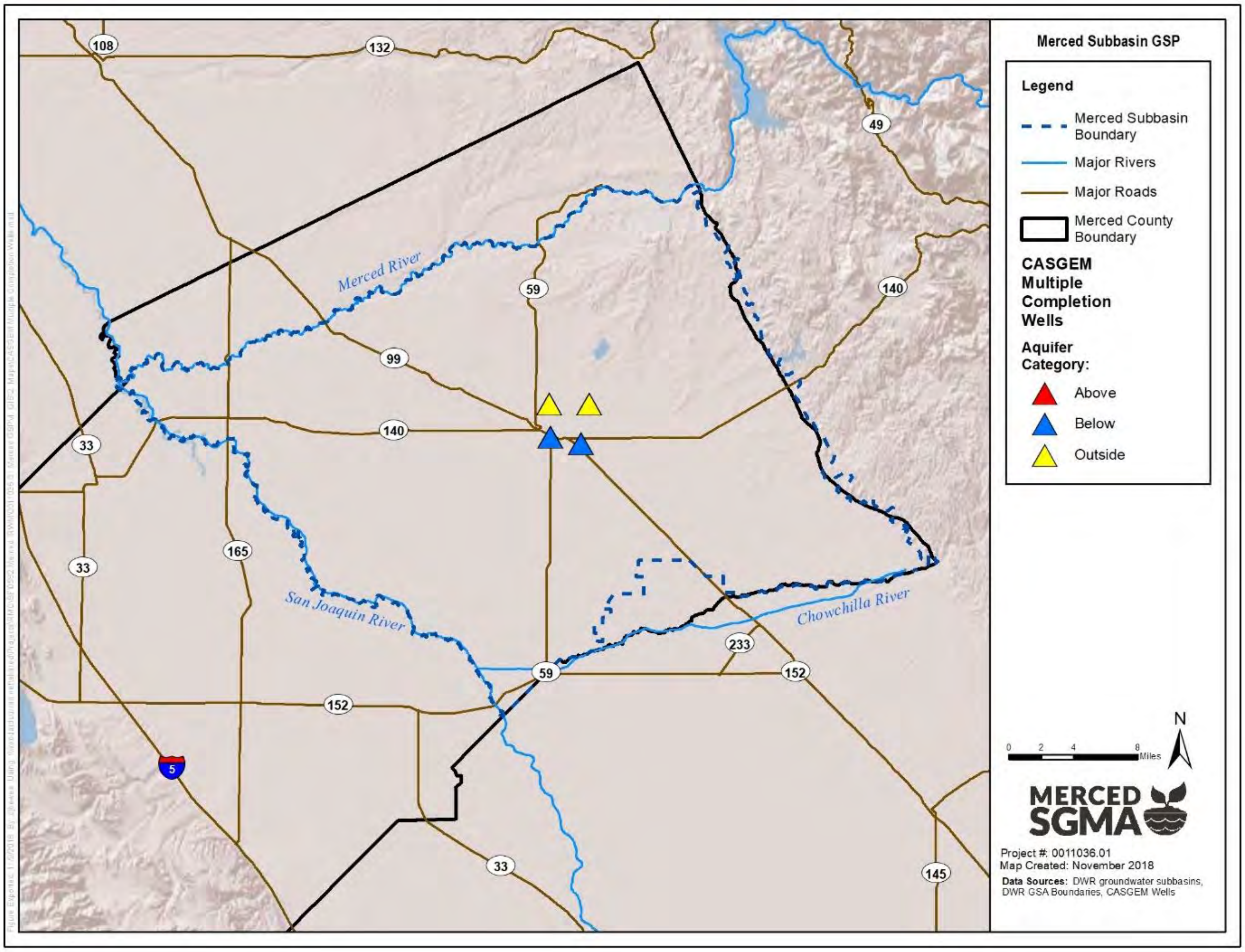


Figure 1-12: Vertical Gradient at Wells with Site Code Beginning 372964N1204867 (Below Corcoran Clay)

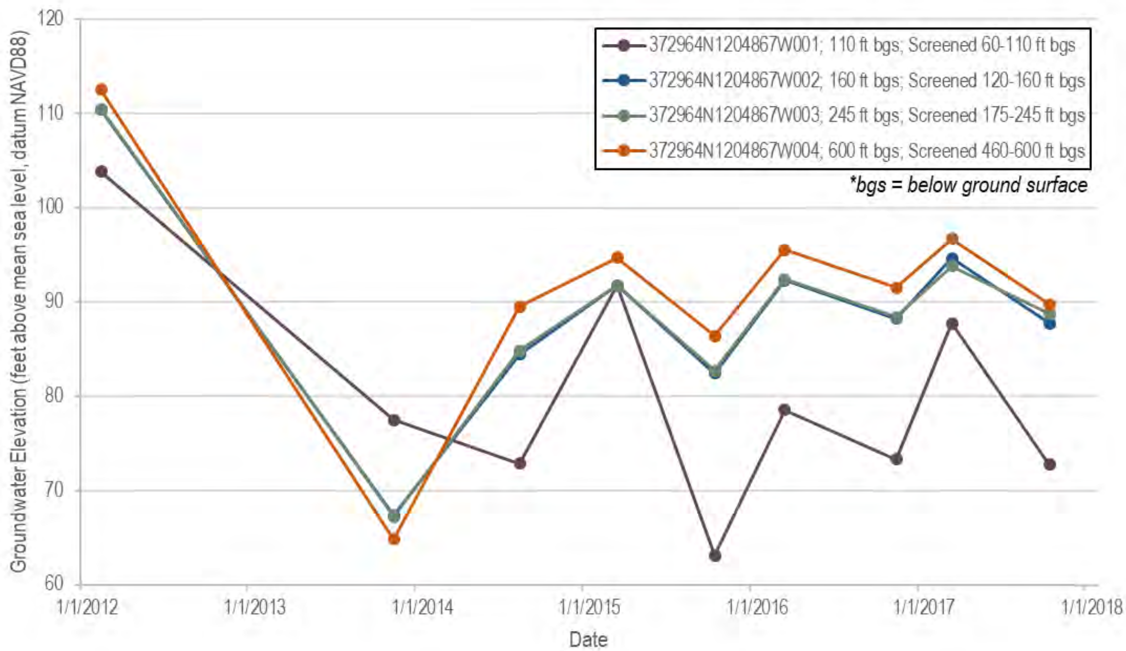


Figure 1-13: Vertical Gradient at Wells with Site Code Beginning 372904N1204207 or 372904N1204529 (Below Corcoran Clay)

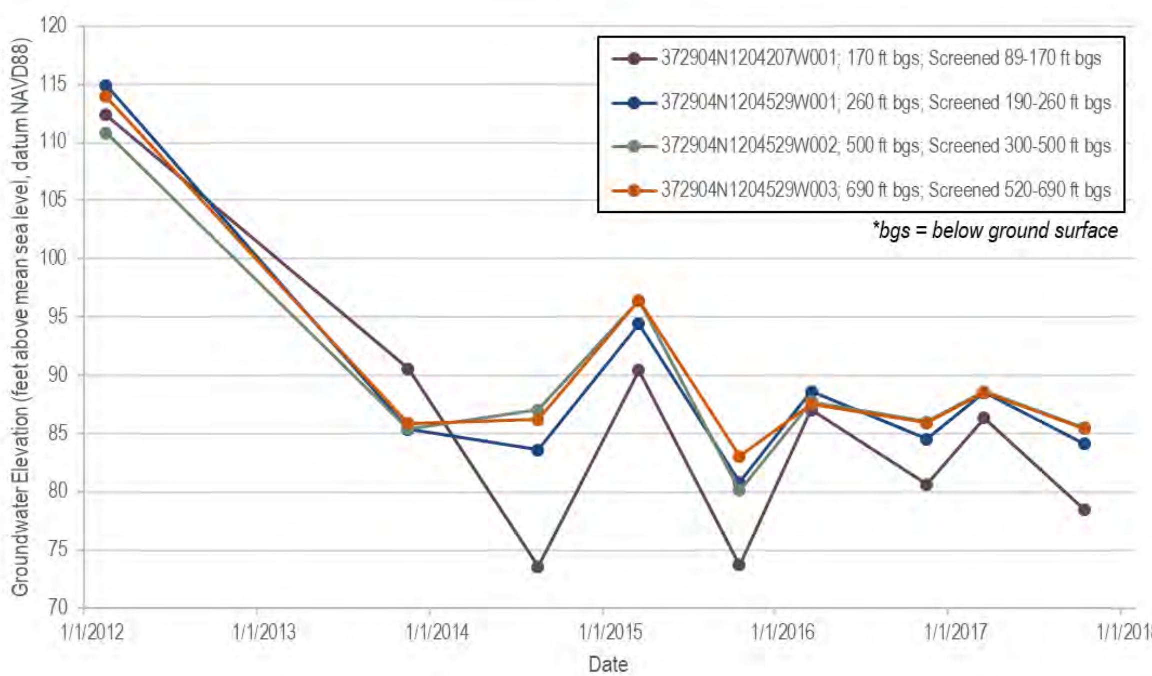


Figure 1-14: Vertical Gradient at Wells with Site Code Beginning 373260N1204432 (Outside Corcoran Clay)

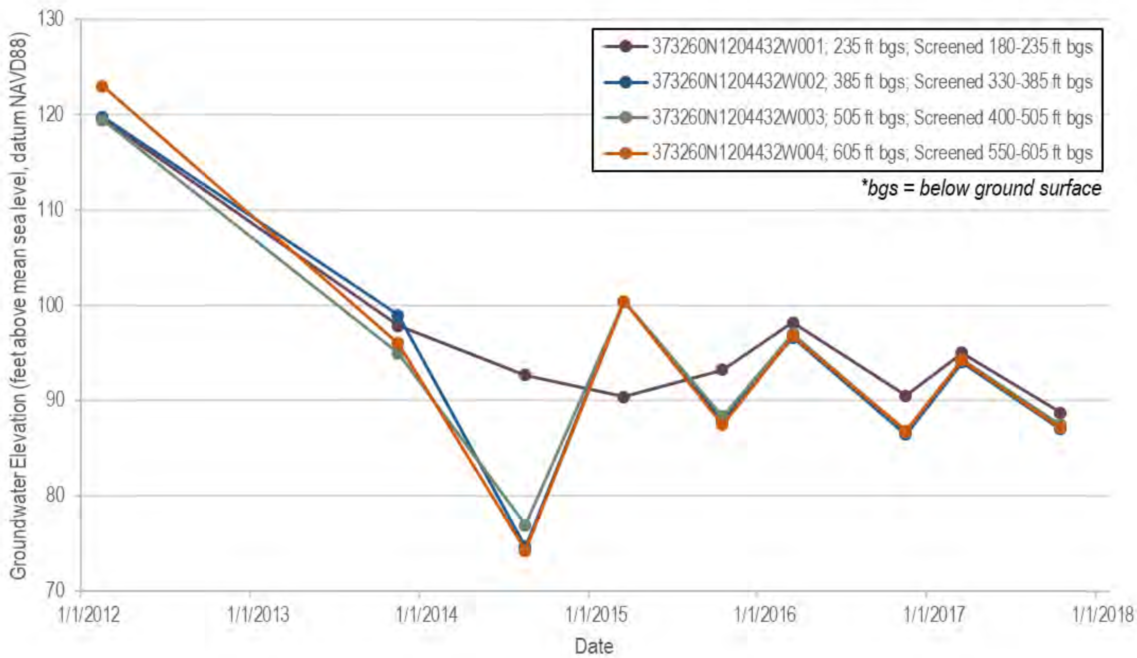
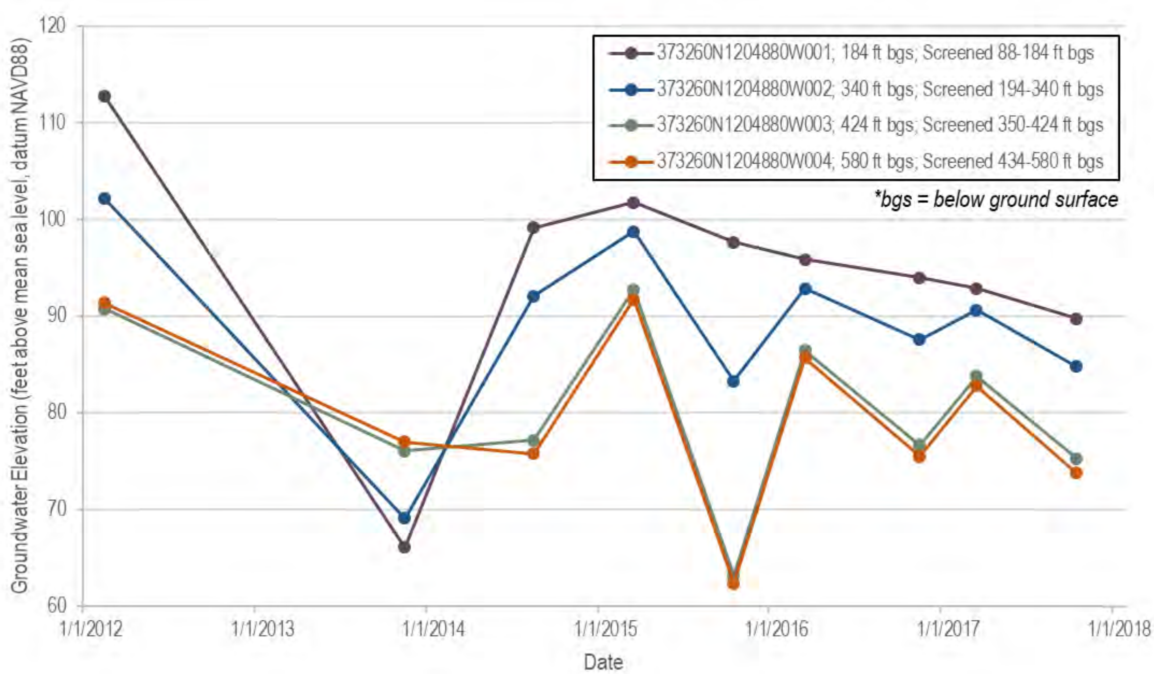


Figure 1-15 Vertical Gradient at Wells with Site Code Beginning 373260N1204880 (Outside Corcoran Clay)



1.1.2 Groundwater Storage

The MercedWRM was used to estimate historical change in storage of the Merced Subbasin from 1995-2015. Figure 1-16 shows annual total storage for each MercedWRM layer (not including the deep layer of relative higher salinity) as well as the cumulative change in storage. In 2015, the total fresh groundwater storage was estimated as 45.3 million acre-feet (MAF) and the cumulative change in storage over 1995-2015 was estimated as -2.55 MAF, or 0.13 MAF per year. An additional 72 MAF in Layer 6 of the model (not pictured) is a water body of relative higher salinity. More information about the layers of the MercedWRM and calculation of storage changes can be found in Appendix X. Figure 1-17 shows the same cumulative change in storage against budgeted groundwater uses and water year type.

Figure 1-16: Historical Modeled Change in Storage by MercedWRM Layer

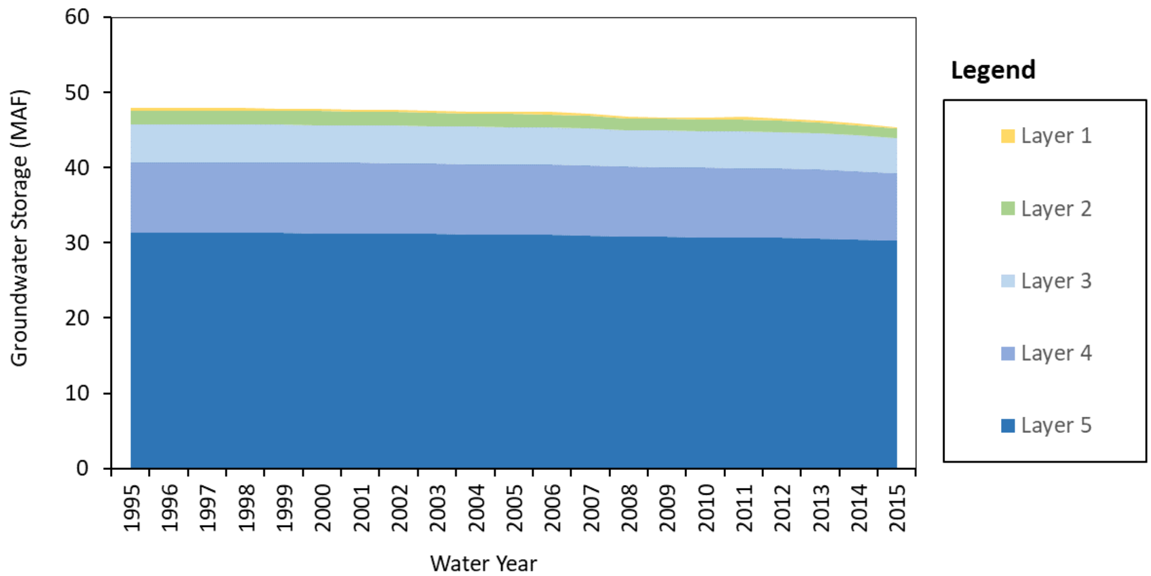
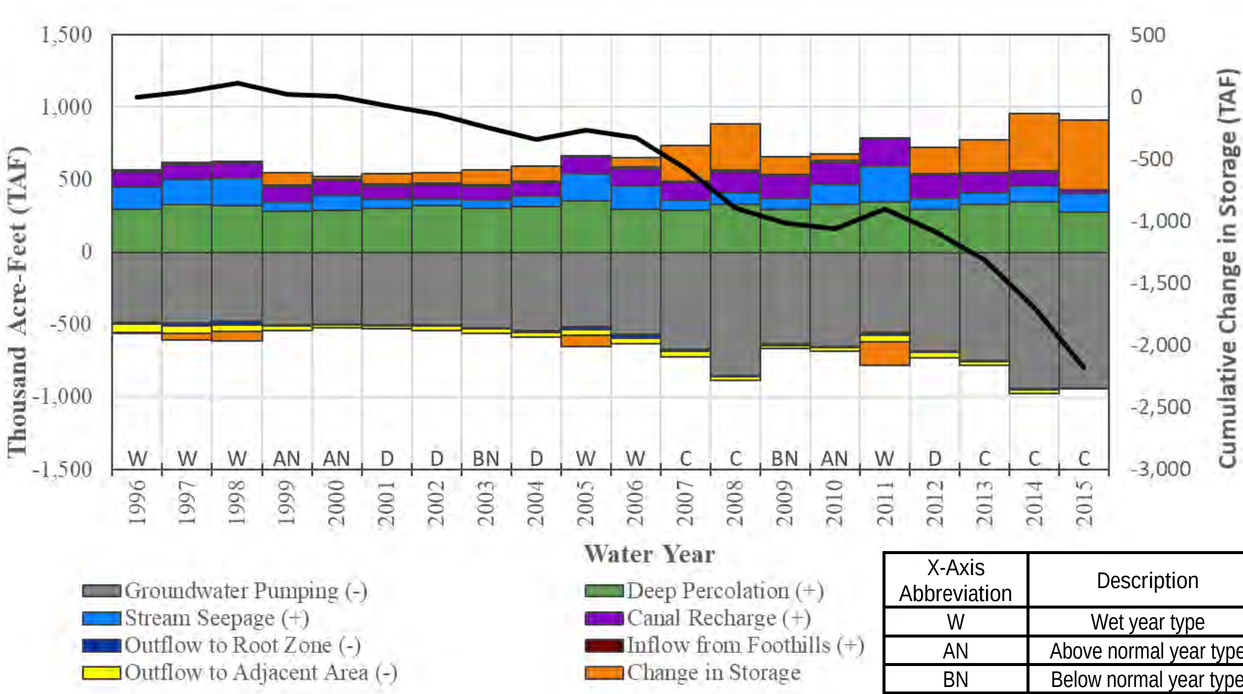


Figure 1-17: Historical Modeled Change in Storage with Groundwater Use and Water Year Type



X-Axis Abbreviation	Description
W	Wet year type
AN	Above normal year type
BN	Below normal year type
D	Dry year type
C	Critical year type

[1] "Change in Storage" is placed on the chart to balance the water budget. For instance, if annual outflows (-) are greater than inflows (+), there is a decrease in storage, and this is shown on the positive side of the bar chart to balance out the increased outflows on the negative side of the bar chart.

Source: Water Year Types based on San Joaquin Valley Water Year Index (DWR, 2018)

1.1.3 Seawater Intrusion

Seawater intrusion is not a potential risk in the Merced Subbasin, as the Subbasin is not near any seawater source. However, groundwater quality conditions related to salinity are described in the following section.

1.1.4 Groundwater Quality

Groundwater in the Merced Subbasin contains both anthropogenic and naturally occurring constituents. While groundwater quality is often sufficient to meet beneficial uses, some of these constituents either currently impact groundwater use within the Subbasin or have the potential to impact it in the future. Depending on the water quality constituent, the issue may be widespread or more of a localized concern.

The primary naturally-occurring water quality constituents of concern are arsenic and uranium. There are also aesthetic issues related to iron and manganese.

The primary water quality constituents of concern related to human activity include salinity, nitrate, hexavalent chromium, perchlorate, petroleum hydrocarbons (such as benzene and MTBE), pesticides (such as DBCP, EDB, 1,2,3 TCP), solvents (such as PCE, TCE), and emerging contaminants (such as PFOA, PFOS). Of these issues, nitrate is the most widespread issue with a direct impact on public health. Salinity is also an issue due to the widespread nature of the problem and difficulty of management given increases in salinity as a result of both urban and agricultural use.

The Merced County Department of Public Health, Division of Environmental Health maintains a list of areas of known adverse water quality in the County, shown below in Table 1-1.

Table 1-1: Adverse Groundwater Quality by Area

Region	Parameters
Atwater	Nitrates, DBCP[2], EDB[2], TCE[3] and 1,2,3 TCP[2&3]
Cressey	Nitrates & DBCP
El Nido	Nitrates, Arsenic, Sodium, & TDS[4]
Le Grand	Hard Water[1]
Livingston	Nitrates, Arsenic, DBCP, EDB, TCE and 1,2,3 TCP
McSwain Area	Nitrates, DBCP, EDB, TCE and 1,2,3 TCP
Merced	Nitrates & Hard Water
Planada	DBCP & Hard Water
Stevinson	Arsenic, Sodium, TDS[4], Manganese, Chlorides, Hard Water, & Tannins
Winton	Nitrates, DBCP, EDB, TCE and 1,2,3 TCP

Source: (Merced County Department of Public Health, Division of Environmental Health, 2018)

1 Hard Water = Total hardness > 150 mg/L (mg/L = milligrams per liter = parts per million)
2 Dibromochloropropane (DBCP), Ethylene Dibromide (EDB) and 1,2,3 Trichloropropane (1,2,3 TCP) are soil fumigants, use of DBCP and EDB was banned in 1977.
3 TCE and 1,2,3 TCP are solvent/degreases.
4 TDS refers to the total dissolved solids in water.

General Notes from the Merced County Department of Public Health, Division of Environmental Health:

a. Chlorides, manganese, hard water, iron, tannins, TDS, and sodium in drinking water are, of themselves, not known causes of health problems.
b. The water quality information above refers to private wells in unincorporated areas and does not necessarily apply to the municipal water supply of the towns and cities.

The sections below provide information on the historical and current groundwater quality conditions for constituents grouped by (1) salinity and nutrient constituents (Section 1.1.4.1), (2) metals (Section 1.1.4.2), (3) pesticides (Section 1.1.4.3), and (4) point-source contamination (Section 1.1.4.4), which includes petroleum hydrocarbons, solvents, and emerging contaminants. Salinity and nitrate data from 2008-2018 are described in the section below for each of the Principal Aquifers. Water quality data for the remaining constituents are based on more limited range of data collected 2007-2012, largely without depth, that were analyzed for the 2013 Salt and Nutrient Study as part of the Merced Integrated Regional Water Management (IRWMP). These data limitations have been identified as a data gap, and it is expected that additional water quality monitoring will be developed as part of this GSP which will further inform the understanding of current water quality conditions in the Subbasin, particularly as they pertain to depth and the characterization of the three Principal Aquifers.

1.1.4.1 Salinity and Nutrient Constituents

As part of the comprehensive Salt and Nutrient Management Plan (SNMP) for the Central Valley, developed by the Central Valley Salinity Alternatives for Long Term Sustainability (CV-SALTS) program, detailed water quality analysis was conducted for salinity (represented by total dissolved solids [TDS]) and nitrates measured in wells across multiple agencies from 2000-2016. Supporting documents contain summary information about these constituents by subbasin, including Merced (Luhdorff and Scalmanini Consulting Engineers, 2016). Within the Central Valley, several aquifer zones were established in which to categorize well depths and segregate summary statistics. These zones are summarized below:

- Upper Zone
  - Includes the depth from the bottom of the vadose zone to the top of the Lower Zone
  - Where the Corcoran Clay is present, the Upper Zone does not extend below the Corcoran Clay

- Lower Zone
    - Includes the depth from the bottom of the Upper Zone to the depth of the bottom of the Lower Zone
    - Within the Corcoran Clay area, the Lower Zone is bounded at the bottom by the top of the Corcoran Clay layer
- Production Zone
    - Combination of Upper Zone and Lower Zone
- Lower Part of the Aquifer System (Below the Corcoran Clay)
    - This refers to the groundwater beneath the Corcoran Clay, where present, and groundwater at greater depths than most municipal well depths where the Corcoran Clay is not present

The two subsections below provide more detail and analysis specific to nitrates and salinity.

1.1.4.1.1 Nitrates

Nitrate (NO_3) occurs from both natural and anthropogenic sources and is widespread in groundwater in many parts of the San Joaquin Valley. High nitrate concentrations in groundwater are often associated with the use of fertilizers (commercial/animal waste) and onsite wastewater treatment systems (OWTS or septic systems).

Table 1-2 shows a summary of the number of wells with nitrate results, broken down by CV-SALTS aquifer category and agency type. Nitrate statistical summary information by aquifer category is shown in Table 1-3. Generally, nitrate concentrations were found to be higher, on average, in the Upper Zone than in the Below Corcoran Clay Zone.

Table 1-2: Wells with Nitrate Results (Merced Subbasin)

Aquifer Well Source	Number of Wells	Wells with Construction Information[1]	Wells Without Construction Information[1]
Upper	355	52	303
California Department of Public Health (CDPH)	6	6	0
Domestic	226	0	226
Environmental monitoring (wells)	111	36	75
United States Geological Survey (USGS) (Unknown well type)	12	10	2
Upper and Lower	15	15	0
CDPH	13	13	0
USGS (Unknown well type)	2	2	0
Lower	108	37	71
Agricultural	38	0	38
CDPH	59	34	25
USGS (Unknown well type)	3	3	0
Water supply (wells)	8	0	8
Below Corcoran Clay	191	55	136
Agricultural	109	0	109
CDPH	64	44	20
Environmental monitoring (wells)	4	4	0
USGS (Unknown well type)	7	7	0
Water supply (wells)	7	0	7
Too Deep[2]	1	1	0
CDPH	1	1	0
Total	**670**	**160**	**510**

[1]` Construction information means information is available about the depth(s) of well screens which indicates which aquifer the well is drawing from. With absent well construction information, water quality data is more difficult to interpret.

[2]` Indicates a small number of wells uncharacteristically deep for the region in which they are located.

Source: CV-SALTS (Luhdorff and Scalmanini Consulting Engineers, 2016)

Table 1-3: Average Well Nitrate Concentration (mg/L as N) Statistics (Merced Subbasin)

Aquifer Zone	Number of Wells	Minimum	Average	Median	Maximum
Upper Zone	355	0.10	11.30	5.20	179.61
Upper and Lower Zone	15	0.98	5.26	5.26	12.66
Lower Zone	108	0.23	4.58	3.40	24.60
Below Corcoran Clay Zone	191	0.10	7.52	3.00	71.00

Source: CV-SALTS (Luhdorff and Scalmanini Consulting Engineers, 2016)

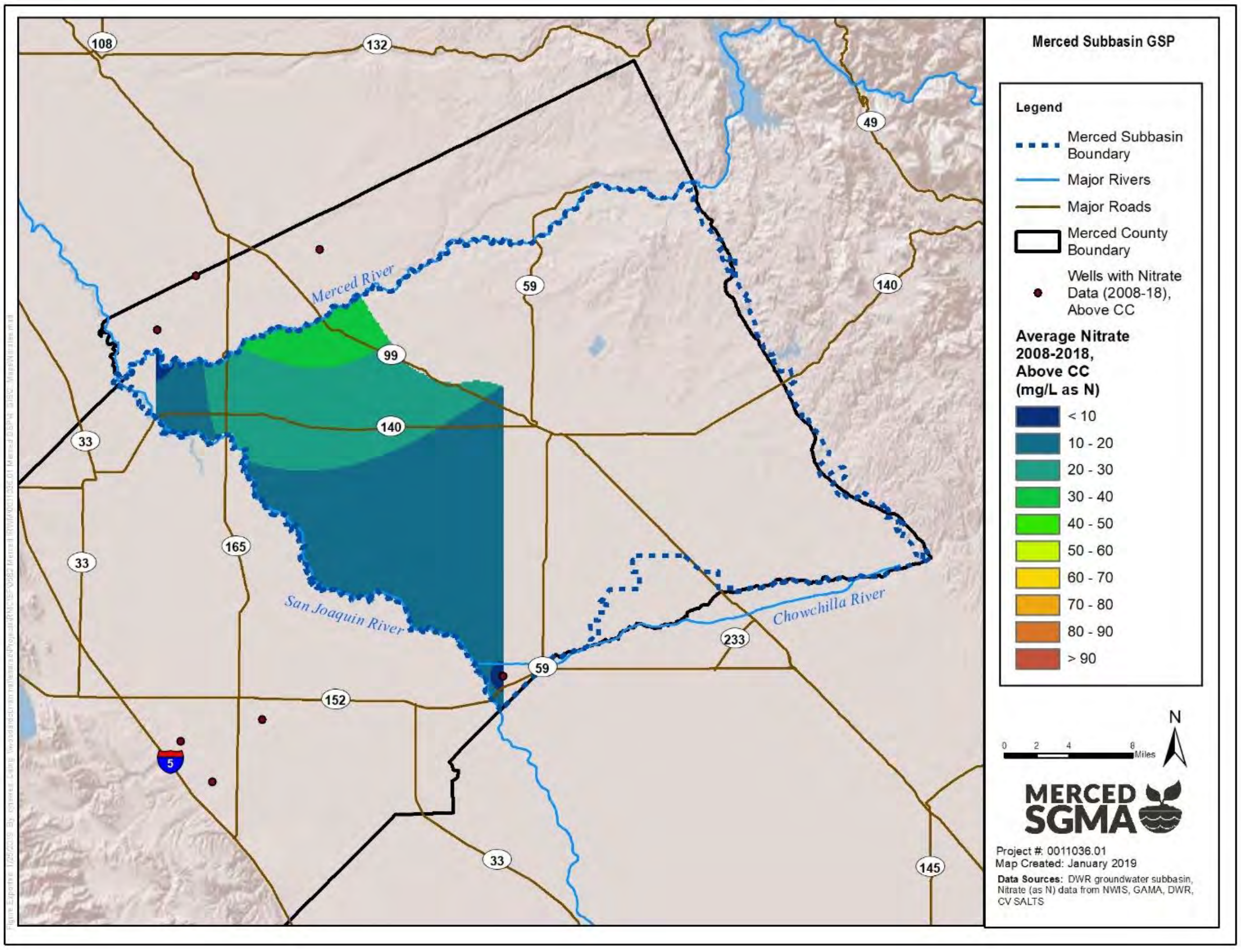
For the purpose of mapping nitrate concentration separately for each principal aquifer, nitrate data was collected from several data sources including National Water Information System (NWIS), Groundwater Ambient Monitoring Assessment (GAMA), DWR, and CV-SALTS. Wells located within the boundary of the extent of the Corcoran Clay were sorted into their respective Above (see Figure 1-18) or Below (see Figure 1-19) Corcoran Clay Principal Aquifer if depth information was available. Wells with nitrate data but without depth information were mapped as "Unknown Aquifer" (see Figure 1-20). Wells located outside of the Corcoran Clay (regardless of availability of depth information) were mapped as Outside Corcoran Clay (see Figure 1-21). Nitrate concentrations at each well were averaged over a period of 2008-2018.

Nitrate data availability for wells with depth information is very limited. For both the Above and Below Corcoran Clay Principal Aquifers, the limited number of data points for 2008-2018 mean that spatial interpolation across the aquifer areas produces results with expected low accuracy.

In the northwest quadrant (Figure 1-20 for Unknown Aquifer), there are several small areas where nitrate concentrations exceed 40 mg/L and several larger areas where nitrate concentrations range from 20 to 40 mg/L. The elevated nitrate concentration in these areas may be associated with animal confinement facilities and other agricultural non-point sources (Amec, 2013). Elevated nitrate in groundwater exists in small areas northeast of Merced and southwest of Atwater among areas where high density OWTS occur (Figure 1-21 for Outside Corcoran Clay). The primary Maximum Contaminant Level (MCL) for nitrate is 45 mg/L (SWRCB, 2018).

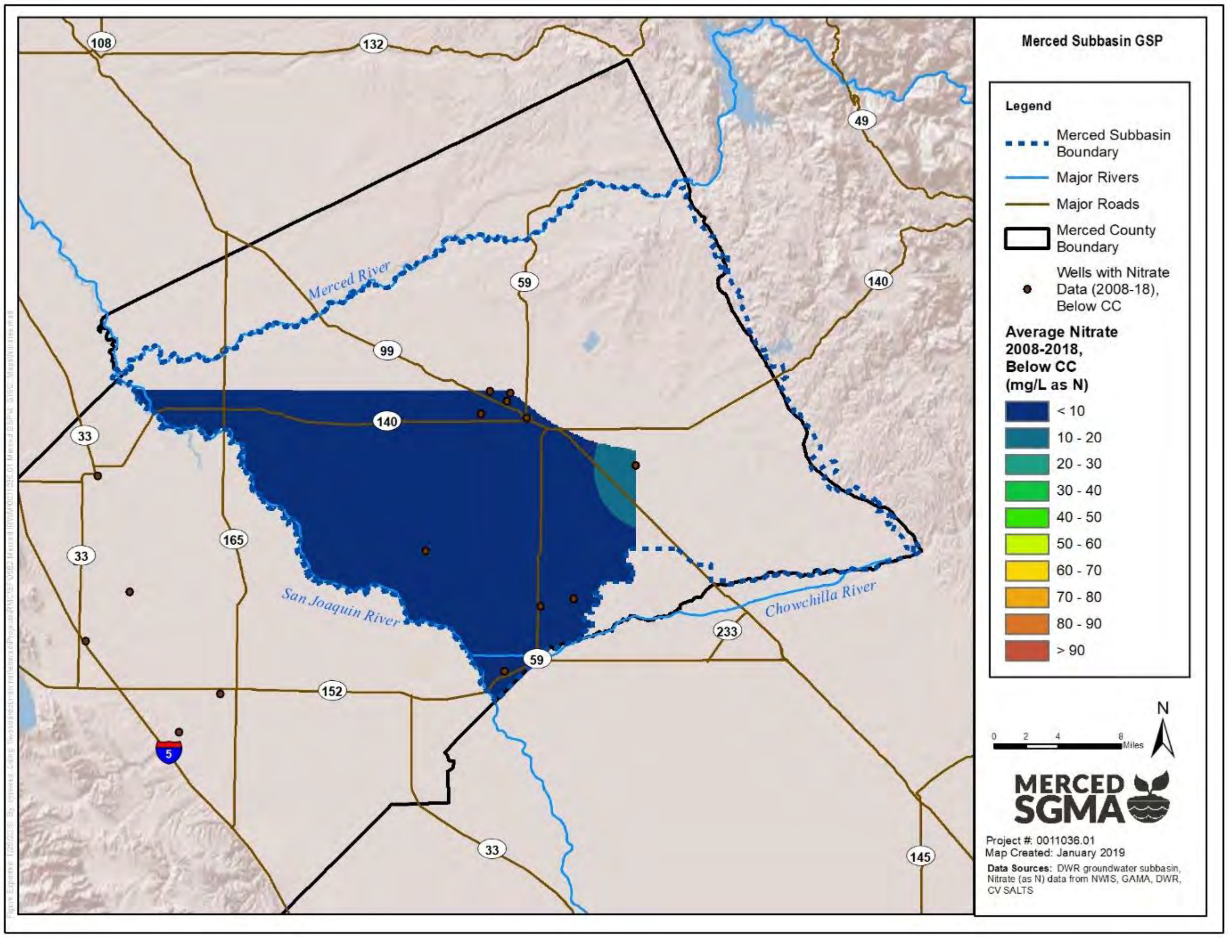
Time concentration plots of Nitrate from 2007-2012 are shown in Appendix #.

Figure 1-18: Average Nitrate (as N) Concentration 2008-2018, Above Corcoran Clay[1]



[1] Nitrate data availability for wells with depth information is very limited. The Above Corcoran Clay Principal Aquifer contains only one confirmed data point for average nitrate 2008-2018 within the Subbasin, meaning that spatial interpolation across the aquifer area produces results with expected low accuracy.

Figure 1-19: Average Nitrate Concentration 2008-2018, Below Corcoran Clay[1]



[1] Nitrate data availability for wells with depth information is very limited. The Below Corcoran Clay Principal Aquifer contains only ten confirmed data points for average nitrate 2008-2018 within the Subbasin, meaning that spatial interpolation across the aquifer area produces results with expected low accuracy.

Figure 1-20: Average Nitrate Concentration 2008-2018, Unknown Aquifer

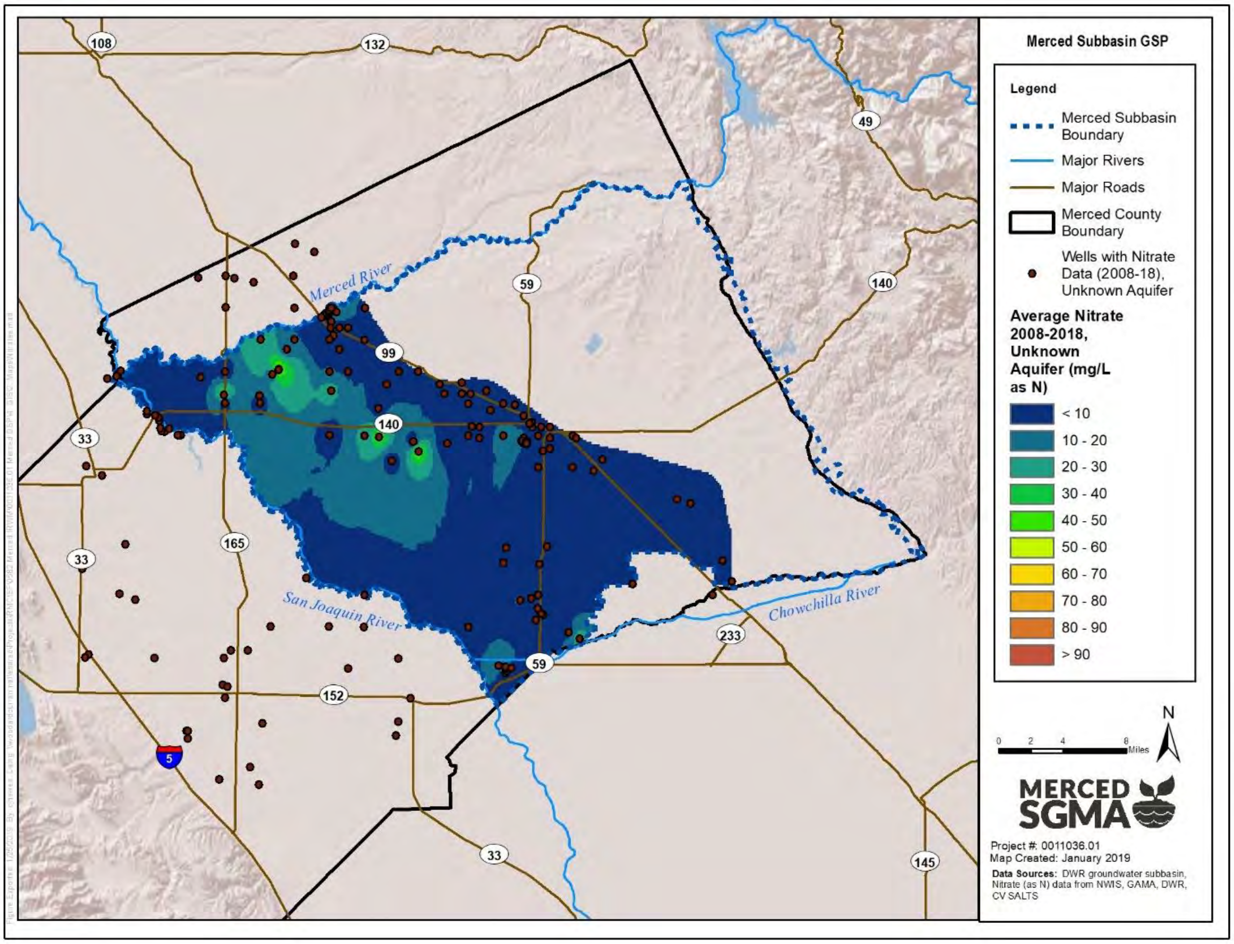
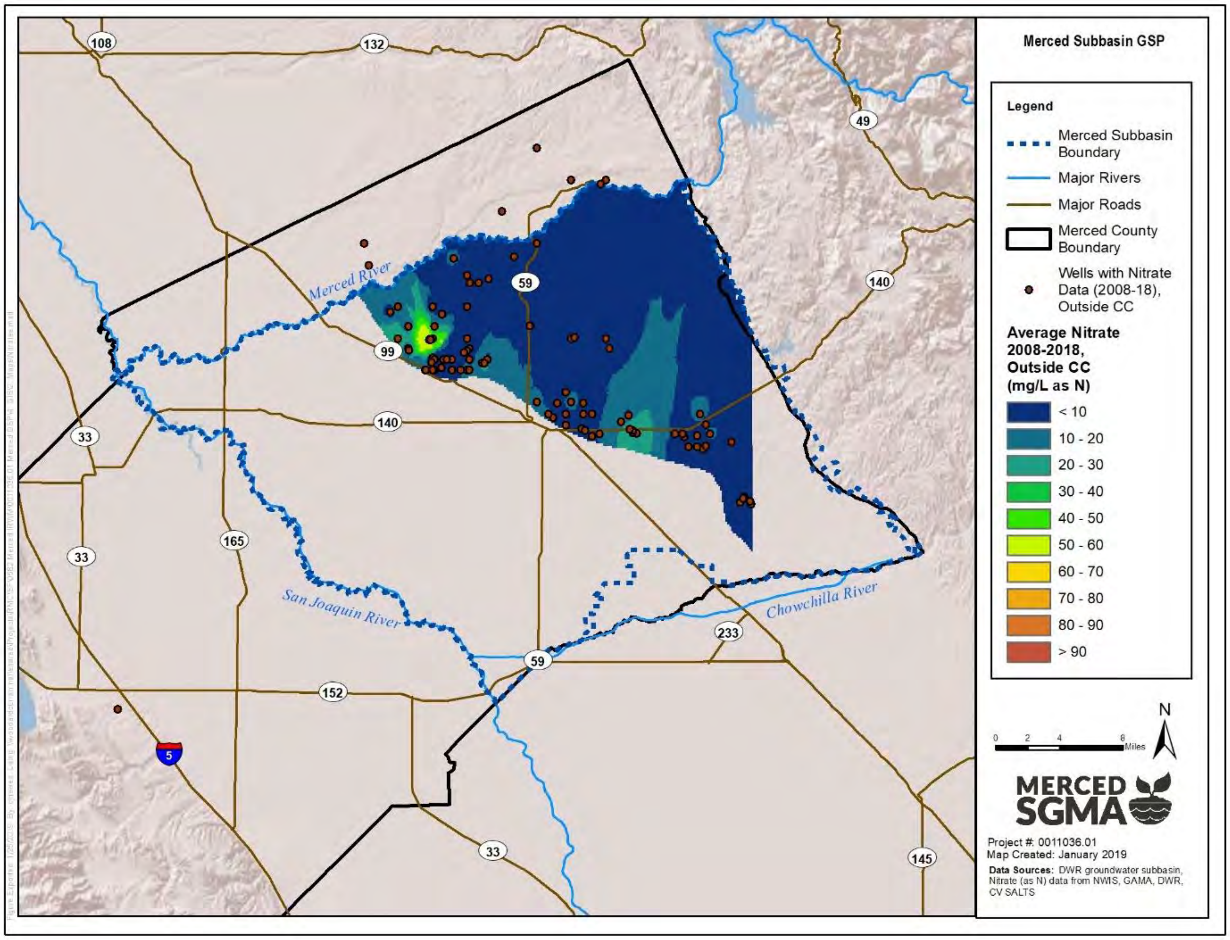


Figure 1-21: Average Nitrate Concentration 2008-2018, Outside Corcoran Clay



1.1.4.1.2 Salinity

Salinity levels within the Merced Subbasin range from less than 90 to greater than 3,000 mg/L as measured by TDS. The recommended drinking water secondary MCL for TDS is 500 mg/L, with an upper limit of 1,000 mg/L and a short-term limit[1] of 1,500 mg/l (SWRCB, 2006). The secondary MCL is established by the USEPA and then adopted by the SWRCB. The secondary MCL is a Secondary Drinking Water Standard that is established for aesthetic reasons such as taste, odor, and color and is not based on public health concerns. For agricultural uses, salt tolerance varies by crop, with common crops within the Merced Subbasin tolerant of irrigated water with TDS below 640 mg/LInvalid source specified.. TDS in the northern portion of the Subbasin is slightly elevated beneath the Atwater and Winton areas. Otherwise, TDS in the eastern two-thirds of the Subbasin is generally less than 400 mg/L. TDS in groundwater increases westward and southwestward towards the San Joaquin River and southward towards the Chowchilla River. In these areas, high TDS water is found in wells deeper than 350 feet (AMEC, 2008).

Better quality groundwater (less than 1,000 mg/L) in these western and southwestern areas is generally found at shallower depths. Groundwater with high TDS concentrations in the Merced Subbasin is principally the result of the migration of a deep water body with relative higher salinity which originates in regionally deposited marine sedimentary

[1] Short-term limits are acceptable only for existing community water systems on a temporary basis pending construction of treatment facilities or development of acceptable new water sources (California Code of Regulations Title 22 § 64449).

rocks that underlie the San Joaquin Valley. The depth of this water body with relative higher salinity within the Merced Subbasin boundaries is very shallow compared to other parts of the San Joaquin Valley (AMEC, 2008).

Groundwater with high concentrations of TDS is present beneath the entire Merced Subbasin at depths from about 400 feet in the west to over 800 feet in the east. The shallowest high TDS groundwater occurs in zones 5 to 6 miles wide adjacent and parallel to the San Joaquin River and the lower part of the Merced River west of Hilmar, where high TDS groundwater is upwelling (AMEC, 2008).

Under natural pressure, the groundwater body of relative higher salinity is migrating upward. Brines move up through permeable sedimentary rocks and also through wells, faults, and fractures. The chemistry of groundwater in the Merced Subbasin indicates that mixing is occurring between the shallow fresh groundwater and the brines, which produces the high TDS groundwater observed. Pumping of deep wells in the western and southern parts of the Merced Subbasin may be causing these saline brines to upwell and mix with fresh water aquifers more rapidly than under natural conditions (AMEC, 2008).

The Corcoran Clay has provided a natural impediment to the migration of high TDS groundwater from the confined aquifer into the unconfined aquifer. High permeability pathways through the clay from the confined to the unconfined aquifer may be created by wells perforated in both the unconfined and confined aquifers (AMEC, 2008).

Table 1-4 shows a summary of the number of wells with TDS results, broken down by CV-SALTS aquifer category and agency type. TDS statistical summary information by aquifer category is shown in Table 1-5. Generally, TDS concentrations were found to average higher in the Upper Zone than the Below Corcoran Clay Zone.

Table 1-4: Wells with TDS Results (Merced Subbasin)

Aquifer Well Source	Number of Wells	Wells with Construction Information[1]	Wells Without Construction Information[1]
Upper	80	39	41
CDPH	4	4	0
Environmental monitoring (wells)	55	20	35
USGS (Unknown well type)	21	15	6
Upper and Lower	13	13	0
CDPH	9	9	0
USGS (Unknown well type)	4	4	0
Lower	62	32	30
CDPH	40	29	11
USGS (Unknown well type)	3	3	0
Water supply (wells)	19	0	19
Below Corcoran Clay	74	49	25
CDPH	48	37	11
USGS (Unknown well type)	12	12	0
Water supply (wells)	14	0	14
Too Deep[2]	2	2	0
CDPH	1	1	0
USGS (Unknown well type)	1	1	0
Total	**231**	**135**	**96**

[1] Construction information means information is available about the depth(s) of well screens which indicates which aquifer the well is drawing from. With absent well construction information, water quality data is more difficult to interpret.

[2] Indicates a small number of wells uncharacteristically deep for the region in which they are located.

Source: CV-SALTS (Luhdorff and Scalmanini Consulting Engineers, 2016)

Table 1-5: Average Well TDS Concentration (mg/L) Statistics (Merced Subbasin)

Aquifer Zone	Number of Wells	Minimum	Average	Median	Maximum
Upper Zone	80	111	498	392	1,951
Upper and Lower Zone	13	125	249	236	354
Lower Zone	62	111	289	211	2,005
Below CC Zone	74	90	268	224	1,035
Below Production Zone	2	246	280	280	314

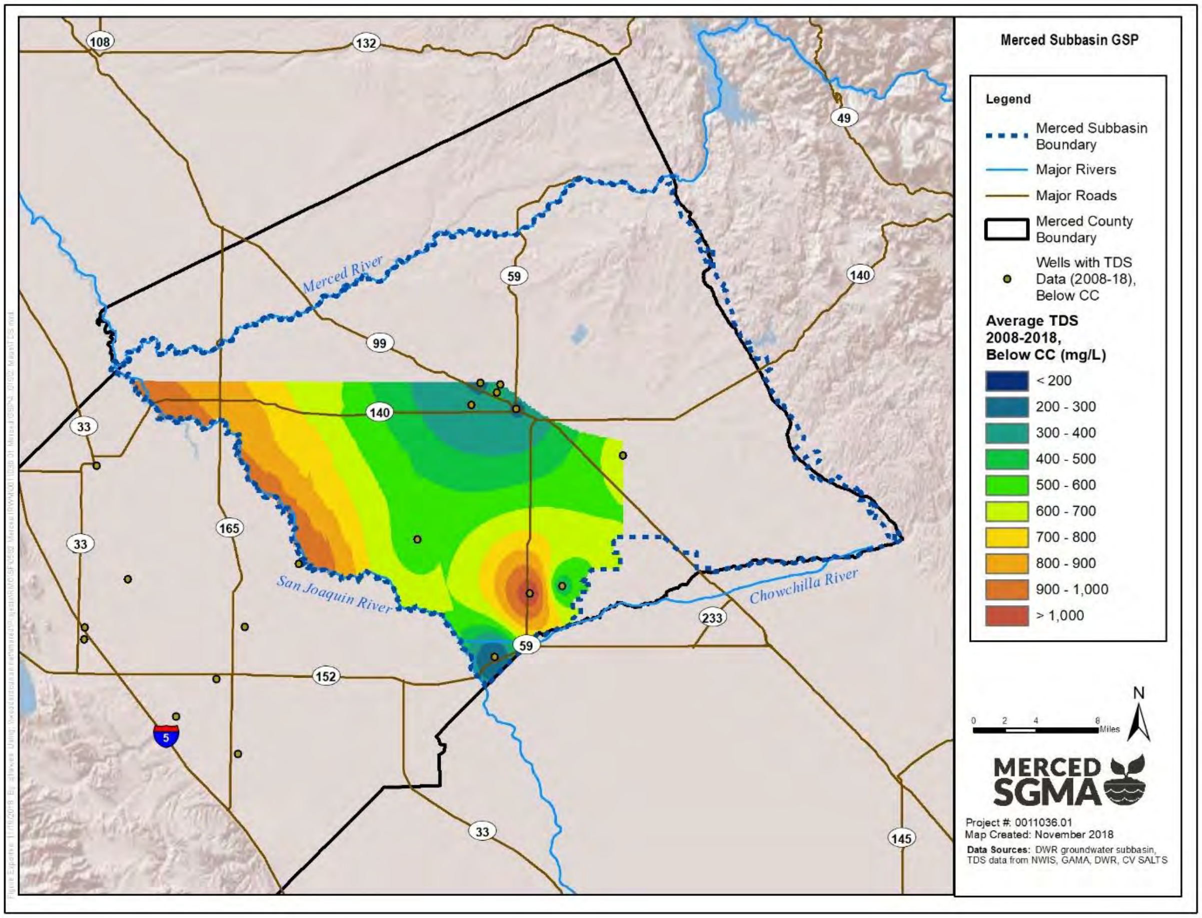
Source: CV-SALTS (Luhdorff and Scalmanini Consulting Engineers, 2016)

For the purpose of mapping TDS concentration separately for each principal aquifer, TDS data was collected from several data sources including NWIS, GAMA, DWR, and CV-SALTS within all of Merced County. Wells located within the boundary of the extent of the Corcoran Clay were sorted into their respective Principal Aquifer. There was only one well with TDS measurements within the Above Corcoran Clay Principal Aquifer (located in the very southern tip of the Subbasin), and so a contour map could not be developed due to lack of data. Wells completed within the Below Corcoran Principal Aquifer are shown in Figure 1-22. Wells with TDS data but without depth information were mapped as “Unknown Aquifer” (see Figure 1-23). Wells located outside of the Corcoran Clay (regardless of availability of depth information) were mapped as Outside Corcoran Clay (see Figure 1-24). TDS concentrations at each well were averaged over a period of 2008-2018.

TDS data availability for wells with depth information is very limited. For both the Above and Below Corcoran Clay Principal Aquifers, the limited number of data points for 2008-2018 mean that spatial interpolation across the aquifer areas produces results with expected low accuracy.

Time concentration plots of TDS from 2007-2012 are shown in Appendix #.

Figure 1-22: Average TDS Concentration 2008-2018, Below Corcoran Clay[1]



1 TDS data availability for wells with depth information is very limited. The Below Corcoran Clay Principal Aquifer contains only ten confirmed data points for average TDS 2008-2018 within the Subbasin, meaning spatial interpolation across the aquifer area produces results with expected low accuracy.

Figure 1-23: Average TDS Concentration 2008-2018, Unknown Aquifer

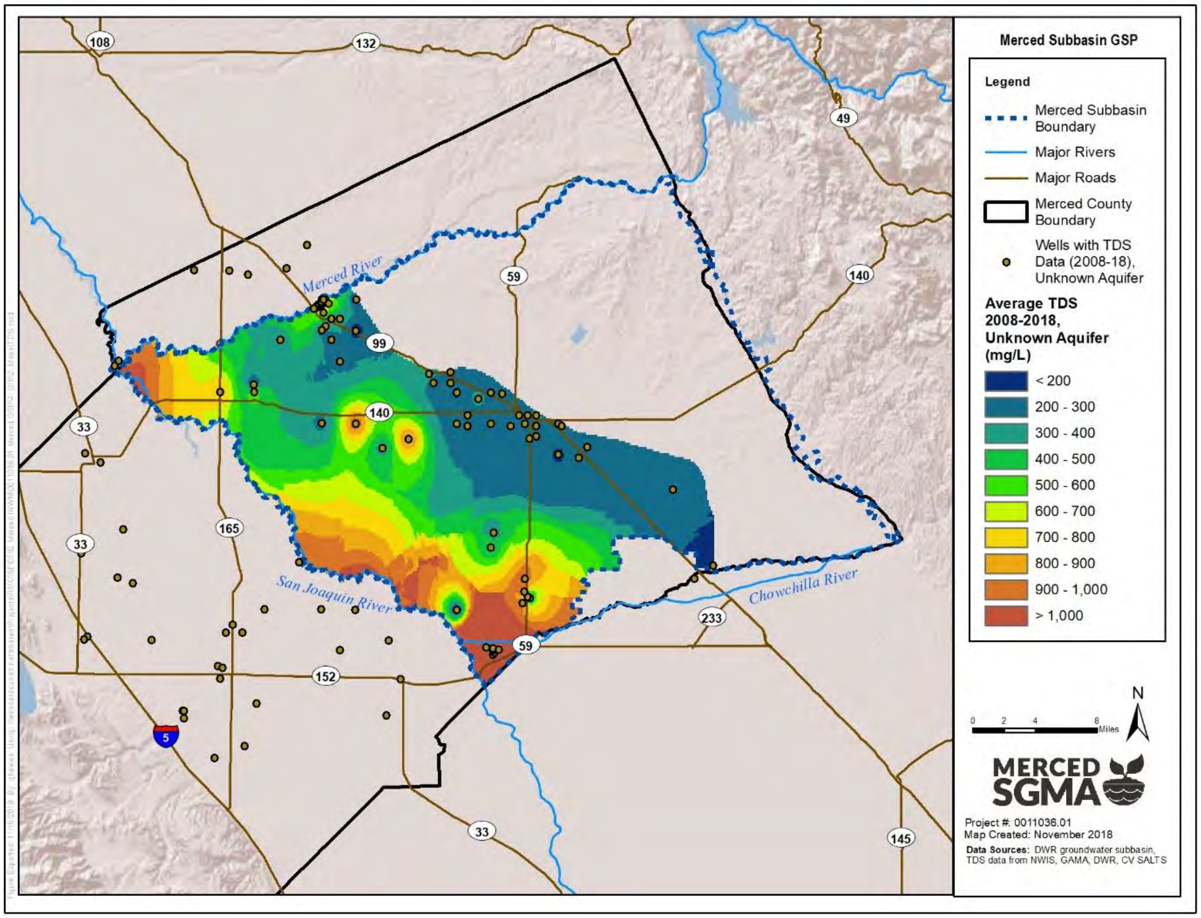
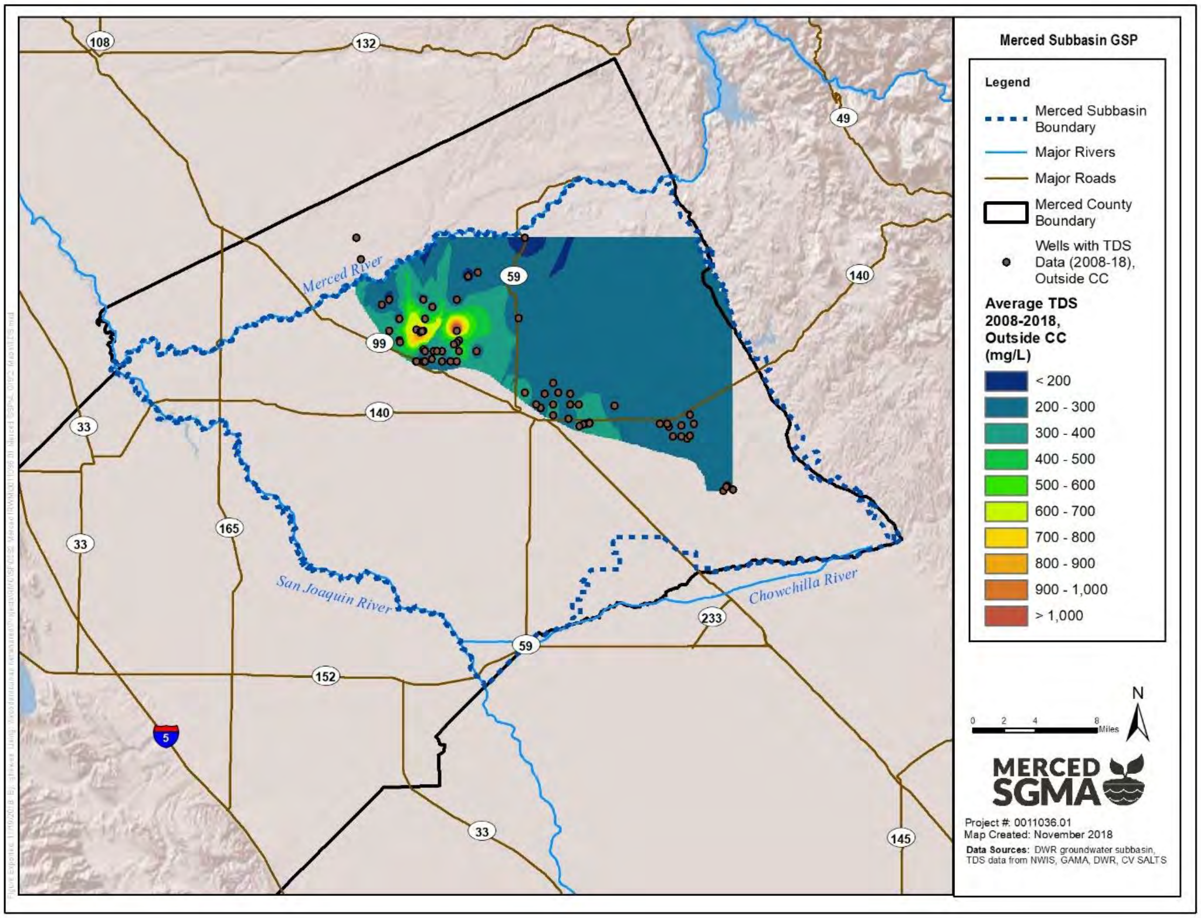


Figure 1-24: Average TDS Concentration 2008-2018, Outside Corcoran Clay

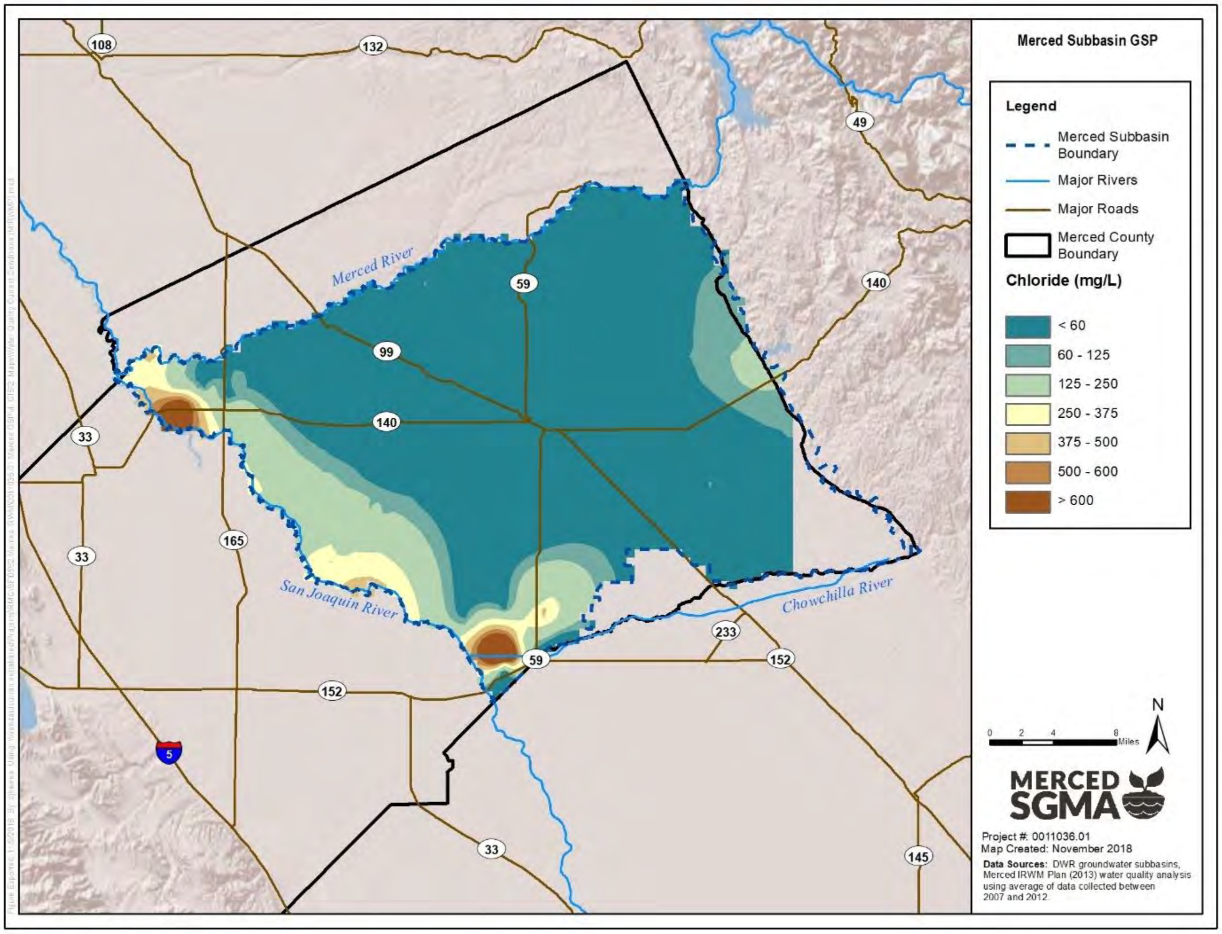


1.1.4.1.3 Chloride

Chloride (Cl) is a dissolved salt commonly associated with saline groundwater. Within the Merced Subbasin area, chloride concentrations range from non-detect (typically less than 2 mg/L) to as much as 1,850 mg/L. The recommended secondary MCL for Cl is 250 mg/L and the upper secondary MCL is 500 mg/L (SWRCB, 2006). The secondary MCL is established by the USEPA and then adopted by the SWRCB. The secondary MCL is a Secondary Drinking Water Standard that is established for aesthetic reasons such as taste, odor, and color and is not based on public health concerns. The 5-year average (2007-2012) Cl concentration in groundwater in the northern two quadrants of the Merced Subbasin area is generally less than 50 mg/L (Figure 1-25). Like TDS, Cl in groundwater increases in the southern quadrants towards the San Joaquin River to as much as 500 mg/L.

Time concentration plots of Cl are shown in Appendix #.

Figure 1-25: 5-Year Average Distribution of Chloride in Groundwater (2012-2017)



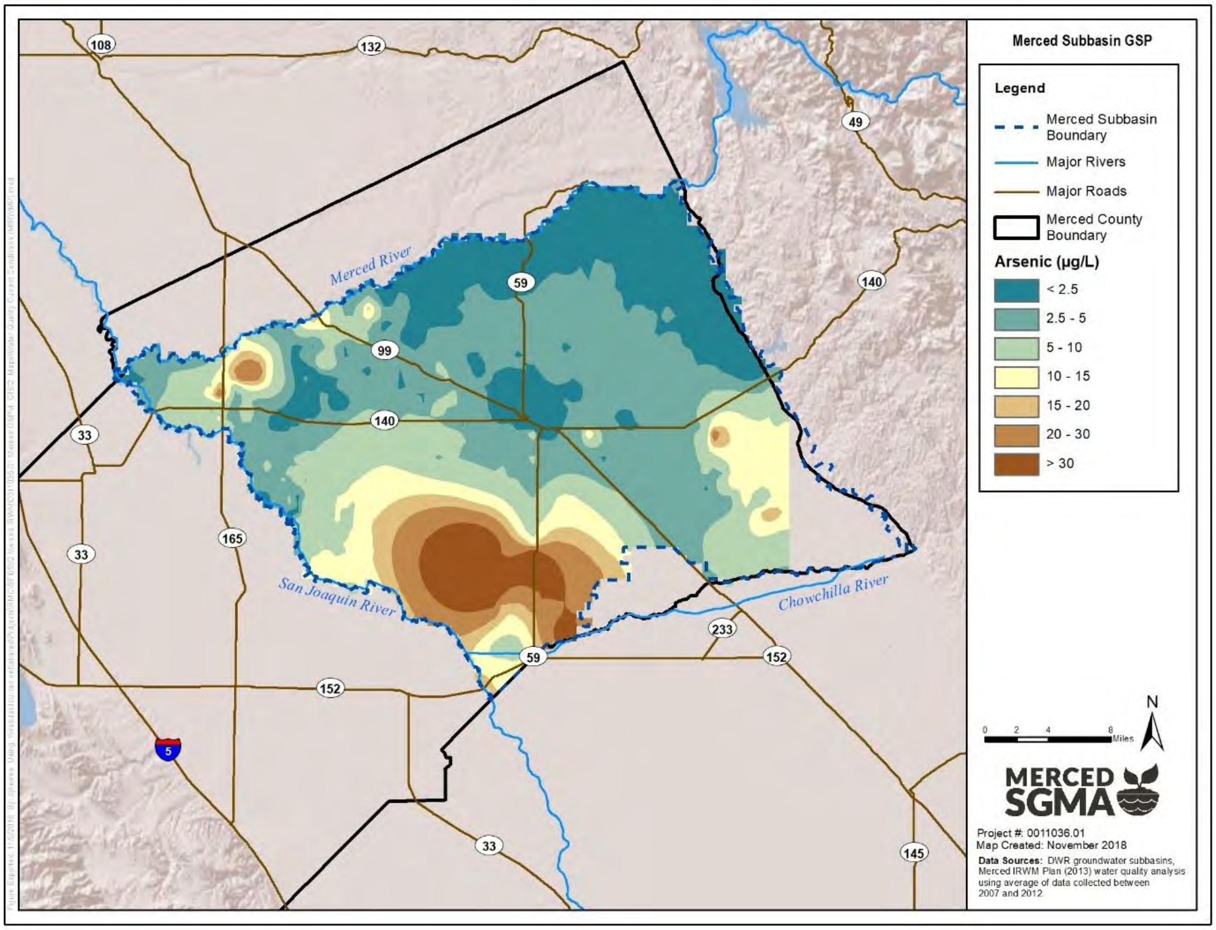
1.1.4.2 Metals

1.1.4.2.1 Arsenic

Arsenic (As) is a dissolved metal found in many bedrock formations which can have human health impacts. Within the Merced Subbasin area, As concentrations range from non-detect (less than 1 microgram per liter [µg/L]) to as much as 800 µg/L. The primary MCL for As is 10 µg/L (SWRCB, 2018). The 5-year average (2007-2012) As concentration in groundwater in the northern two quadrants of the Merced Subbasin area is generally less than 10 µg/l (Figure 1-26). There are localized areas where the average As concentrations in shallow groundwater range between 20 and 50 µg/L northeast of Atwater, near Stevenson, and in the southwest Merced Subbasin area near the intersection of Sandy Mush Road and Highway 59. The City of Livingston also has wells with As levels at or above the MCL. The City has constructed groundwater treatment systems at multiple wells to reduce As concentrations below the MCL (City of Livingston, 2016).

Time concentration plots of As are shown in Appendix #.

Figure 1-26: 5-Year Average Distribution of Arsenic in Groundwater (2007-2012)

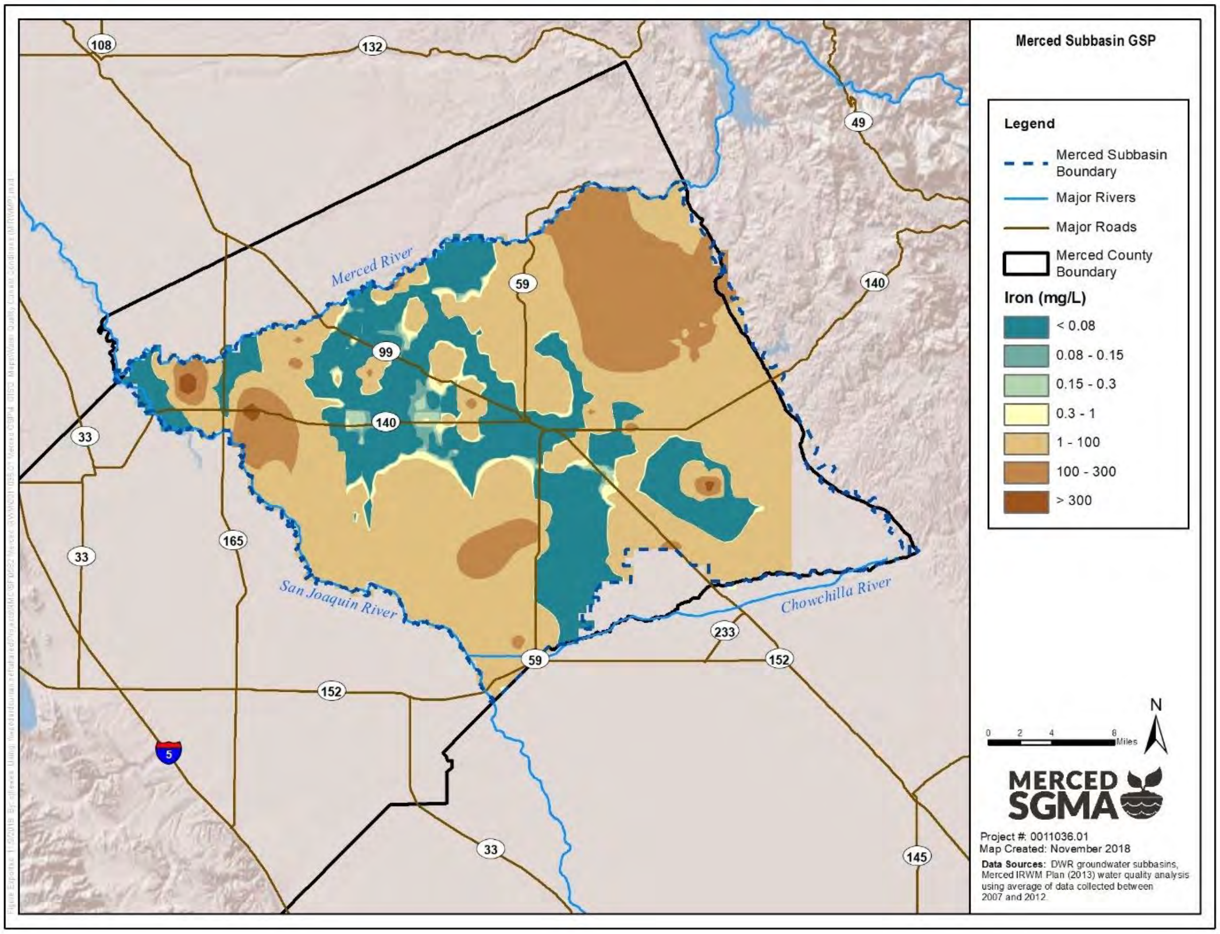


1.1.4.2.2 Iron

Iron (Fe) is a dissolved metal commonly associated with mineralized groundwater. Within the Merced Subbasin area, Fe concentrations range from non-detect (less than 1 mg/L) to as much as 600 mg/L. The secondary MCL for Fe is 0.3 mg/L (SWRCB, 2006). The secondary MCL is established by the USEPA and then adopted by the SWRCB. The secondary MCL is a Secondary Drinking Water Standard that is established for aesthetic reasons such as taste, odor, and color and is not based on public health concerns. The 5-year average (2007-2012) Fe concentration in groundwater in the eastern two quadrants of the Merced Subbasin area ranges from non-detect to over 300 mg/L (Figure 1-27), while the Fe concentration in groundwater in the western two quadrants is generally between 1 and 100 mg/L in most areas. The elevated Fe concentration in the eastern portion of the Merced Subbasin area is a result of leaching of Fe from the subsurface materials in the source area. The Fe in groundwater oxidizes and precipitates as the groundwater moves west towards the San Joaquin River (Amec, 2013).

Time concentration plots of Fe are shown in Appendix #.

Figure 1-27: 5-Year Average Distribution of Iron in Groundwater (2007-2012)

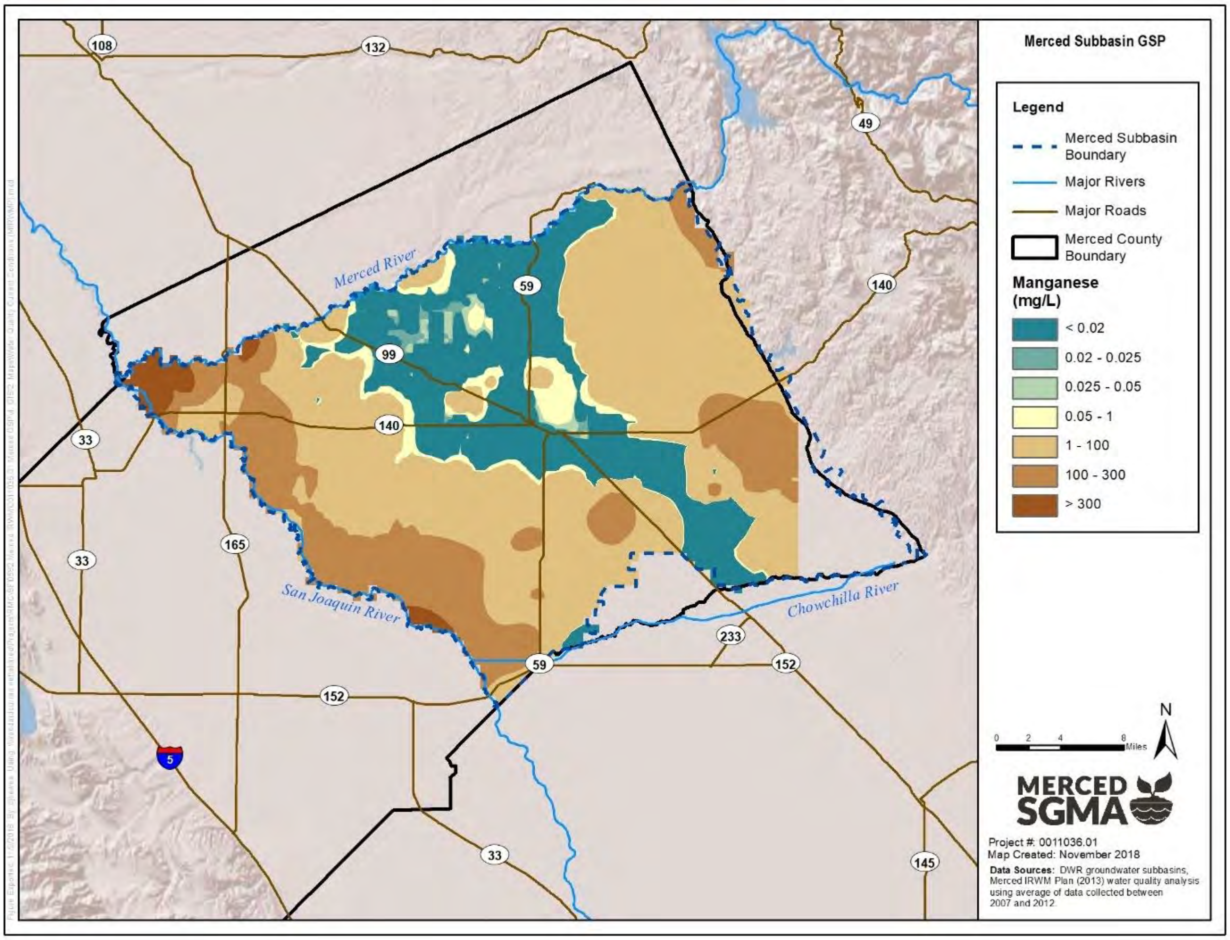


1.1.4.2.3 Manganese

Manganese (Mn) is a dissolved metal commonly associated with mineralized groundwater. Within the Merced Subbasin area, Mn concentrations range from non-detect (less than 1 μg/L) to as much as 1,300 mg/L. The secondary MCL for Mn is 0.05 mg/L (SWRCB, 2006). The 5-year average (2007-2012) Mn concentration in groundwater beneath most of the center of the Subbasin is below 0.05 mg/L, with elevated levels from 0.05 mg/L to over 300 mg/L along the eastern and western portions of the Subbasin (Figure 1-28). Like TDS, the Mn concentration in groundwater increases towards the San Joaquin River to as much as 500 mg/L.

Time concentration plots of Mn are shown in Appendix #.

Figure 1-28: 5-Year Average Distribution of Manganese in Groundwater (2012-2017)

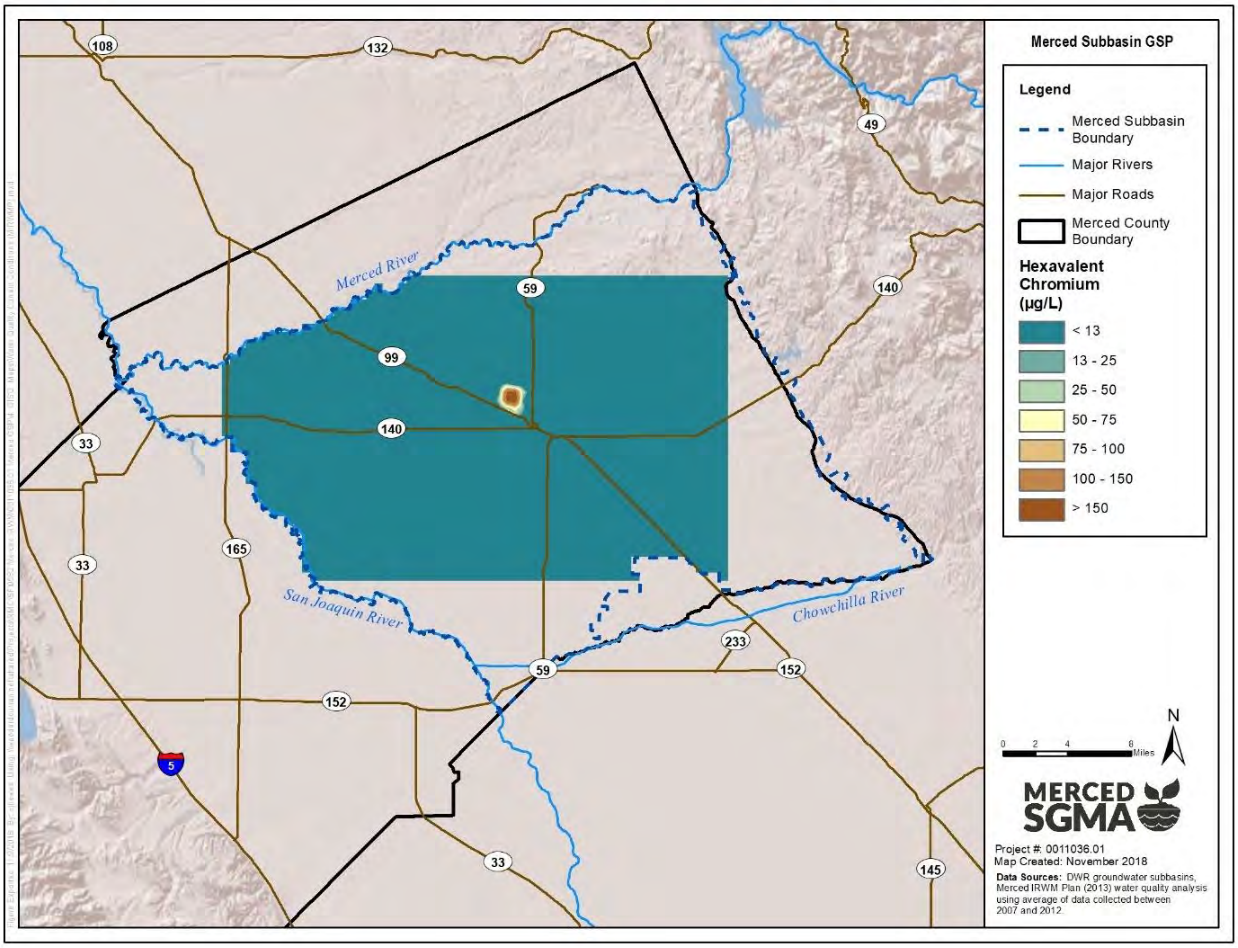


1.1.4.2.4 Hexavalent Chromium

Hexavalent Chromium (Cr^6) is a dissolved metal that rarely occurs naturally and is usually associated with industrial contamination in groundwater. Within the Merced Subbasin area, Cr^6 concentrations range from non-detect (less than 0.01 µg/L) to as much as 370 µg/L. The SWRCB established an MCL for Cr^6 of 10 µg/L in 2014, but it was withdrawn in August 2017 due to a state court ruling. Instead, the SWRCB publishes a Detection Limit for Purposes of Reporting (DLR) of 1 µg/L (SWRCB, 2017). The 5-year average (2007-2012) Cr^6 concentration in groundwater in the Merced Subbasin area is generally less than 1 µg/L, except for a small area of over 100 µg/L in the northwest quadrant (Figure 1-29) due to a point source in the Beachwood subdivision (Central Valley RWQCB, 2011).

Time concentration plots of Cr^6 are shown in Appendix #.

Figure 1-29: 5-Year Average Distribution of Hexavalent Chromium in Groundwater (2012-2017)



1.1.4.3 Pesticides

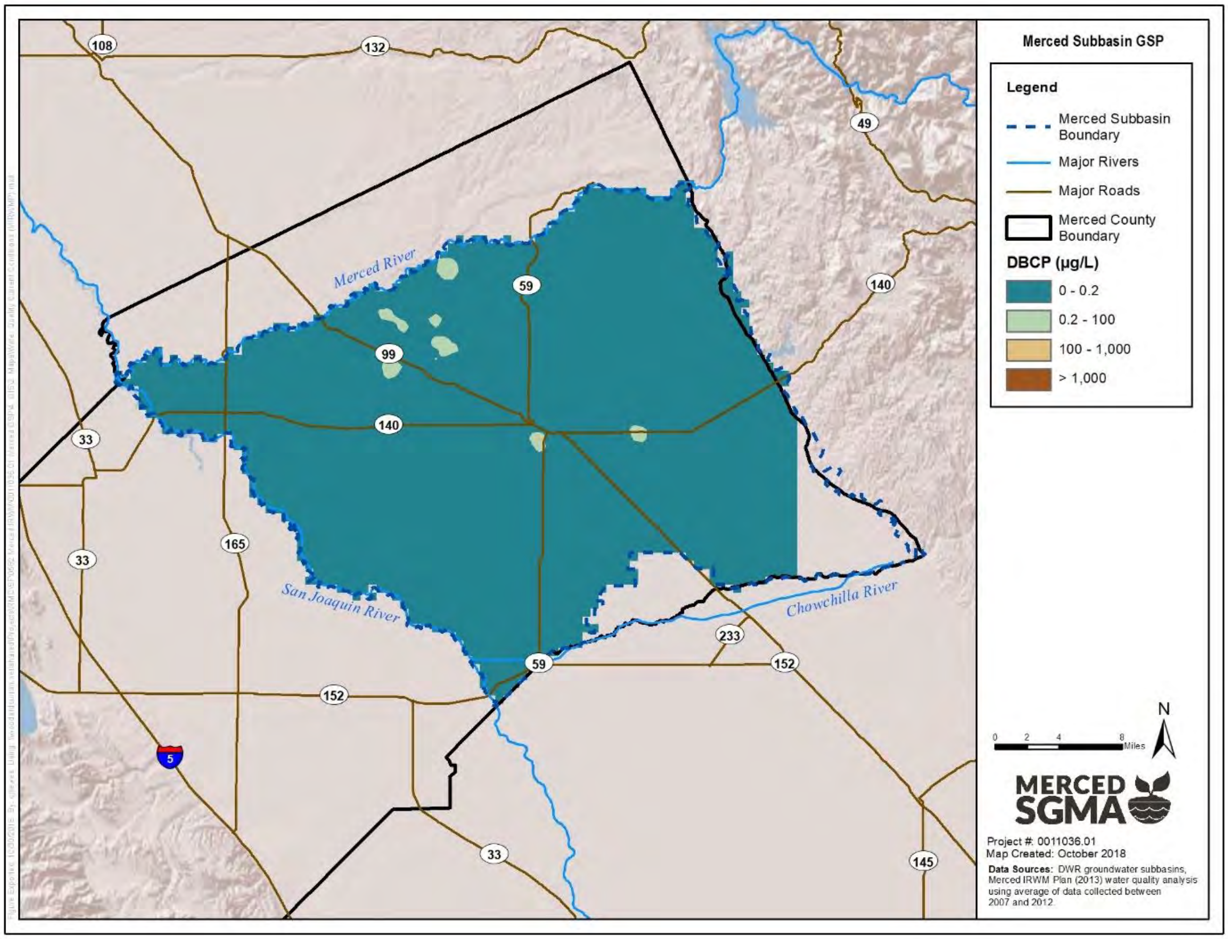
The following information on pesticides includes subsections for Dibromochloropropane (DBCP) and 1,2,3-Trichloropropane (123-TCP).

1.1.4.3.1 Dibromochloropropane (DBCP)

The pesticide DBCP was a common pesticide used to control nematodes in vineyards prior to 1977. DBCP concentrations in groundwater in the Merced Subbasin range from non-detect (variable, but typically 0.2 µg/L) to 335 µg/L. The primary MCL for DBCP is 0.2 µg/L (SWRCB, 2018). The 5-year average (2007-2012) DBCP concentration in groundwater in the Merced Subbasin is generally less than 0.2 µg/L (Figure 1-30), with elevated concentrations found in localized areas near the Cities of Atwater, Delhi, Le Grand, Livingston, Merced, Planada, and Winton.

Time concentration plots of DBCP are shown in Appendix #.

Figure 1-30: 5-Year Average Distribution of DBCP in Groundwater (2012-2017)

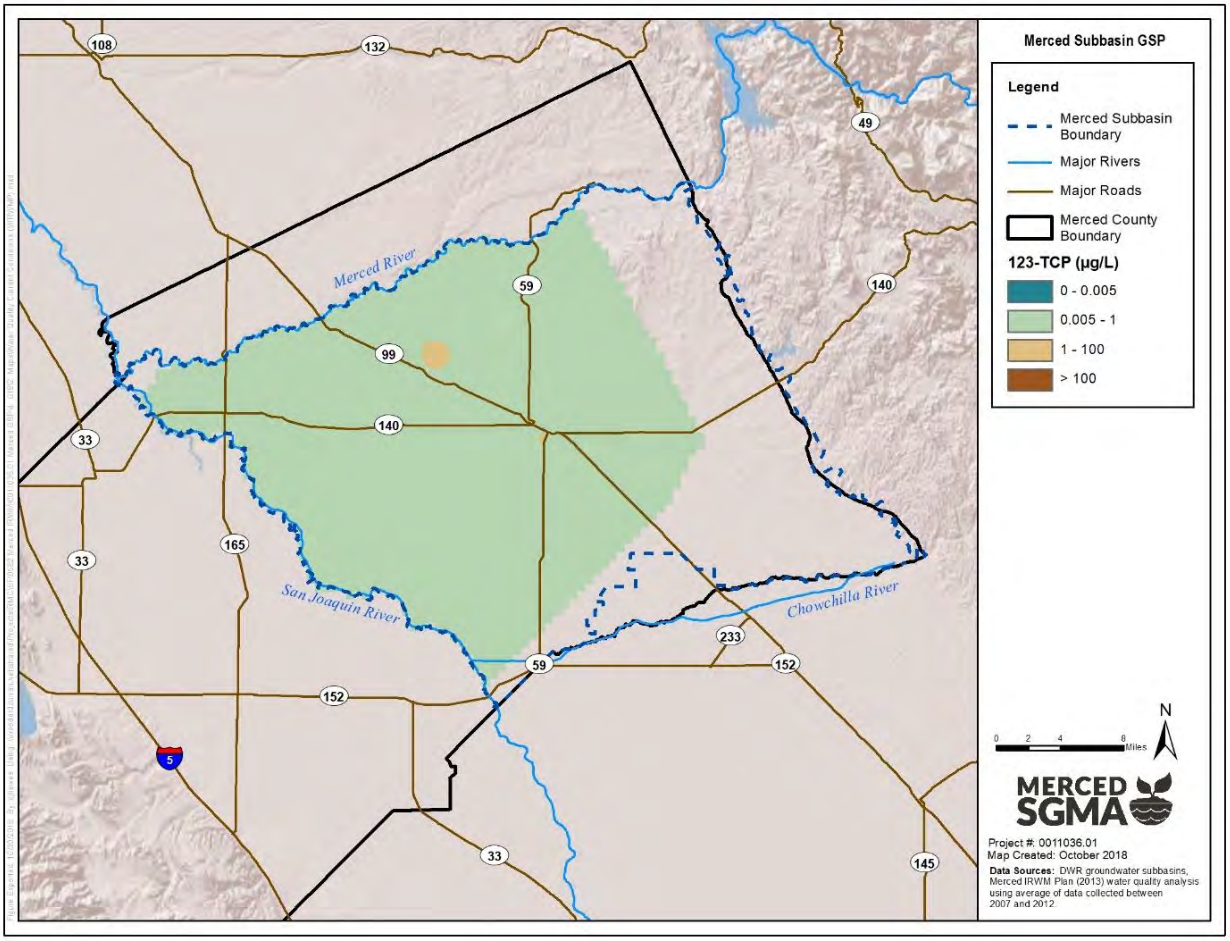


1.1.4.3.2 1,2,3-Trichloropropane (123-TCP)

The volatile organic compound (VOC) 123-TCP is a commonly used solvent in manufacturing facilities and as a carrier solvent for DBCP and other pesticides. 123-TCP concentrations in groundwater in the Merced Subbasin range from non-detect (variable, but typically 0.5 µg/L) to over 300 µg/L. The primary MCL for 123-TCP is 0.000005 µg/L (SWRCB, 2018). The 5-year average (2007-2012) 123-TCP concentration in groundwater in the Merced Subbasin is generally between 0.005 µg/L and 1 µg/L (Figure 1-31), with elevated concentrations found in localized areas in the northwest quadrant and beneath the City of Merced. Note, however, that the typical detection limit of 0.5 µg/L is greater than the 0.000005 µg/L MCL, meaning that non-detects could still indicate MCL exceedances. This indicates better lab analysis is needed for detection of 123-TCP at lower concentrations.

Time concentration plots of 123-TCP are shown in Appendix #.

Figure 1-31: 5-Year Average Distribution of 123-TCP in Groundwater (2012-2017)

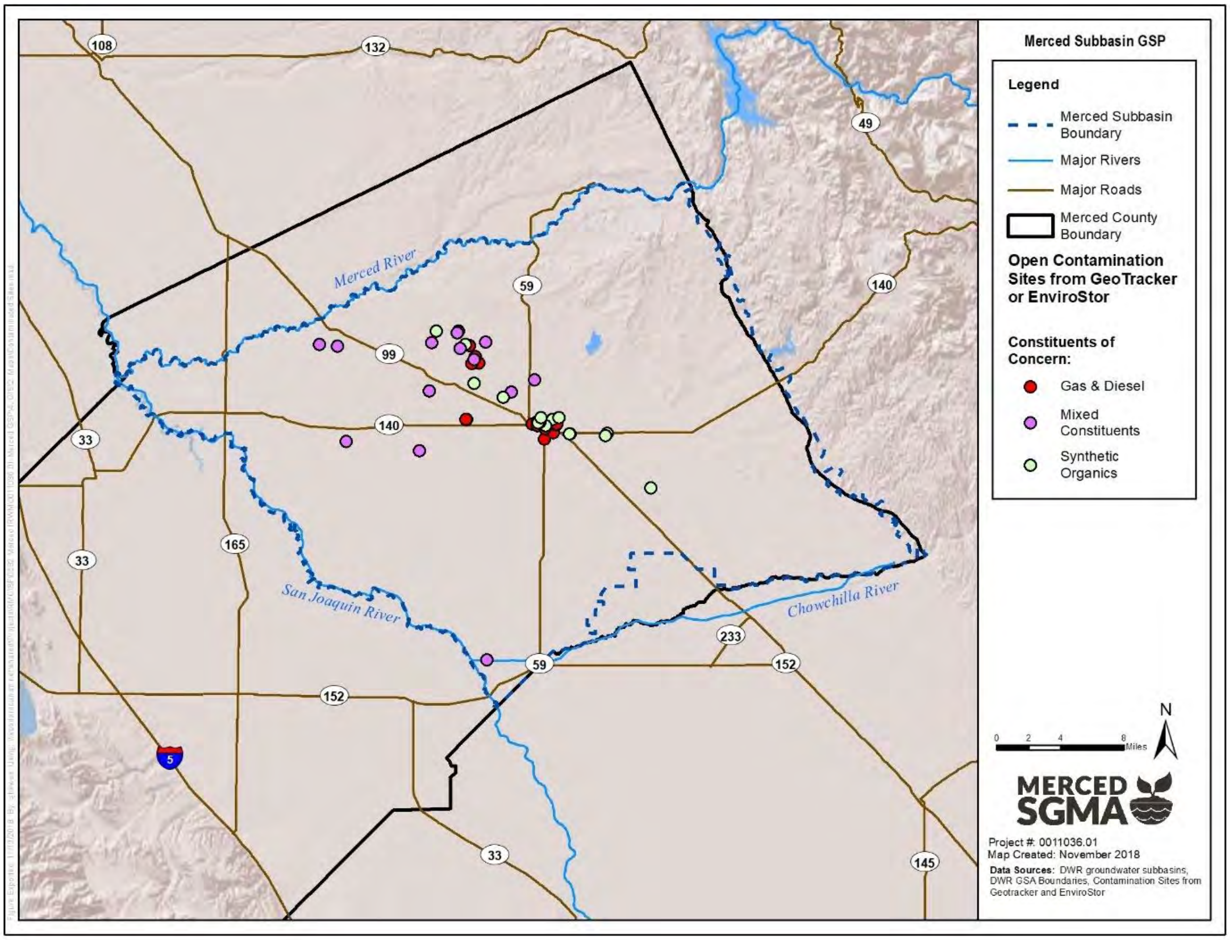


1.1.4.4 Point-Source Contamination

Data collection activities also take place in the Merced Subbasin in response to known or potential sources of groundwater contamination. These sources include areas in and around Castle Air Force Base, leaking underground storage tanks, landfills, and others. Groundwater has been monitored and evaluated at Castle Air Force Base since the 1980s and has resulted in the removal of contaminant sources and the implementation of remedial activities such as the installation of groundwater treatment facilities (SWRCB - GeoTracker).

The Regional Water Quality Control Board's (RWQCB) GeoTracker GAMA database shows 31 open Leaking Underground Storage Tank (LUST) or other cleanup sites with potential or actual groundwater contamination located within the Merced Subbasin. The California Department of Toxic Substances Control (DTSC) EnviroStor database shows 21 additional open cleanup sites with potential or actual groundwater contamination located within the Merced Subbasin. Figure 1-32 shows the location of the combined sites from GAMA and EnviroStor, color-coding the sites based on groupings of constituents of concern: gas and diesel, synthetic organics (pesticides, herbicides, etc.), or mixed constituents (multiple categories, such as heavy metals and pesticides).

Figure 1-32: Contaminated Sites (GeoTracker and EnviroStor)



1.1.4.4.1 Petroleum Hydrocarbons

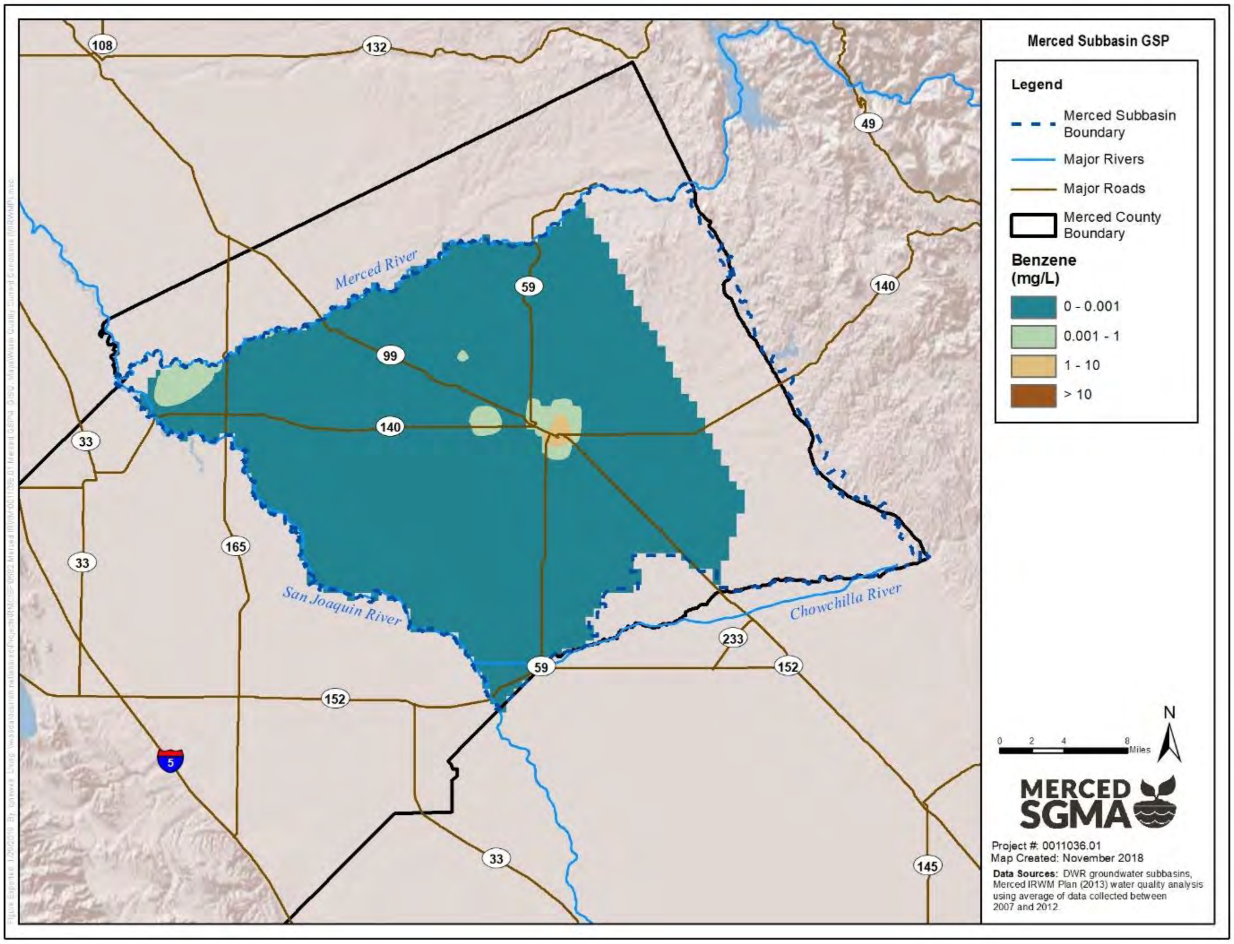
More than 150 unauthorized releases of petroleum hydrocarbons from underground storage tanks have occurred in the Merced Subbasin, according to the SWRCB GeoTracker database. The primary hydrocarbons of concern are benzene and MTBE, both of which are suspected carcinogens.

1.1.4.4.2 Benzene

Benzene concentrations in groundwater in the Merced Subbasin range from non-detect (variable, but typically less than 0.5 mg/L) to greater than 15,000 mg/L (Figure 1-33). The primary MCL for benzene is 0.001 mg/L (SWRCB, 2018). The 5-year average (2007-2012) benzene concentration in groundwater in the Merced Subbasin is generally less than 0.001 mg/L, with elevated concentrations found in localized urban areas along transportation corridors, including Highway 99 and Highway 140.

Time concentration plots of benzene are shown in Appendix #.

Figure 1-33: 5-Year Average Distribution of Benzene in Groundwater (2012-2017)

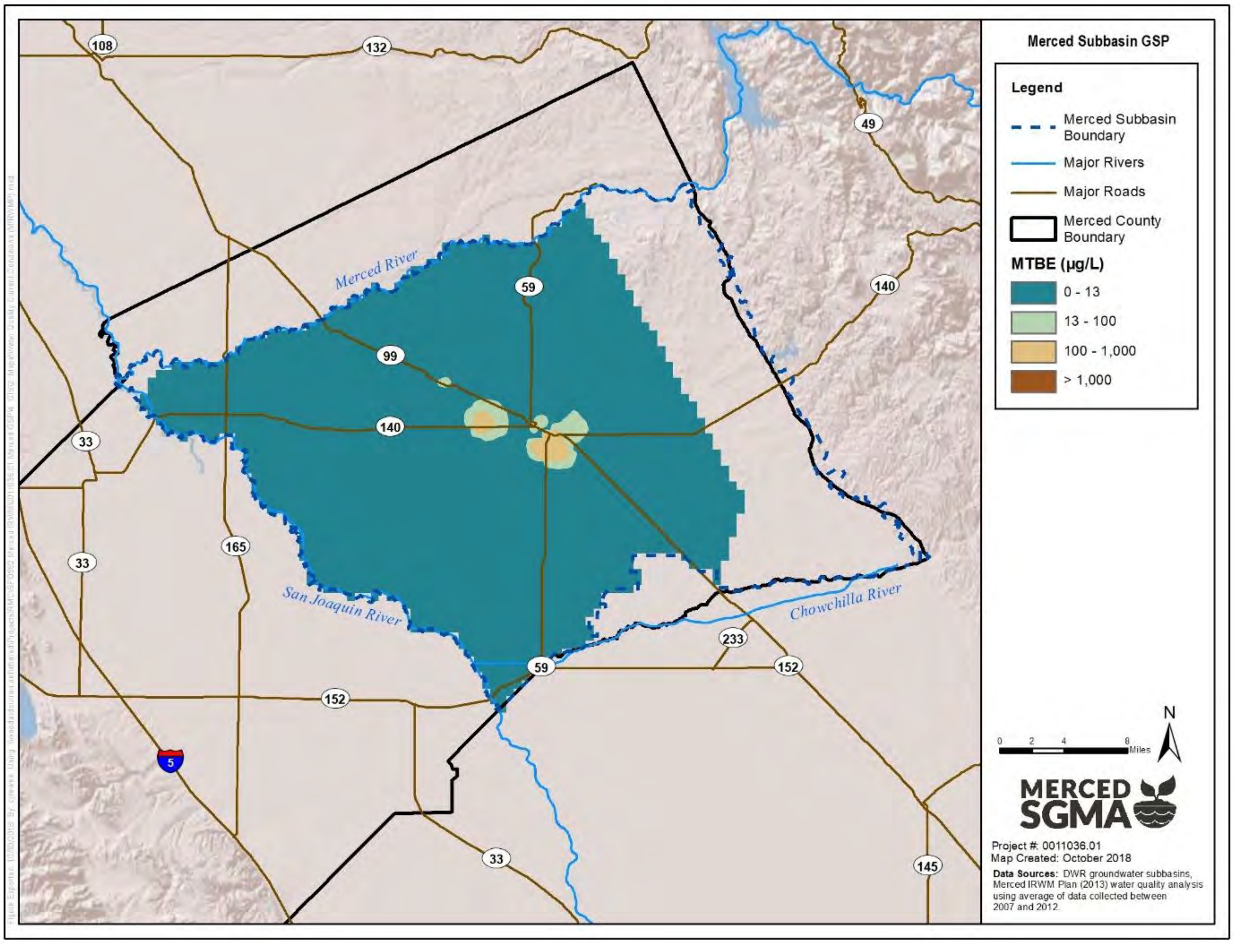


1.1.4.4.3 Methyl Tertiary Butyl Ether (MTBE)

MTBE concentrations in groundwater in the Merced Subbasin range from non-detect (variable, but typically less than 0.2 µg/L) to greater than 440,000 µg/L. The primary MCL for MTBE is 13 µg/L (SWRCB, 2018). The 5-year average (2007-2012) MTBE concentration in groundwater in the Merced Subbasin is generally less than 5 µg/L (Figure 1-34), with elevated concentrations generally found in localized urban areas along Highway 99.

Time concentration plots of MTBE are shown in Appendix #.

Figure 1-34: 5-Year Average Distribution of MTBE in Groundwater (2012-2017)



1.1.4.4.4 Solvents

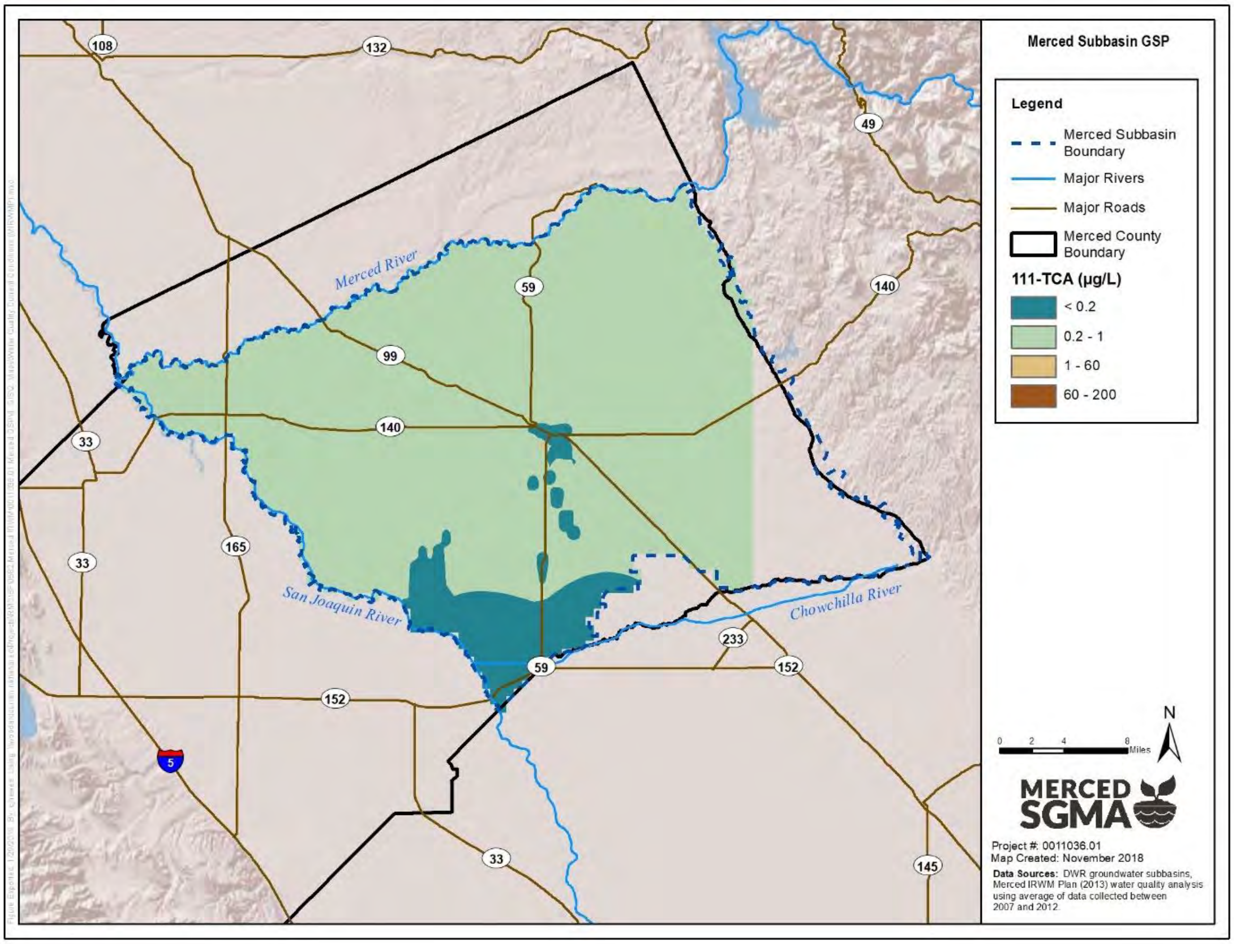
Solvents includes subsections for 1,1,1-Trichloroethane (111-TCA), Tetrachloroethylene (PCE), and Trichloroethylene (TCE).

1.1.4.4.5 1,1,1-Trichloroethane (111-TCA)

The VOC 111-TCA is a commonly used solvent utilized in manufacturing facilities, auto repair shops, and various other uses within the Merced Subbasin. 111-TCA concentrations in groundwater in the Merced Subbasin range from non-detect (variable, but typically 0.2 µg/L) to 60 µg/L. The primary MCL for 111-TCA is 200 µg/L (SWRCB, 2018). The 5-year average (2007-2012) 111-TCA concentration in groundwater in the Merced Subbasin is generally less than 1 µg/L (Figure 1-35).

Time concentration plots of 111-TCA are shown in Appendix #.

Figure 1-35: 5-Year Average Distribution of 111-TCA in Groundwater (2012-2017)

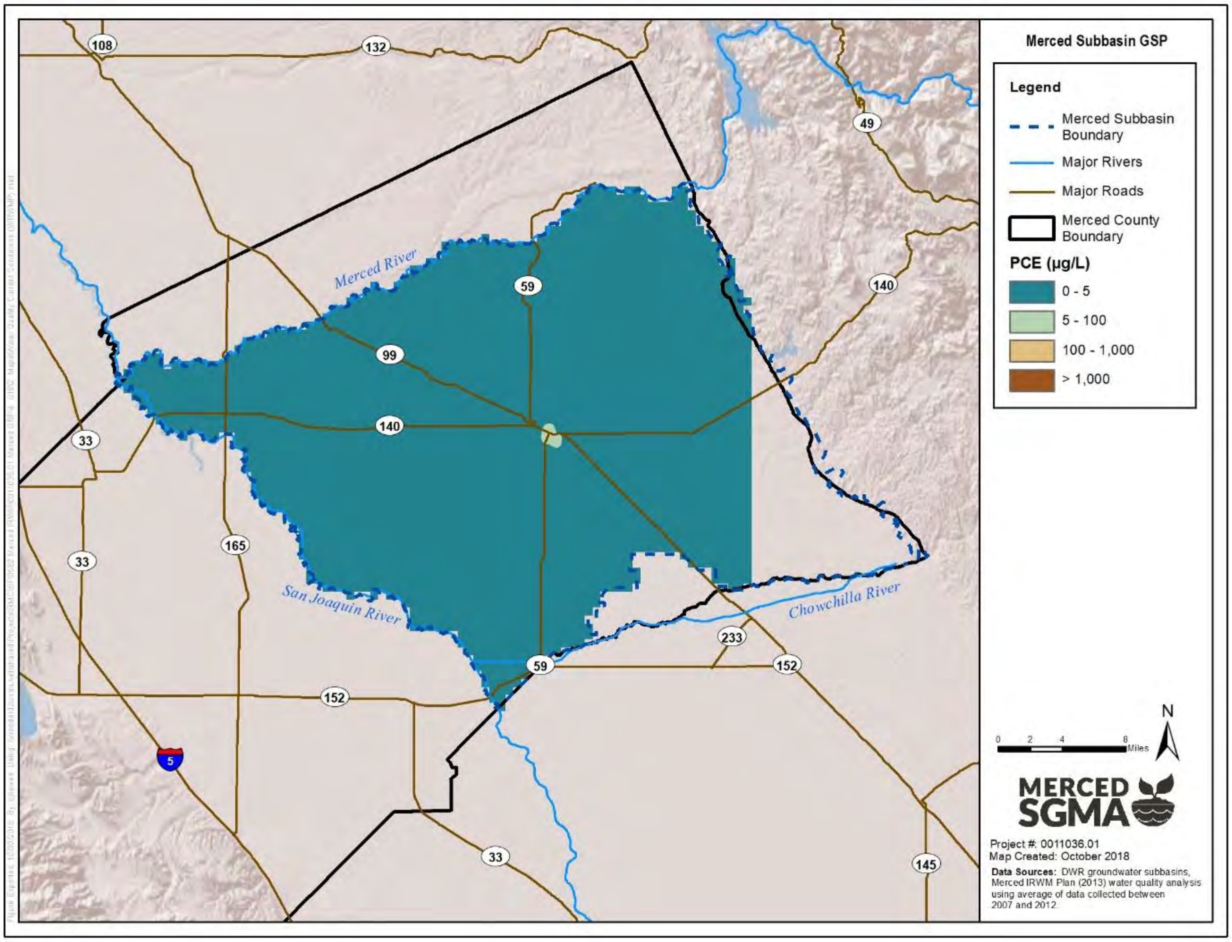


1.1.4.4.6 Tetrachloroethylene (PCE)

The VOC PCE is a commonly used solvent in manufacturing facilities and dry cleaners. PCE concentrations in groundwater in the Merced Subbasin range from non-detect (0.5 µg/L) to over 500 µg/L. The primary MCL for PCE is 5 µg/L (SWRCB, 2018). The 5-year average (2007-2012) PCE concentration in groundwater in the Merced Subbasin is generally less than 5 µg/L (Figure 1-36), with elevated concentrations found in localized areas in the northwest quadrant, beneath the City of Merced.

Time concentration plots of PCE are shown in Appendix #.

Figure 1-36: 5-Year Average Distribution of PCE in Groundwater (2012-2017)

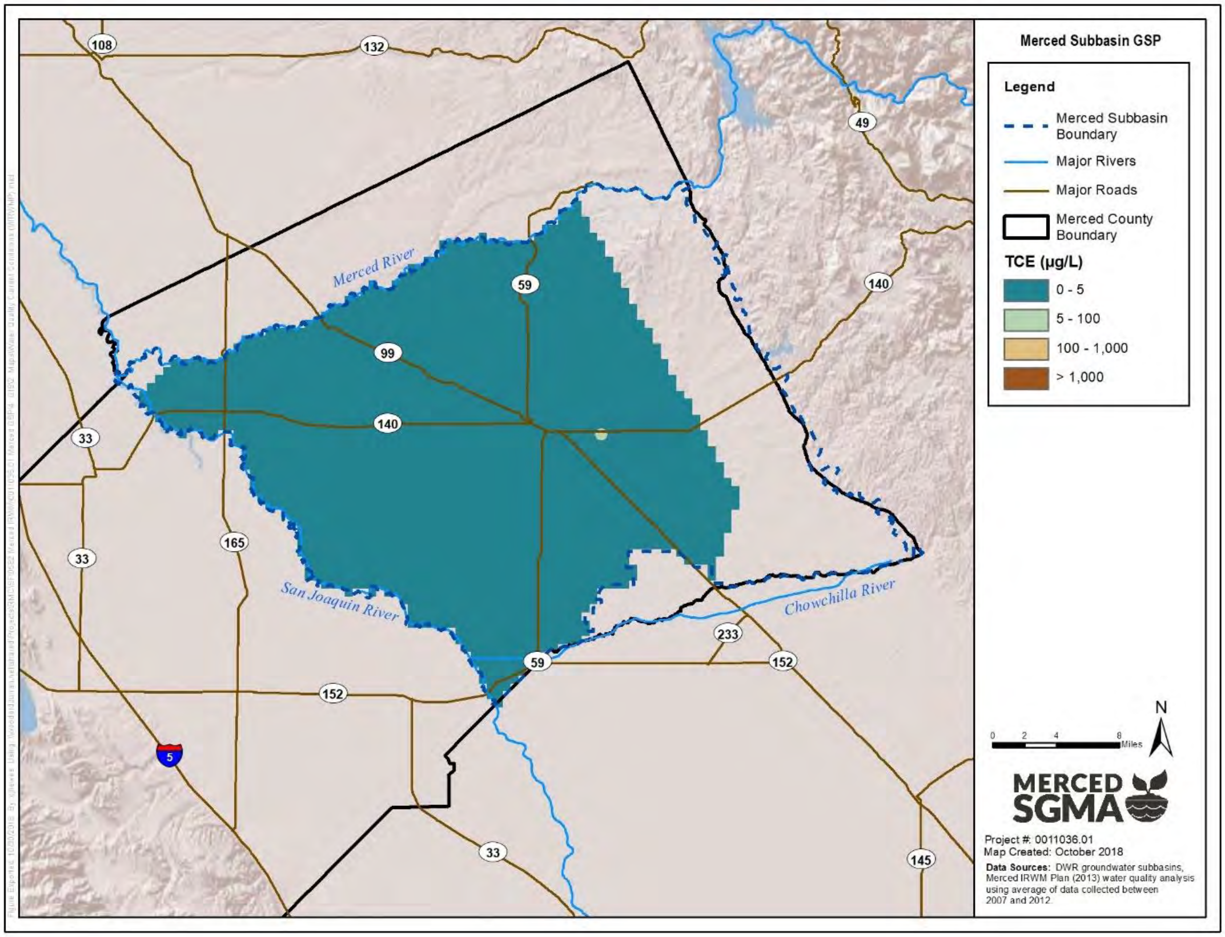


1.1.4.4.7 Trichloroethylene (TCE)

The VOC TCE is a commonly used solvent in manufacturing facilities. TCE concentrations in groundwater in the Merced Subbasin range from non-detect (0.5 µg/L) to over 800 µg/L. The primary MCL for TCE is 5 µg/L (SWRCB, 2018). The 5-year average (2007-2012) TCE concentration in groundwater in the Merced Subbasin is generally less than 5 µg/L (Figure 1-37). While not shown directly in the figure, the Merced IRWMP indicates that elevated concentrations can be found in localized areas in the northwest quadrant and along Highway 140 beneath a point source (RMC Water and Environment, 2013).

Time concentration plots of TCE are shown in Appendix #.

Figure 1-37: 5-Year Average Distribution of TCE in Groundwater (2012-2017)



1.1.4.4.8 Emerging Contaminants

Many chemical and microbial constituents that have not historically been considered as contaminants are occasionally, and in some cases with increasing frequency, detected in groundwater. These newly recognized (or emerging) contaminants are commonly derived from municipal, agricultural, industrial wastewater, and domestic wastewater sources and pathways. These newly recognized contaminants are dispersed to the environment from domestic, commercial, and industrial uses of common household products and include caffeine, artificial sweeteners, pharmaceuticals, cleaning products, and other personal care products. Residual waste products of genetically modified organisms are also of potential concern. A recently completed survey for pharmaceuticals at dairies in the Merced Subbasin area by UC Davis and the USGS detected pharmaceuticals in shallow groundwater (Watanabe, Harter, and Bergamaschi, 2008 as cited by (Amec, 2013)).

Perfluorooctanesulfonic acid (PFOS) and perfluorooctantoic acid (PFOA) are organic chemicals synthesized for water and lipid resistance, used in a wide variety of consumer products as well as fire-retarding foam and various industrial processes. These chemicals tend to accumulate in groundwater, though typically in a localized area in association with a specific facility, such as a factory or airfield (California Water Boards, 2018). There are currently no MCLs for PFOS or PFOA.

Currently, data on PFOS and PFOA is limited in the Merced Subbasin since these are emerging contaminants. However, according to the Geotracker database, both PFOA and PFOS have been detected at the Castle Air Force

Base military cleanup sites. In 2004, USEPA and the State of California concurred that the Air Force was suitably implementing plume capture and cleanup which is still underway (SWRCB - GeoTracker).

1.1.5 Land Subsidence

Land subsidence is a significant issue in the southwestern portion of the Subbasin and in the neighboring Delta-Mendota and Chowchilla Subbasins. While there are no extensometers in the area to provide data on the depths at which compaction is occurring, the subsidence is thought to be caused by groundwater extraction below the Corcoran Clay and compaction of clays below the Corcoran Clay (DWR, 2017).

The transition from pasture or fallowed land to row and permanent crops adjacent to the San Joaquin River is thought to have created an increased groundwater pumping demand in an area that is not, at this time, serviced by an irrigation district or alternate surface water supply (Reclamation, 2016). This demand is thought to have resulted in recent increases in land subsidence along the river. The subsidence poses difficulties for local, state, and federal agencies with existing or planned infrastructure in the area (Reclamation, 2016).

Subsidence rates are variable, and highest during the drought period. Annual subsidence averaged up to 0.45 feet per year from December 2011 to December 2017, as shown in Figure 1-38 based on data from USBR's San Joaquin River Restoration Program (SJRRP) (see description of program in SECTION X). This relatively long period averages years of drought and years of normal or wet precipitation. Noting that these measurements incorporate both elastic and inelastic subsidence, the highest maximum annual rate of subsidence reported in Reclamation's regular mapping program was -0.67 feet per year, seen from December 2012 to December 2013 (see Figure 1-39), closely followed by -0.65 feet per year from December 2014 to December 2015. The lowest maximum annual rate of subsidence reported in Reclamation's regular mapping program was -0.18 feet per year, seen from December 2016 to December 2017 (see Figure 1-40).

Figure 1-38: Average Land Subsidence December 2011 – December 2017

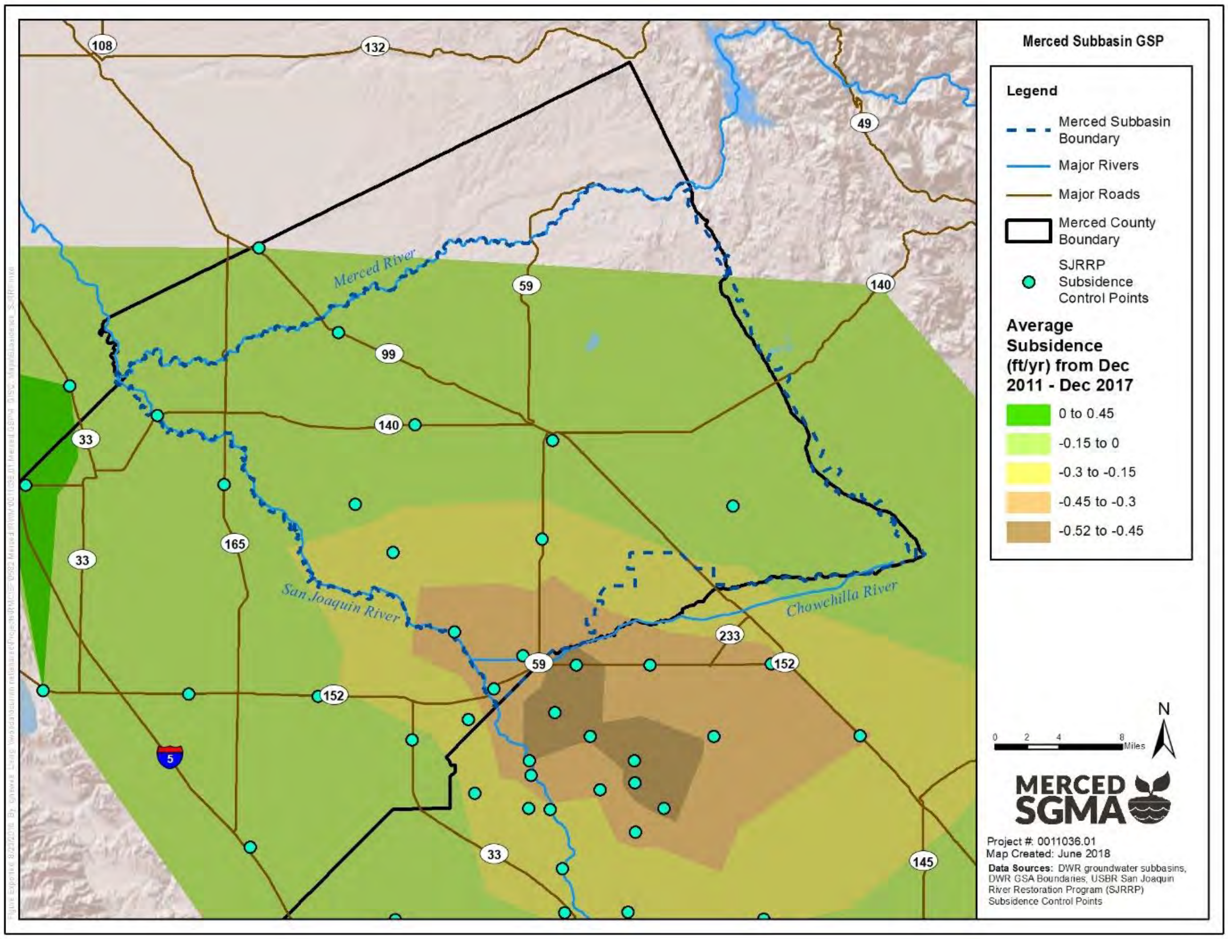


Figure 1-39: Land Subsidence December 2012 – December 2013

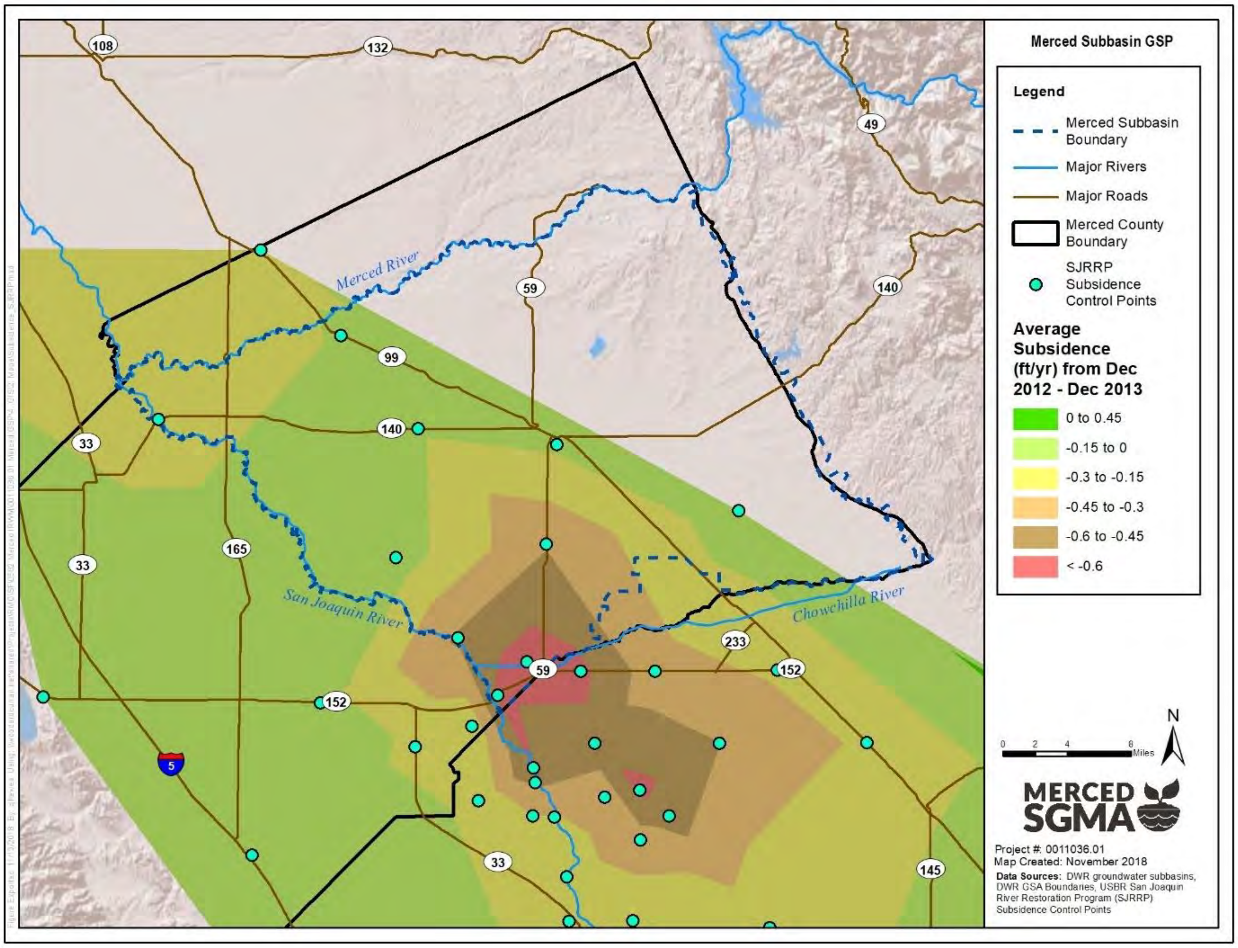
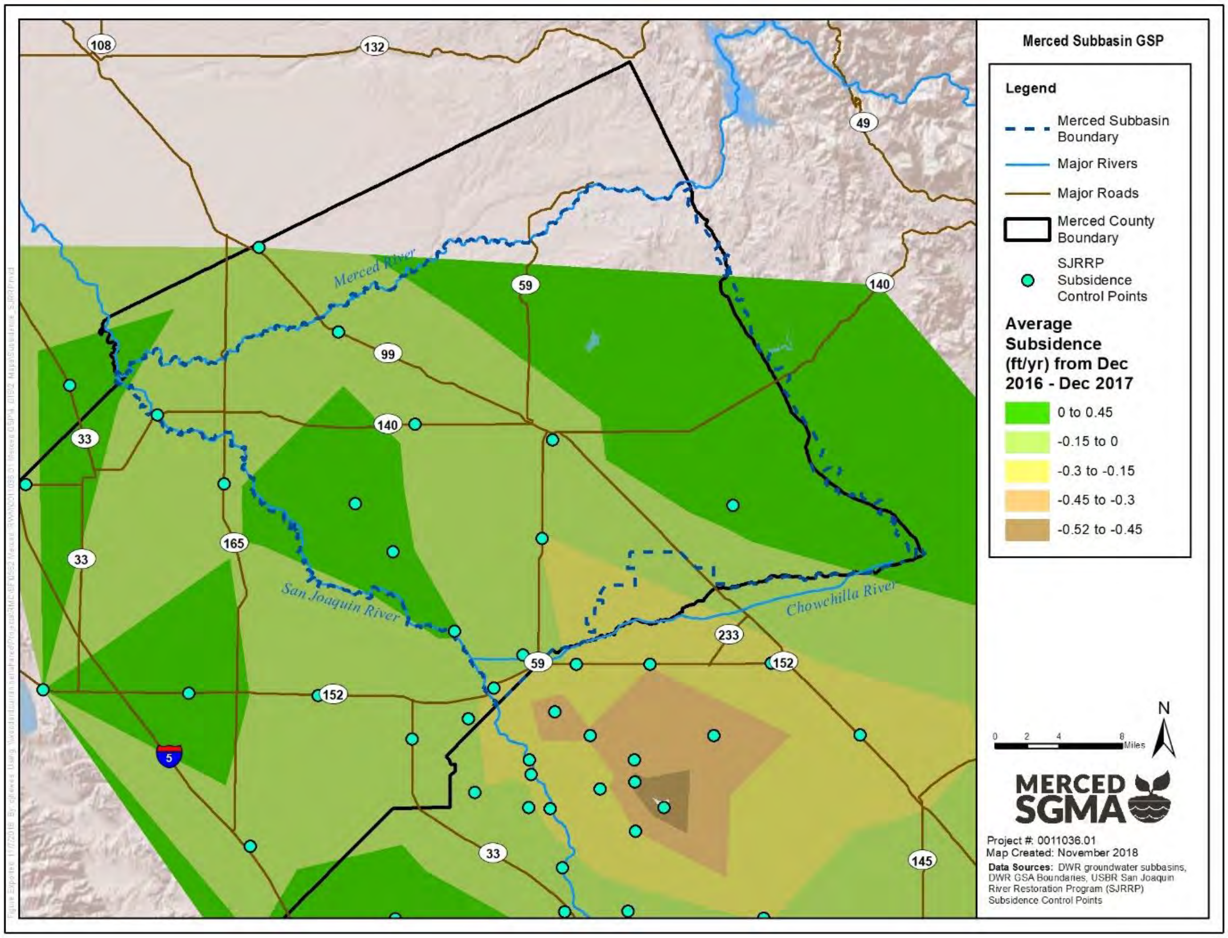


Figure 1-40: Land Subsidence December 2016 – December 2017



Subsidence in the southern corner of the Subbasin was compared against groundwater levels measured in the Below Corcoran Clay principal aquifer. Subsidence locations and historical land surface elevations measurements were obtained from two control points in the San Joaquin River Restoration Program. Historical groundwater elevations were obtained from two wells in the CASGEM program. Figure 1-41 shows a map of the four locations.

Figure 1-42 shows that at SJRRP point 156, subsidence has continued at a relatively steady pace from December 2011 until December 2016 where the decline in land surface elevation paused between December 2016 and December and 2017. At CASGEM well 371130N1205654W001, groundwater elevation increased during the same time period where subsidence halted. In this case, rising groundwater levels appear to have stabilized land subsidence.

Figure 1-43 shows that at SJRRP point 2065, subsidence has continued at a relatively steady pace from December 2011 through the most recent data point in December 2017. At CASGEM well 371852N1203899W001, groundwater elevation decreased from December 2011 through December 2015, showing a small net increase between December 2016 and December 2017. In this case, rising groundwater levels do not appear to have an impact on land subsidence, though groundwater levels fluctuated (i.e., was not a steady increase) during this time.

There are no additional available wells located in the Below Corcoran Clay Principal Aquifer with historical groundwater elevation data for further comparisons against SJRRP land subsidence data.

Figure 1-41: Map of Subsidence and Groundwater Well Comparison Points

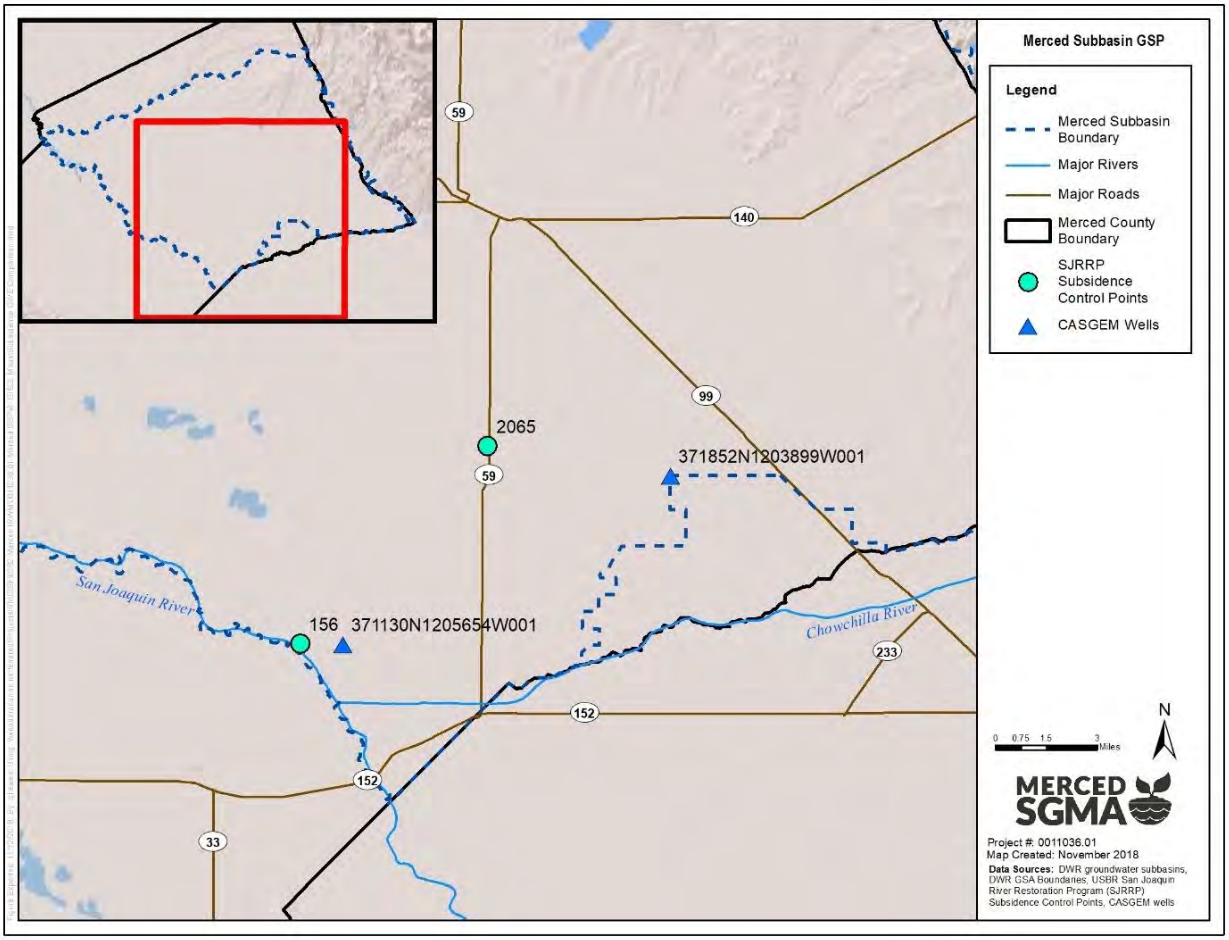


Figure 1-42: Subsidence vs Groundwater Elevation Comparison #1

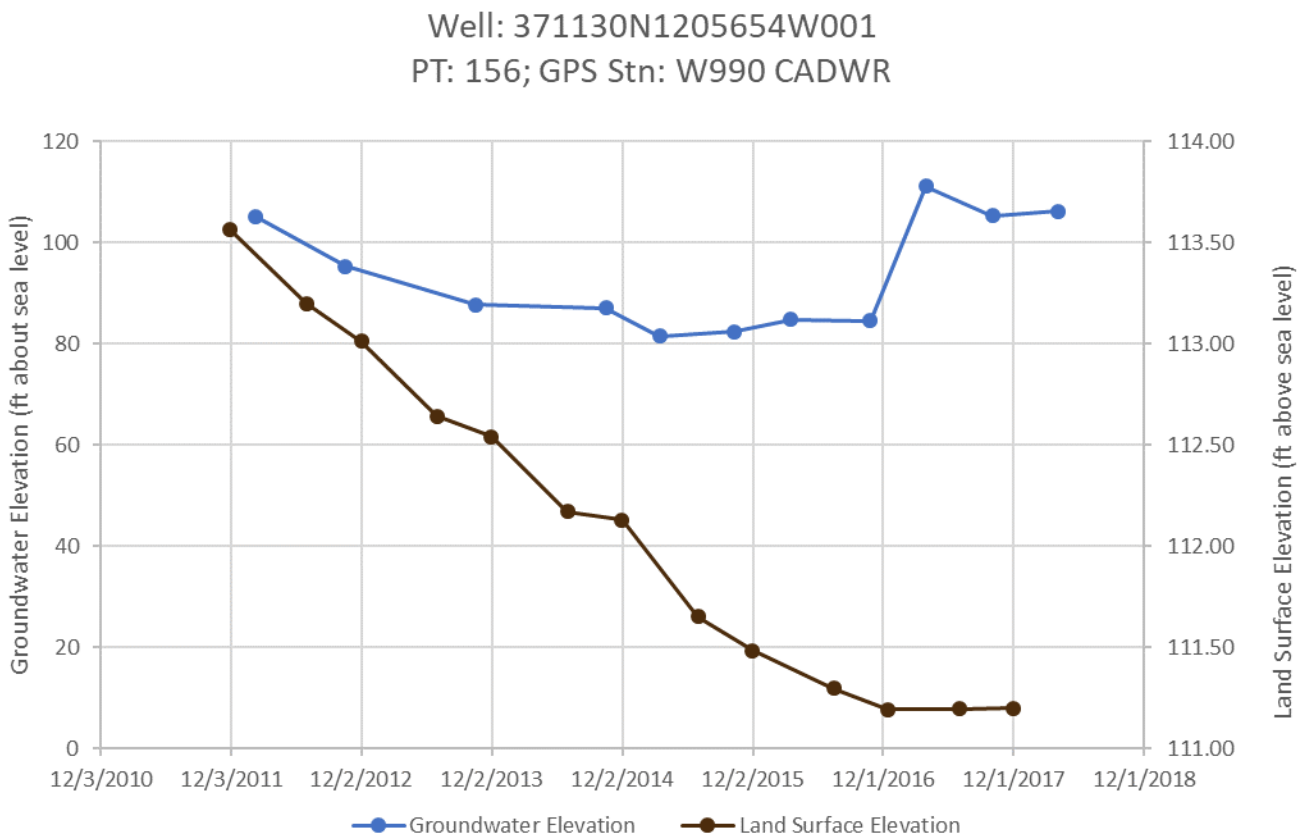


Figure 1-43: Subsidence vs Groundwater Elevation Comparison #2

1.1.6 Interconnected Surface Water Systems

Interconnected surface waters are surface water features that are hydraulically connected by a saturated zone to the groundwater system. In other words, where water table elevations and surface water features intersect at the same elevations and locations. Interconnected surface waters may be either gaining or losing, wherein the surface water feature is either gaining water from the aquifer system or losing water to outflowing into the aquifer system.

See Section #.# in the HCM for identification of Interconnected/Disconnected streams and Gaining/Losing streams. Increased losses or decreased gains (to either groundwater or stream systems) can be expected due to groundwater pumping adjacent to streams, but this is difficult to quantify. While the MercedWRM has been used to identify connections and disconnections between the groundwater system and streams, depletions have not yet been calculated. There are no known field studies of interconnected surface water systems within the Subbasin. More information on stream gains and losses is provided in Appendix X.

1.1.7 Groundwater-Dependent Ecosystems

(Section currently under development.)

1.1.8 Management Areas (as Applicable)

(Section to be developed if applicable.)

2. REFERENCES

AMEC. (2008, July 29). Merced Groundwater Basin Groundwater Management Plan Update. *Merced Groundwater Basin Groundwater Management Plan Update, Merced County, CA*.

Amec. (2013). *Salt and Nutrient Study (from MIRWMP).*

Bartow, J. A. (1991). *The Cenozoic Evolution of the San Joaquin Valley, California (USGS Professional Paper 1501).* USGS.

California Geological Survey. (2010). Fault Activity Map of California. Retrieved from http://maps.conservation.ca.gov/cgs/fam/

California Regional Water Quality Control Board Central Valley Region. (2016, July). The Water Quality Control Plan (Basin Plan) - Sacramento River Basin and San Joaquin River Basin.

California Water Boards. (2018, July 13). Perfluorooctanoic acid (PFOA) and Perfluorooctanesulfonic acid (PFOS). Retrieved October 29, 2018, from https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/PFOA_PFOS.html

Catalyst. (2018, February 7). Merced Basin Groundwater Sustainability Stakeholder Engagement Strategy.

Central Valley RWQCB. (2011). Order No. R5-2011-0006 Soil Remediation Waste Discharge Requirements for Track Four, Inc. (a Wholly Owned Subsidiary of Amsted Industries Inc.), and Merck & Co., Inc., Former Baltimore Aircoil Company Facility. Retrieved February 7, 2019, from https://www.waterboards.ca.gov/rwqcb5/board_decisions/adopted_orders/merced/r5-2011-0006.pdf

City of Livingston. (2016). *2015 Urban Water Management Plan.*

City of Merced. (2017). *2015 Urban Water Management Plan.*

City of Merced. (n.d.). Code of Ordinances: Chapter 8.12 - Water Wells. Retrieved April 5, 2018

City of Merced Development Services Department. (2011). Merced Vision 2030 General Plan.

County of Madera. (2016, March 29). Chowchilla Subbasin - Modified Boundary Description.

Davis, G. H., Green, J. H., Olmsted, F. H., & Brown, D. W. (1959). *Ground-Water Conditions and Storage Capacity in the San Joaquin Valley California (USGS Water Supply Paper 1469).* USGS.

DWR. (2003). *California's Groundwater Bulletin 118.*

DWR. (2004). *Bulletin 118: San Joaquin Valley Groundwater Basin Merced Subbasin.*

DWR. (2016, January 7). Groundwater Sustainability Agency Frequently Asked Questions. Retrieved May 3, 2018, from https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Groundwater-Sustainability-Agencies/Files/GSA-Frequently-Asked-Questions.pdf

DWR. (2017, June). California Aqueduct Subsidence Study. Retrieved October 30, 2017, from https://water.ca.gov/LegacyFiles/groundwater/docs/Aqueduct_Subsidence_Study-FINAL-2017.pdf

DWR. (2018). Chronological Reconstructed Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices. Retrieved November 29, 2018, from http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST

DWR SGMP. (2016). *Groundwater Sustainability Plan (GSP) Annotated Outline.* Sacramento, CA.

DWR SGMP. (2016). *Preparation Checklist for GSP Submittal.* Sacramento, CA.

Elam, T. (2012, August 1). *The San Joaquin Valley Through Time*. Retrieved from Buena Viesta Museum of Natural History & Science, Bakersfield: http://www.sharktoothhill.org/index.cfm?fuseaction=news_full_view&news_id=7

Elliott, A. L. (1984, August). Groundwater Conditions and Shallow Test-Well Information in the Eastern Half of Merced County, California 1967-82. *U.S. Geological Survey Water Resources Investigations (Report 83-4081)*.

Harter, T., Lund, J. R., Darby, J., Fogg, G. E., Howitt, R., Jessoe, K. K., . . . Rosenstock, T. S. (2012). *Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater.* Report for the State Water Resources Control Board Report to the Legislature. Center for Watershed Sciences, University of California, Davis.

Luhdorff and Scalmanini Consulting Engineers. (2016). *Region 5: Updated Groundwater Quality Analysis and High Resolution Mapping for Central Valley Salt and Nitrate Management Plan.*

Merced County. (2013). *2030 Merced County General Plan.*
Merced County. (2015). *Well Construction, Destruction, Mining, and Export Application/Permit User Guide.* Retrieved April 5, 2018, from http://www.co.merced.ca.us/DocumentCenter/View/10905
Merced County Department of Public Health, Division of Environmental Health. (2018). *Adverse Groundwater Quality by Area in Merced County.*
Merced County. (n.d.). Merced County Code. *Chapter 9.28 - Wells*. Retrieved April 5, 2018, from http://www.qcode.us/codes/mercedcounty/view.php?topic=9-9_28&frames=on
Merced Irrigation District. (2013). Agricultural Water Management Plan.
Merced Irrigation District. (2017). *Attachment 5: Budget for 2017 Merced Groundwater Subbasin Sustainability (DWR Grant Application).*
Merced Subbasin GSA, MIUGSA, Turner Island Water District GSA-#1. (2017, October 13). Memorandum of Understanding.
Merced Subbasin GSA, MIUGSA, Turner Island Water District GSA-#1. (2018, January 8). Notification of Intent to Develop a Groundwater Sustainability Plan for Merced Subbasin.
MID. (2016, July 5). *Agricultural Water Management Plan.* Retrieved from http://www.water.ca.gov/wateruseefficiency/sb7/docs/2016/Merced%20ID%202015%20AWMP.pdf
MIUGSA. (2017). Memorandum of Understanding Forming the Merced Irrigation-Urban Groundwater Sustainability Agency.
MSGSA. (2016). Joint Powers Agreement Creating the Merced Subbasin Groundwater Sustainability Agency.
Pacific Municipal Consultants. (2000). City of Atwater General Plan. Retrieved April 6, 2018, from http://www.atwater.org/dept_communitydevelopment.html#5
Page. (1973). *Base of Fresh Ground Water (Approximately 3,000 Micromhos) in the San Joaquin Valley, California.* USGS.
Page, R. W. (1977). *Appraisal of Ground-Water Conditions in Merced, California, and Vicinity.*
Page, R. W. (1986). *Geology of the Fresh Ground-Water Basin of the Central Valley, California, with Texture Maps and Sections.* Washington: United States Geological Survey.
Page, R. W., & Balding, G. O. (1973). *Geology and Quality of Water in the Modesto-Merced Area, San Joaquin Valley, California, with a Brief Section on Hydrology.*
Quad Knopf, Inc. (1999, December). Livingston General Plan.
Reclamation. (2016). *Draft Environmental Assessment/Initial Study: Water Year 2016-2026 Transfer and Exchange from Madera Irrigation District and Chowchilla Water District to the Red Top Area.*
RMC Water and Environment. (2013). *Groundwater Recharge Feasibility Study (part of MIRWMP).*
RMC Water and Environment. (2013). *Merced Integrated Regional Water Management Plan.*
RMC Water and Environment. (2015). *Creating and Opportunity: Groundwater Recharge through Winter Flooding of Agricultural Land in the San Joaquin Valley.*
RMC Water and Environment. (2017, December). Merced Water Resources Model (MercedWRM) DRAFT Report.
SWRCB - GeoTracker. (n.d.). CASTLE AIR FORCE BASE (T0604719389). Retrieved October 30, 2018
SWRCB. (2006, May). CCR Title 22 Division 4 Chapter 15 Article 16: Secondary Water Standards. State Water Resources Control Board.
SWRCB. (2017, November). Groundwater Information Sheet: Hexavalent Chromium. Retrieved January 29, 2019, from https://www.waterboards.ca.gov/gama/docs/coc_hexchromcr6.pdf
SWRCB. (2018, October). Maximum Contaminant Levels and Regulatory Dates for Drinking Water U.S. EPA vs California. Retrieved from https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/ccr/MCLsEPAvsDWP-2018-10-02.pdf
Wilde, F. (2015). *National Field Manual for the Collection of Water-Quality Data.* USGS. Retrieved from https://water.usgs.gov/owq/FieldManual/compiled/NFM_complete.pdf