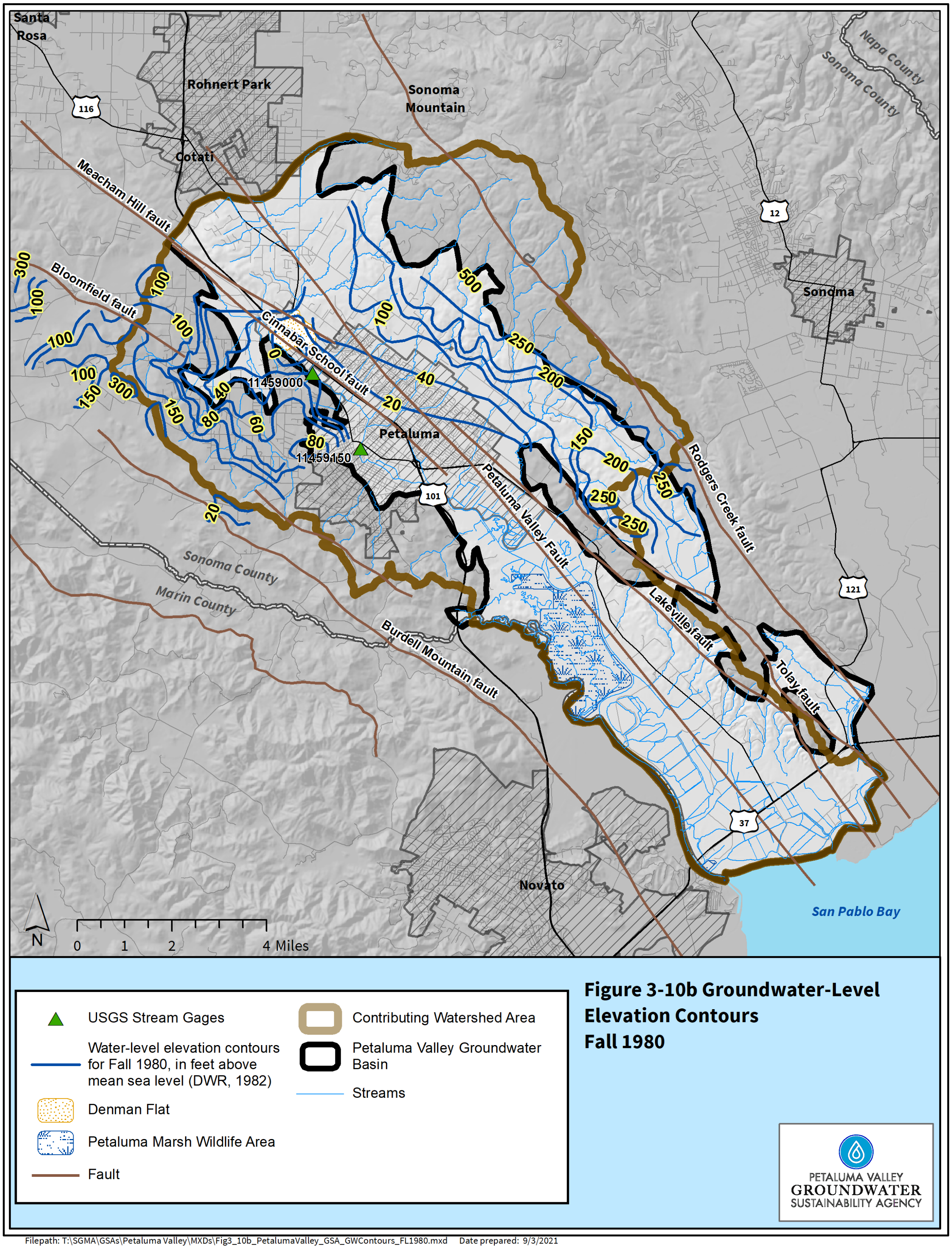
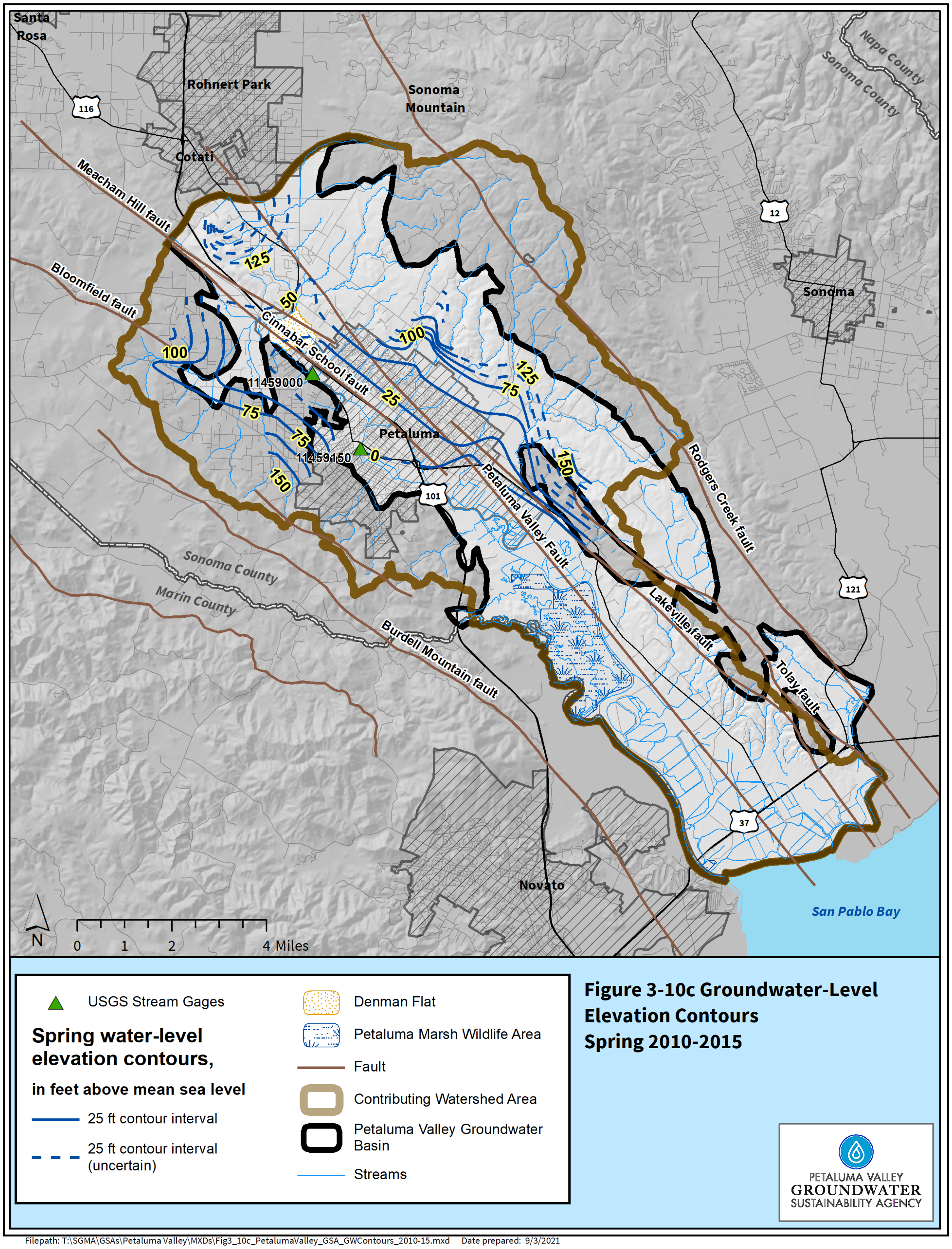


Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_10b_PetalumaValley_GSA_GWContours_FL1980.mxd Date prepared: 9/3/2021

Figure 3-10b. Groundwater-level Elevation Contours Fall 1980



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_10c_PetalumaValley_GSA_GWContours_2010-15.mxd Date prepared: 9/3/2021

Figure 3-10c. Groundwater-level Elevation Contours Spring 2010-2015

3.2.2.2 Groundwater-level Trends

Long-term groundwater-level trends were evaluated using data from 41 wells in the Basin and contributing watershed areas (**Figure 3-11**). In general, long-term trends were evaluated using data collected on a semiannual basis. For some wells, groundwater-level elevation data are available going back to 1980 or earlier (PET0005 has data going back to 1949). The majority of wells have periods of record extending back to 1990 or earlier.

Groundwater-level hydrographs for wells distributed throughout the Basin and contributing watershed areas are provided in **Appendix 3-B**. These hydrographs present the change in groundwater elevation (vertical axis in feet) over time (horizontal axis in WYs). On the hydrographs, spring groundwater-level data are depicted in green and fall groundwater-level data are shown in orange, along with wet and dry periods described in **Section 3.2.1**. Select hydrographs for wells with the longest periods of record and/or with the most discernible trends are presented on **Figures 3-12a** through **3-12e**.

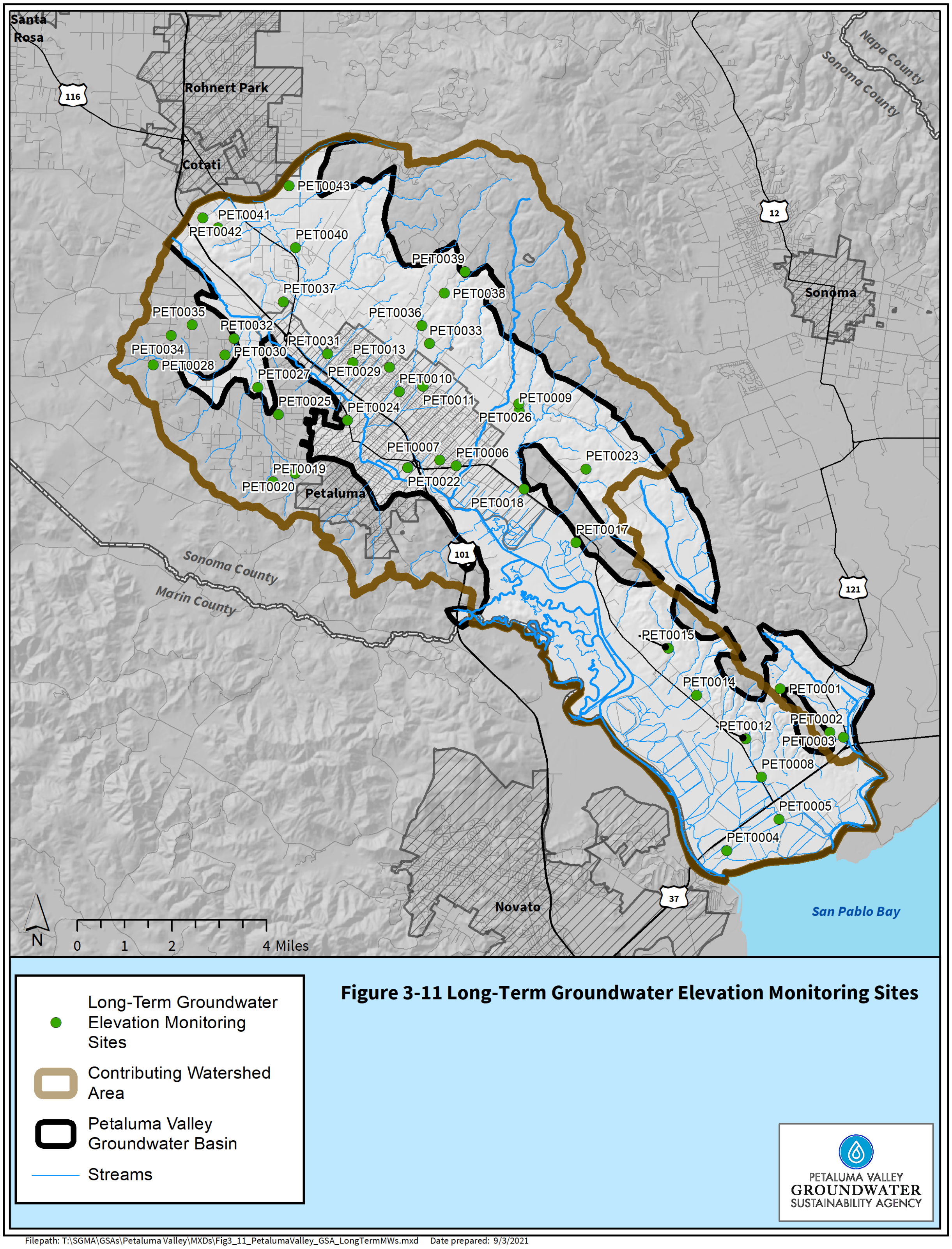
As indicated on the long-term hydrographs, the majority of the observed wells exhibit generally stable groundwater-level trends with typical seasonal variations (that is, higher groundwater levels in the spring and lower groundwater levels in the fall). Observed groundwater-level elevations predominantly remain above sea level except for some wells in the southern portion of the Basin near the Baylands and the tidally influenced reach of the Petaluma River (**Figure 3-12c**) (PET0006, PET0017).

Some wells near the upper reaches of Lynch Creek near the northeastern edge of Basin (**Figure 3-12d**) (PET0036, PET0038, PET0039) exhibit slightly decreasing groundwater-level trends over the period of record. Wells PET0014, PET0017, PET0026, PET0031, PET0033, PET0036, PET0038, PET0039, PET0042, and PET0043 also exhibit large irregular fluctuations, likely due to local periodic groundwater pumping. Near the northern edge of the Basin, well PET0042 and, to a lesser extent, well PET0041 exhibit decreasing groundwater levels from about 2005 to present (**Figure 3-12e**). Conversely, well PET0043, also near the northern edge of the Basin, exhibits stable groundwater levels from 2007 to present and a slightly increasing trend for the overall period of record (1990 to present) (**Figure 3-12e**).

3.2.3 Estimated Changes in Groundwater Storage

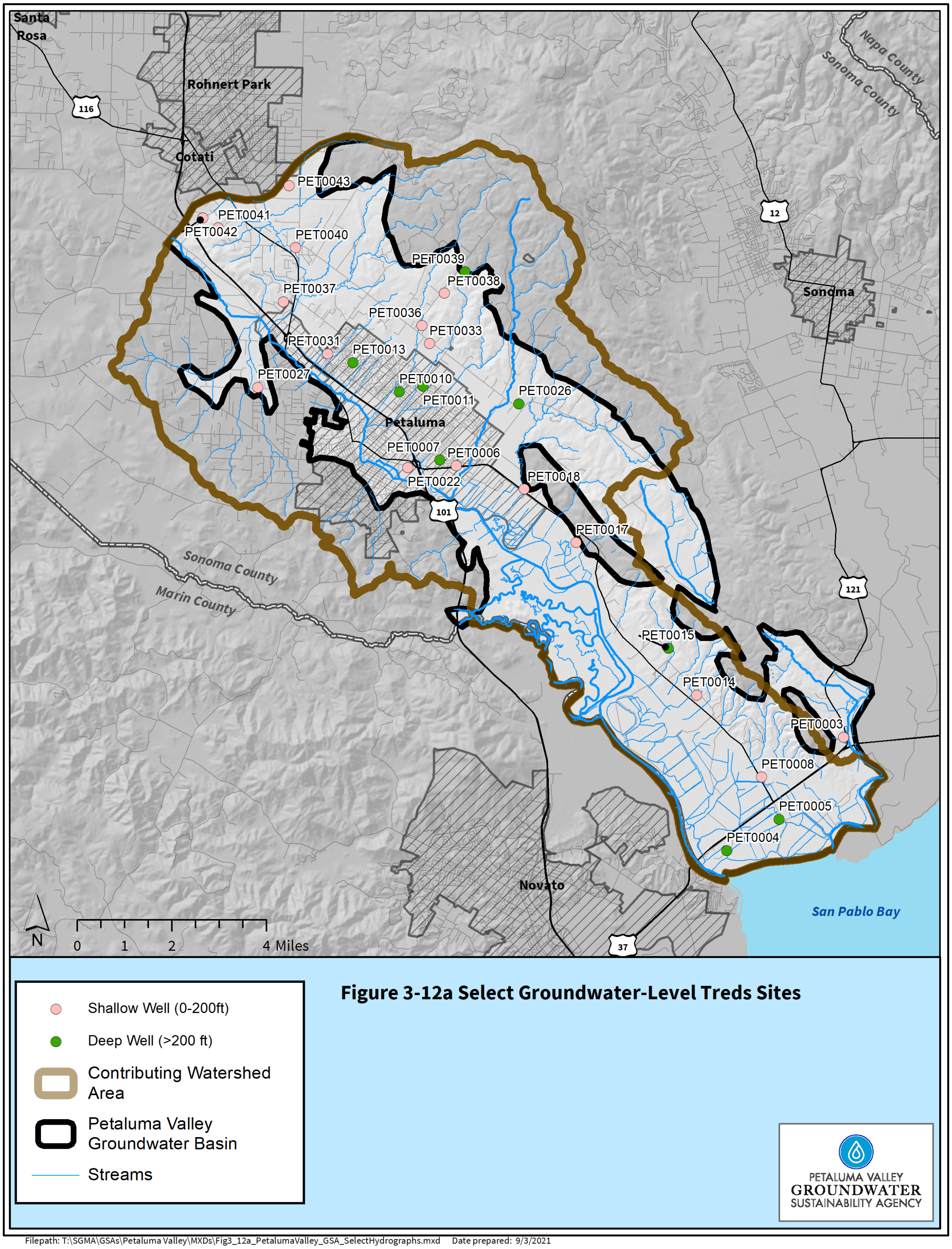
Figure 3-13 shows the entire groundwater water budget and also includes the annual change of groundwater in storage.

A change of groundwater in storage is equal to total inflow minus total outflow in the groundwater budget. A negative change of groundwater in storage indicates groundwater-storage depletion while a positive value indicates groundwater-storage accretion. **Table 3-1** shows the annual change of groundwater in storage for the historical and current time periods.



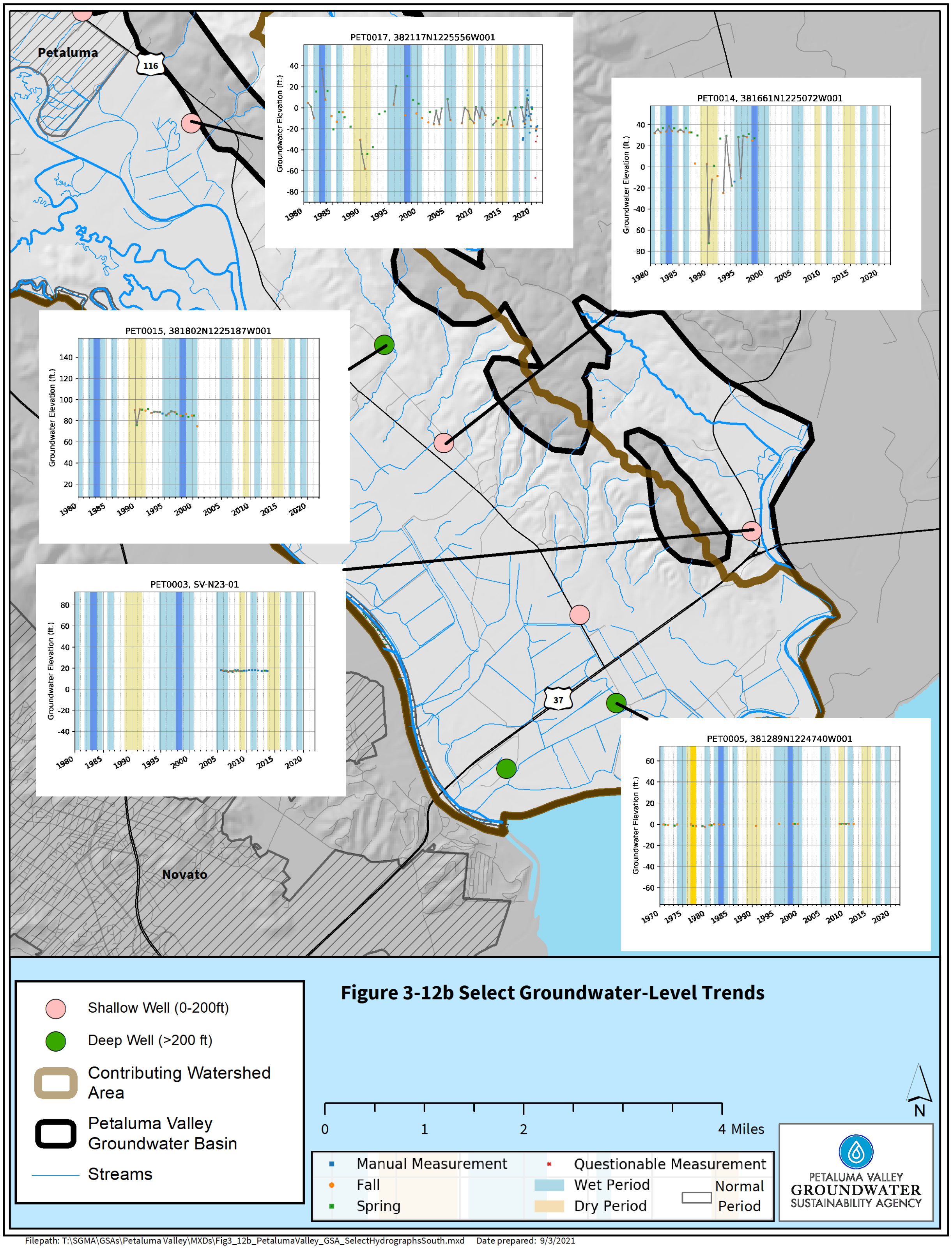
Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_11_PetalumaValley_GSA_LongTermMWs.mxd Date prepared: 9/3/2021

Figure 3-11. Long-term Groundwater Elevation Monitoring Sites



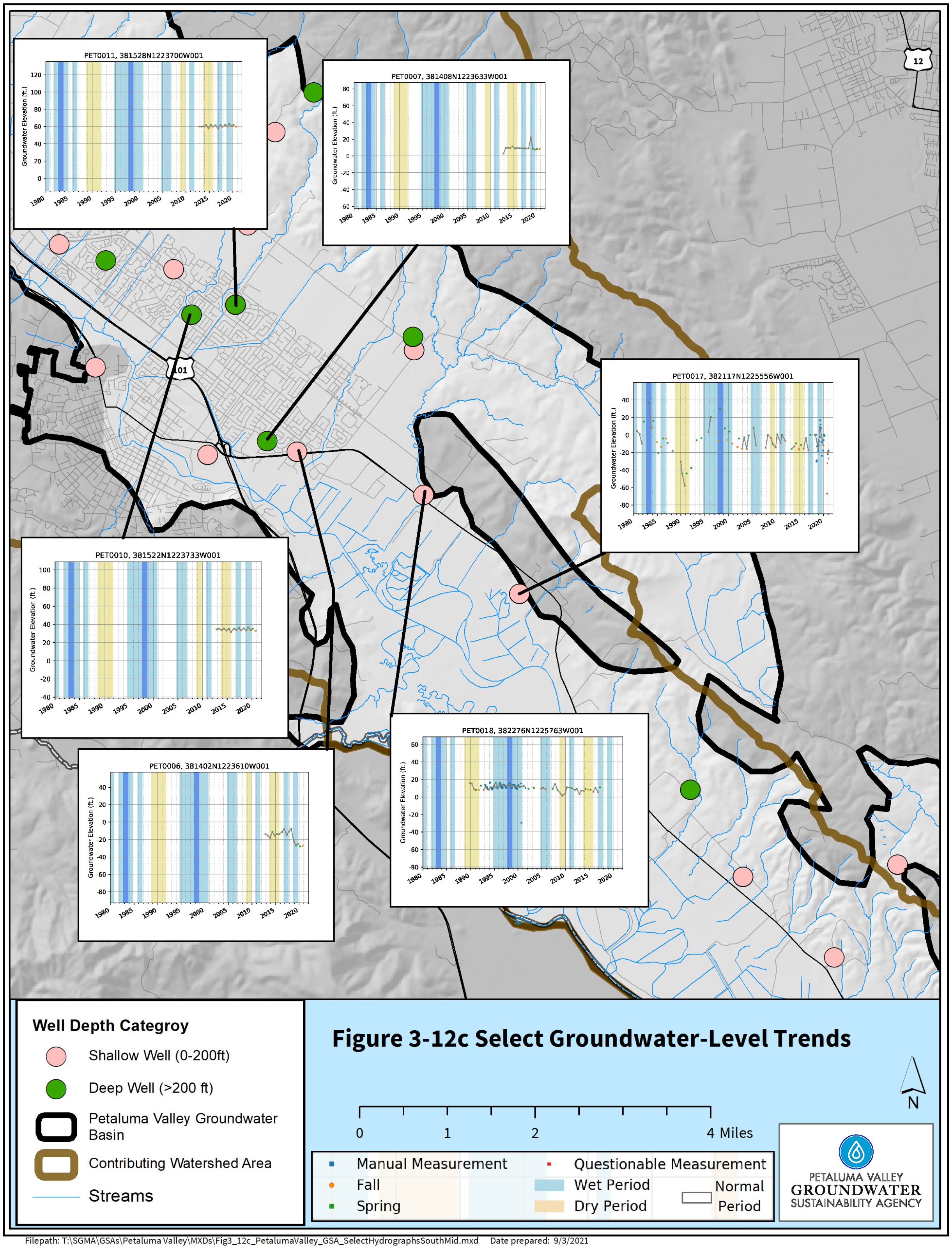
Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_12a_PetalumaValley_GSA_SelectHydrographs.mxd Date prepared: 9/3/2021

Figure 3-12a. Select Groundwater-level Trends Sites



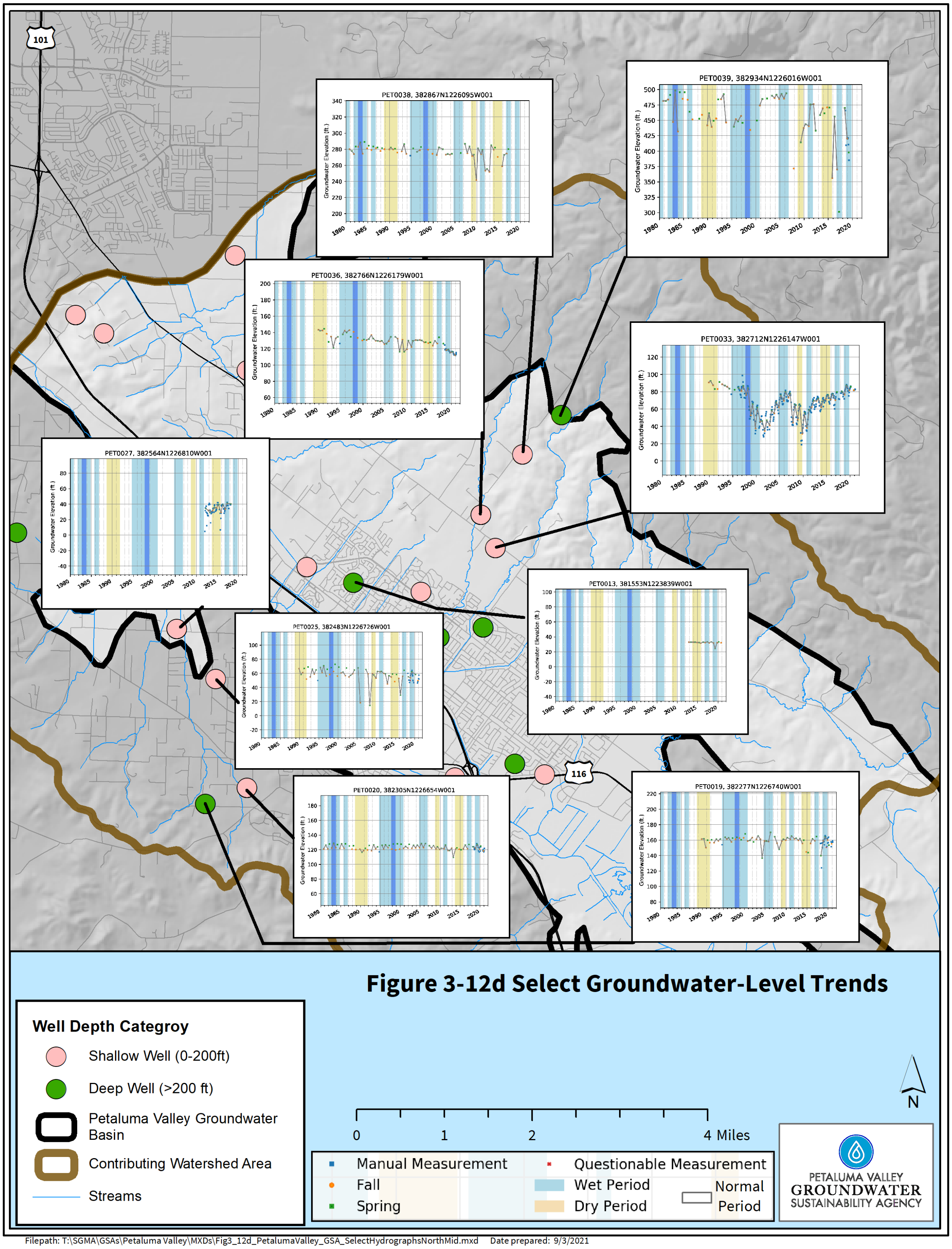
Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_12b_PetalumaValley_GSA_SelectHydrographsSouth.mxd Date prepared: 9/3/2021

Figure 3-12b. Select Groundwater-level Trends



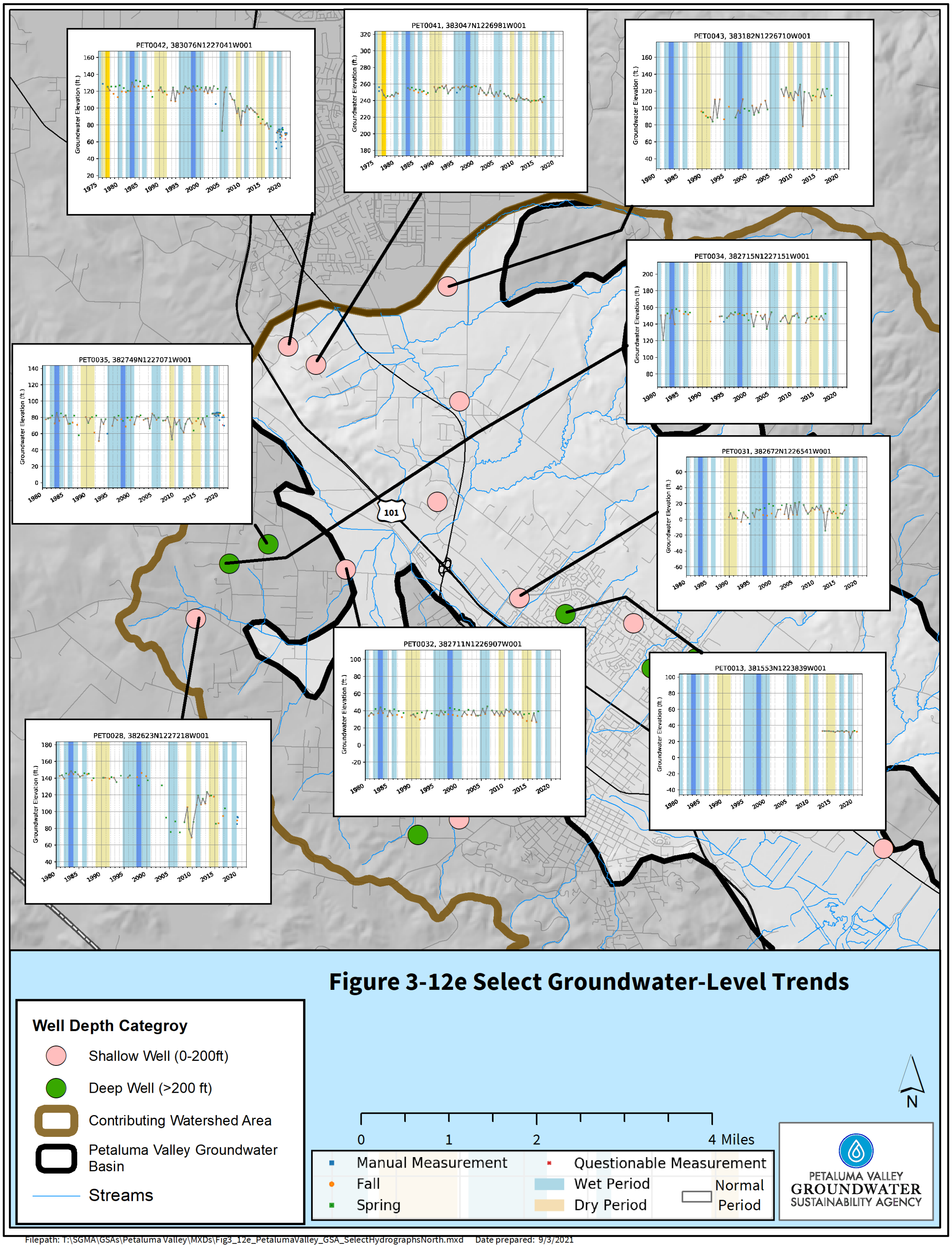
Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_12c_PetalumaValley_GSA_SelectHydrographsSouthMid.mxd Date prepared: 9/3/2021

Figure 3-12c. Select Groundwater-level Trends



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_12d_PetalumaValley_GSA_SelectHydrographsNorthMid.mxd Date prepared: 9/3/2021

Figure 3-12d. Select Groundwater-level Trends



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_12e_PetalumaValley_GSA_SelectHydrographsNorth.mxd Date prepared: 9/3/2021

Figure 3-12e. Select Groundwater-level Trends

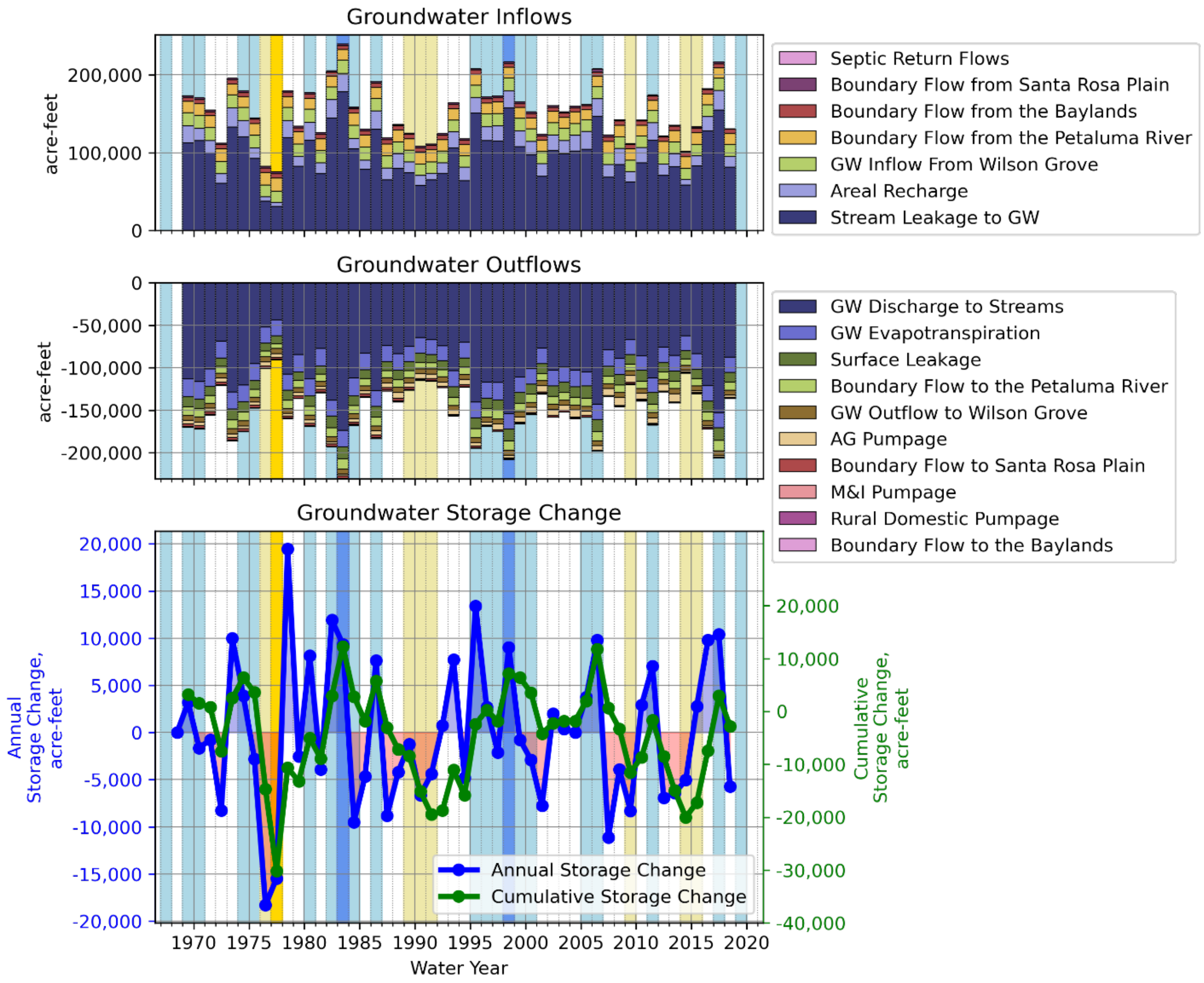


Figure 3-13. Historical and Current Groundwater Budget

On average, the historical period shows minimal net change in groundwater in storage. The mean annual groundwater storage change over the historical period is about -40 AFY, but is rounded and reported as 0 AFY in **Table 3-1**. The current period, which includes the recent drought, shows a mean annual decline of 100 AFY of groundwater in storage. The two largest drops in groundwater storage occurred in the drought of 1976-1978 and the largest increase in groundwater storage occurred during the year following that drought. By about 1982 groundwater storage rebounded to the initial storage from WY 1970. From 1982 through 1992 groundwater storage declined, followed by a period of recovery associated with relatively wet conditions during 1995 through 2002. Cumulative storage change at the end of WY 2018 is a total change of -2,000 acre-feet by the end of WY 2018.

Table 3-1. Average Annual Change of Groundwater in Storage (AFY) [a]

	Historical (WY 1969 through 2018)	Current (WY 2012 through 2018)
Mean	0	-100
Minimum	-18,300	-6,900
Maximum	19,500	10,400
Median	-1,000	-5,000

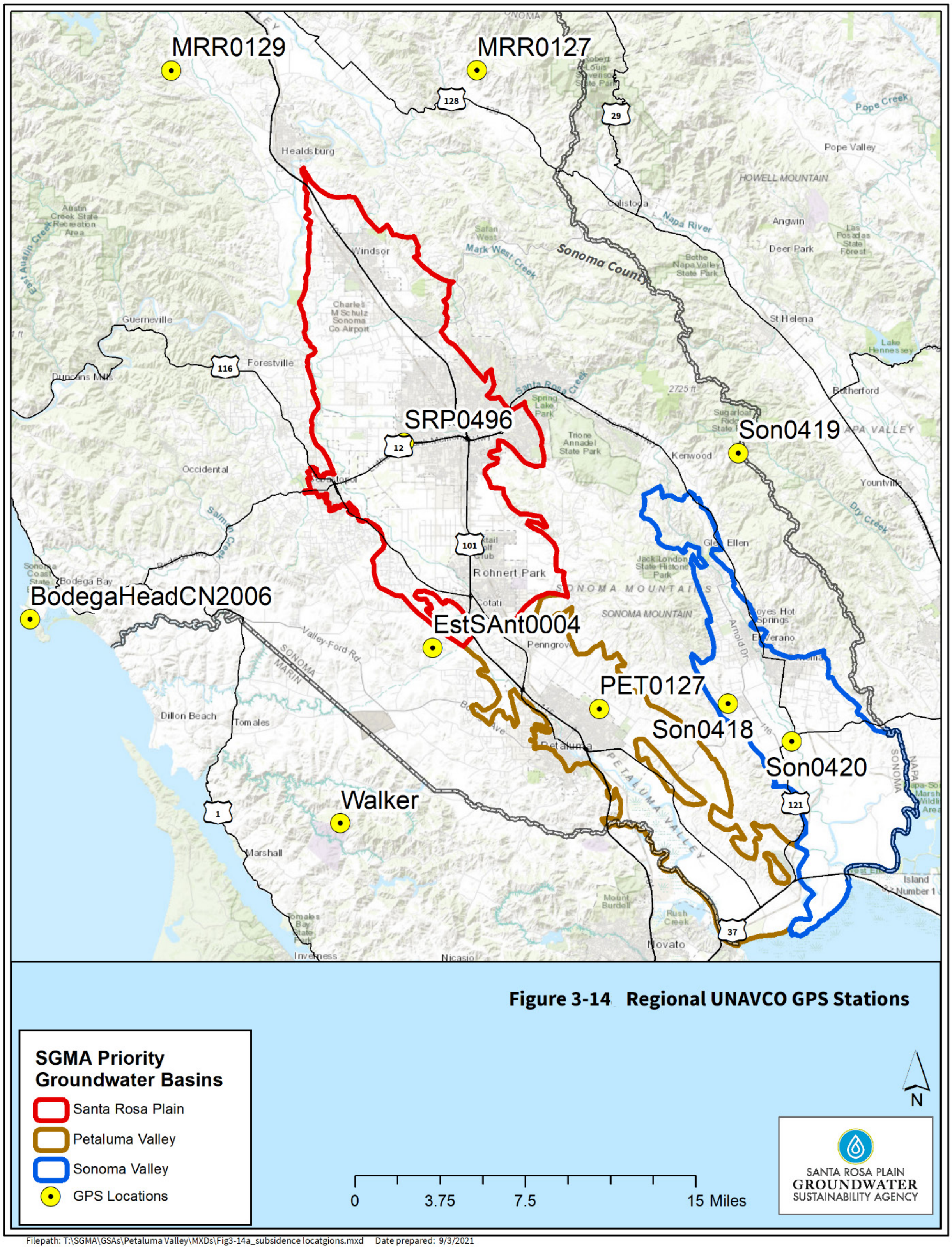
[a] Values may not equal inflows minus outflows due to rounding.

3.2.4 Land Surface Subsidence

Land-surface subsidence is defined as the gradual settling or sudden sinking of the Earth's surface owing to the subsurface movement of earth materials (Galloway et al. 2000). The principal causes are aquifer-system compaction, drainage of organic soils, underground mining, hydrocompaction, natural compaction, sinkholes, and thawing permafrost (National Research Council 1991). The compaction of unconsolidated aquifer systems that can accompany excessive groundwater pumping is by far the single largest cause of subsidence. The overdraft of such aquifer systems has resulted in permanent subsidence and related ground failures.

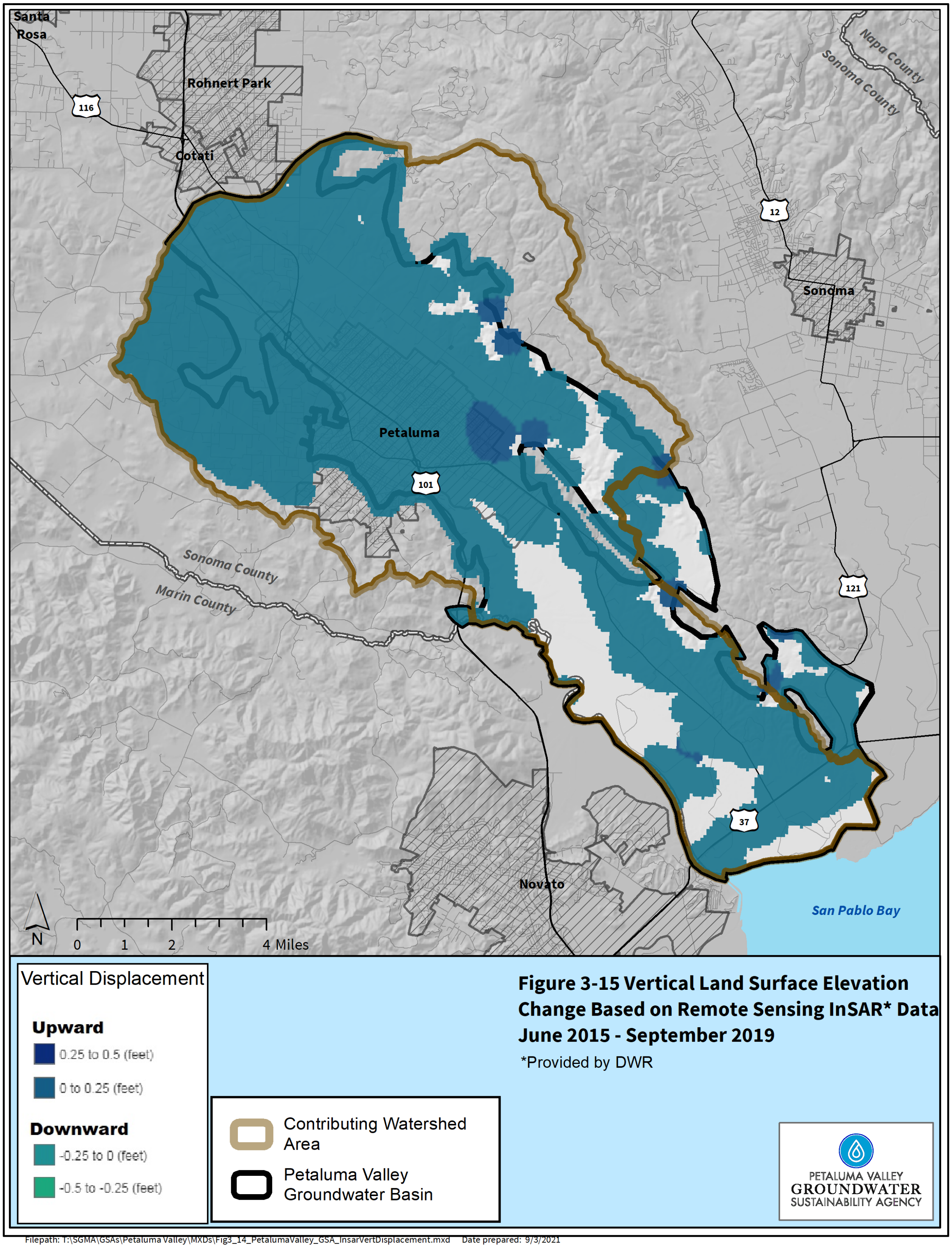
From 2004 to 2019 the GPS station in the Basin has shown vertical changes of +0.5 to -0.75 inches, with a net change of -0.50 inch (**Figure 3-14**). From 2015 to 2019 the vertical change for the station was -0.13 inch, with annual changes of -0.0325 inch per year. The land-surface elevation changes observed in the Basin correlate with nearby stations and regional stations (**Figure 3-14**), including stations in Bodega Bay (BodegaHeadCN2006), Marin, Napa, and in the Russian River areas, which exhibit long-term declines in ground height that closely mirror those of the Petaluma station. Given the similarity in the Petaluma land-surface elevation change with some of the regional stations, it is likely that regional interannual variation in hydrologic isostatic loading is likely the best explanation for the observed trends. The logical corollary to this conclusion is that groundwater pumping in the Basin is likely not the cause of the subsidence observed at the PET0127 station.

The spatial variation of land-surface elevation change within the Basin is shown on **Figure 3-15**. This dataset is provided by DWR and represents changes from June 2015 to 2018 measured by interferometric synthetic-aperture radar (InSAR). The maximum vertical changes are within the +0.25 to -0.25 feet range for the entire basin, with a majority of the basin within the 0.0 to -0.25 feet range over the 3-year period.



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3-14a_subsidence locatgions.mxd Date prepared: 9/3/2021

Figure 3-14. Regional UNAVCO GPS Stations



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_14_PetalumaValley_GSA_InsarVertDisplacement.mxd Date prepared: 9/3/2021

Figure 3-15. Vertical Land Surface Elevation Change Based on Remote Sensing InSAR Data June 2015 - September 2019

3.2.5 Groundwater Quality Conditions and Trends

Groundwater-quality sampling has been performed throughout the Basin for a number of different studies and regulatory programs. This section provides a summary of groundwater quality conditions and trends from these various studies and regulatory programs, which include the following:

- DWR periodic sampling of private wells (1950s to 2010)
- GAMA studies of public water supply wells (2004) and private domestic wells (2012)
- USGS groundwater study
- Data from regulated public water supply system sampling
- Regulated contaminant sites

Groundwater quality is generally adequate to support existing beneficial uses within most areas of the Basin and contributing watershed. Localized areas of poor groundwater quality are primarily related to the following potential sources of impairment: (1) brackish waters of San Pablo Bay and associated tidal marshland areas; (2) deep connate waters associated with ancient seawater entrapped during deposition of Tertiary Era sedimentary units; and (3) anthropogenic inputs associated with certain land-use activities (for example, industrial, agricultural, or urban land uses), including an area of historical nitrate contamination in the northwestern portions of the Basin and contributing watershed.

The following sections describe general groundwater-quality characteristics and the occurrence and distribution of naturally occurring and anthropogenic constituents of interest. Summary results are provided for general minerals major-ion data, TDS, arsenic, nitrate, and chloride, which are constituents that have been identified as constituents of interest in previous studies within the Basin and/or serve as indicators for brackish or saline groundwater. The following descriptions of these constituents within the Basin and contributing watershed areas are based on publicly available data collected within the last 10 years from public water-supply wells and special studies by the USGS and DWR, which included sampling of both public and private water-supply wells. For wells that have been sampled multiple times within the past 10 years, the most recent sampling result is used in this analysis. The analytic results represent samples of native groundwater collected prior to any water-treatment systems and are not representative of the drinking water delivered by the public water systems that are required to treat the water to applicable drinking water standards prior to delivery.

3.2.5.1 General Groundwater Quality Characteristics

Major ion concentrations and stable isotopes were used by the USGS to help classify and characterize the movement of groundwater in the Basin and contributing watershed area.

Teague (Traum et al. 2022) found that stable-isotope data indicate that the primary source of groundwater recharge in the Basin is infiltration of precipitation in the Wilson Grove Highlands and Sonoma Mountains. As groundwater moves from the boundary of the watershed through the major hydrogeologic units toward the axis of the Petaluma Valley and the Petaluma River, water-quality changes are caused by chemical reactions between groundwater and aquifer material and by mixing with infiltration of precipitation. In general, modern (post 1950s) water occurs in samples from shallow wells and mixed-depth wells screened near land surface, and groundwater sampled from deep wells along the axis of Petaluma Valley is pre-modern water.

Groundwater in the Wilson Grove Formation undergoes little change in water quality, moving east from the watershed boundary. The groundwater types in wells perforated in the Wilson Grove Formation were tightly grouped and were primarily mixed cation-bicarbonate (HCO_3) or Ca-HCO_3 type water. Similar major-ion compositions in samples from wells perforated in the Wilson Grove Formation and the sample of surface water from the non-tidally influenced reach of the Petaluma River suggest that groundwater from the Wilson Grove Formation is a substantial input to streamflow in the upper reach of the Petaluma River. Groundwater in wells perforated in the Wilson Grove Formation was generally of good quality, with low to moderate specific conductance (SC), TDS, chlorine, sodium, and calcium values indicating that mixing with saline water does not occur (Traum et al. 2022).

Teague (Traum et al. 2022) found that the general chemistry of groundwater collected from the Petaluma Formation is variable with groundwater in the eastern part of the Petaluma Formation, near the transition from the Sonoma Volcanics, and has a similar water chemistry to groundwater in the Sonoma Volcanics, indicating that groundwater moves through the Sonoma Volcanics with minimal changes in chemistry from reactions with the aquifer material before entering the Petaluma Formation. Groundwater moving west through the Sonoma Volcanics and Petaluma Formation undergoes changes in water quality because of mixing with modern water and reactions with aquifer material.

Groundwater in the Quaternary mixed unit is a mixture of groundwater from the Wilson Grove Formation and the Petaluma Formation. Under current conditions, groundwater movement is from the Wilson Grove and Petaluma Formation toward the Quaternary mixed unit (Traum et al. 2022).

3.2.5.2 Naturally Occurring Constituents of Interest

Arsenic, TDS, and chloride have been identified as naturally occurring constituents of interest through previous studies within the Basin.

Arsenic

Arsenic is a relatively common naturally occurring element. Arsenic is considered a carcinogen, and the maximum contaminant level (MCL) for arsenic has been set at 10 micrograms per liter (µg/L) (EPA 2021). Arsenic solubility increases with increasing water temperature and tends to desorb from aquifer matrix materials under alkaline conditions (pH greater than 8.0) (USGS 2014). Due to its increased solubility with increased temperature, arsenic is commonly elevated in groundwater that is affected by hydrothermal fluids.

Water-sample analyses for arsenic were available from 33 wells within the Basin and contributing watershed areas between 2010 and 2019. The occurrence and distribution of arsenic in groundwater samples is displayed on **Figure 3-16**. Groundwater samples from 6 of the 33 wells (18.2 percent) exceeded the MCL of 10 µg/L for arsenic.

Total Dissolved Solids

TDS refers to the amount of minerals, salts, metals, cations, and anions dissolved in water. Pure water, such as distilled water, will have a very low TDS and sea water, brackish water, older connate water, and mineralized thermal waters exhibit high TDS concentrations. TDS has a secondary maximum contaminant level (SMCL) of 500 milligrams per liter (mg/L) based on taste thresholds (EPA 2021).

Water sample analyses for TDS (and SC as a surrogate for TDS) were available from 33 wells within the Basin and contributing watershed areas between 2010 and 2019. The occurrence and distribution of TDS in groundwater is displayed on **Figure 3-17**. Groundwater samples from 7 of the 33 wells (21.2 percent) exceeded the secondary MCL of 500 mg/L for TDS.

Chloride

Chlorides are widely distributed in nature as salts of sodium (NaCl), potassium (KCl), and calcium ($CaCl_2$). Chlorides are leached from various rocks into soil and water by weathering and can also be an indicator for seawater intrusion. Chloride has an SMCL of 250 mg/L based on taste thresholds (EPA 2021).

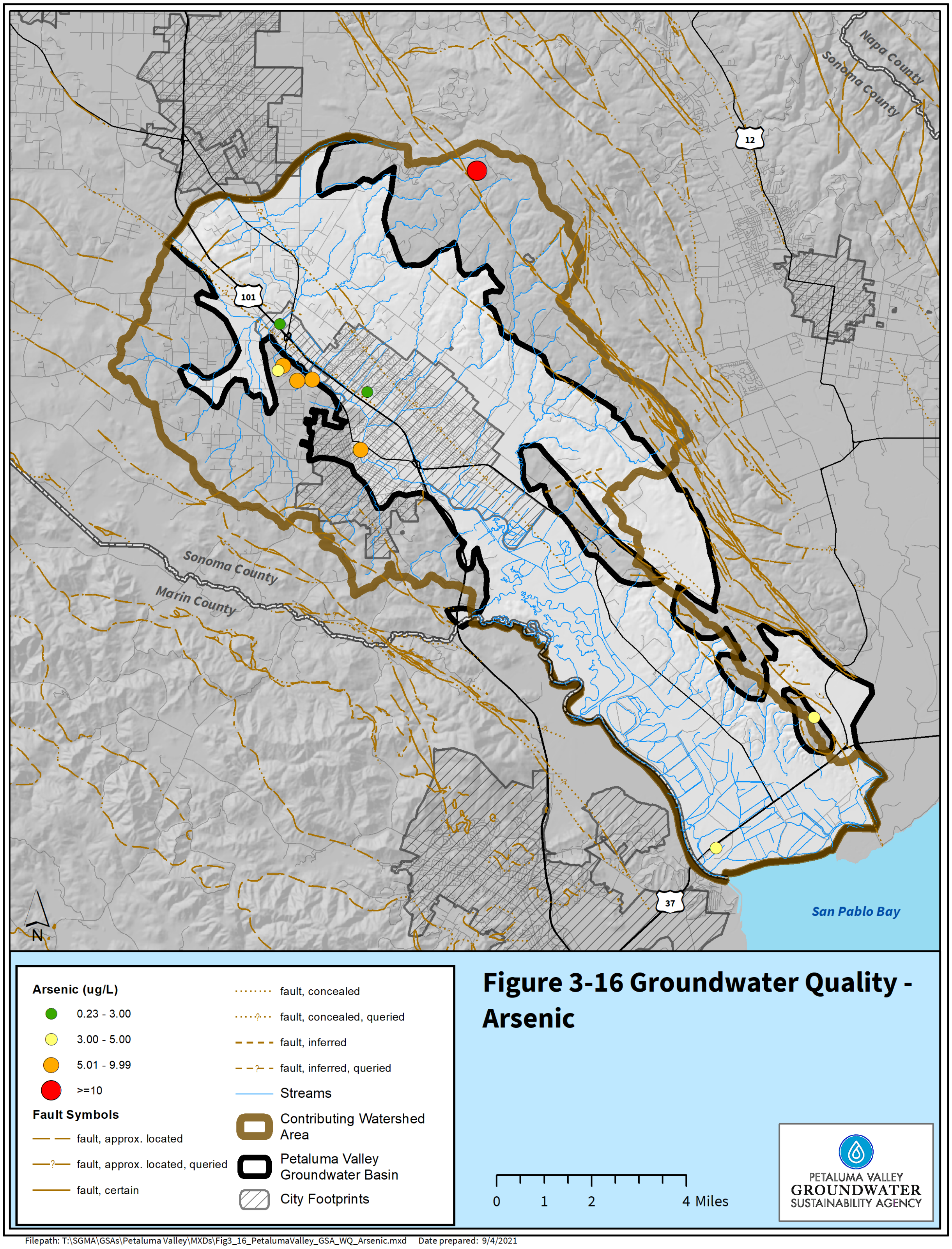
Water sample analyses for chloride were available from 32 wells within the Basin and contributing watershed areas between 2010 and 2019. The occurrence and distribution of chloride in groundwater is displayed on **Figure 3-18**. Groundwater samples from 2 of the 32 wells (6.2 percent) exceeded the secondary MCL of 250 mg/L for chloride.

3.2.5.3 Anthropogenic Constituents of Interest

Nitrate

Nitrate (NO_3) is a widespread contaminant and its occurrence in groundwater systems is attributable to natural sources such as precipitation and decomposition (oxidation or mineralization) of organic material (Hem 1992) and anthropogenic sources such as agricultural activities, septic systems, confined animal facilities, landscape fertilization, and wastewater treatment facility discharges. Elevated levels of NO_3 in drinking water are considered to be especially unhealthy for infants and pregnant women (SWRCB 2012) and the MCL for NO_3 as N is 10 mg/L, which is equivalent to 45 mg/L as dissolved NO_3 (EPA 2021).

Water sample analyses for nitrate were available from 30 wells within the Basin and contributing watershed areas between 2010 and 2019. The occurrence and distribution of nitrate in groundwater within the watershed is displayed on **Figure 3-19a**. Groundwater samples from 1 of the 30 wells (3.3 percent) exceeded the MCL of 10 mg/L for nitrate (as nitrogen).



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_16_PetalumaValley_GSA_WQ_Arsenic.mxd Date prepared: 9/4/2021

Figure 3-16. Groundwater Quality – Arsenic

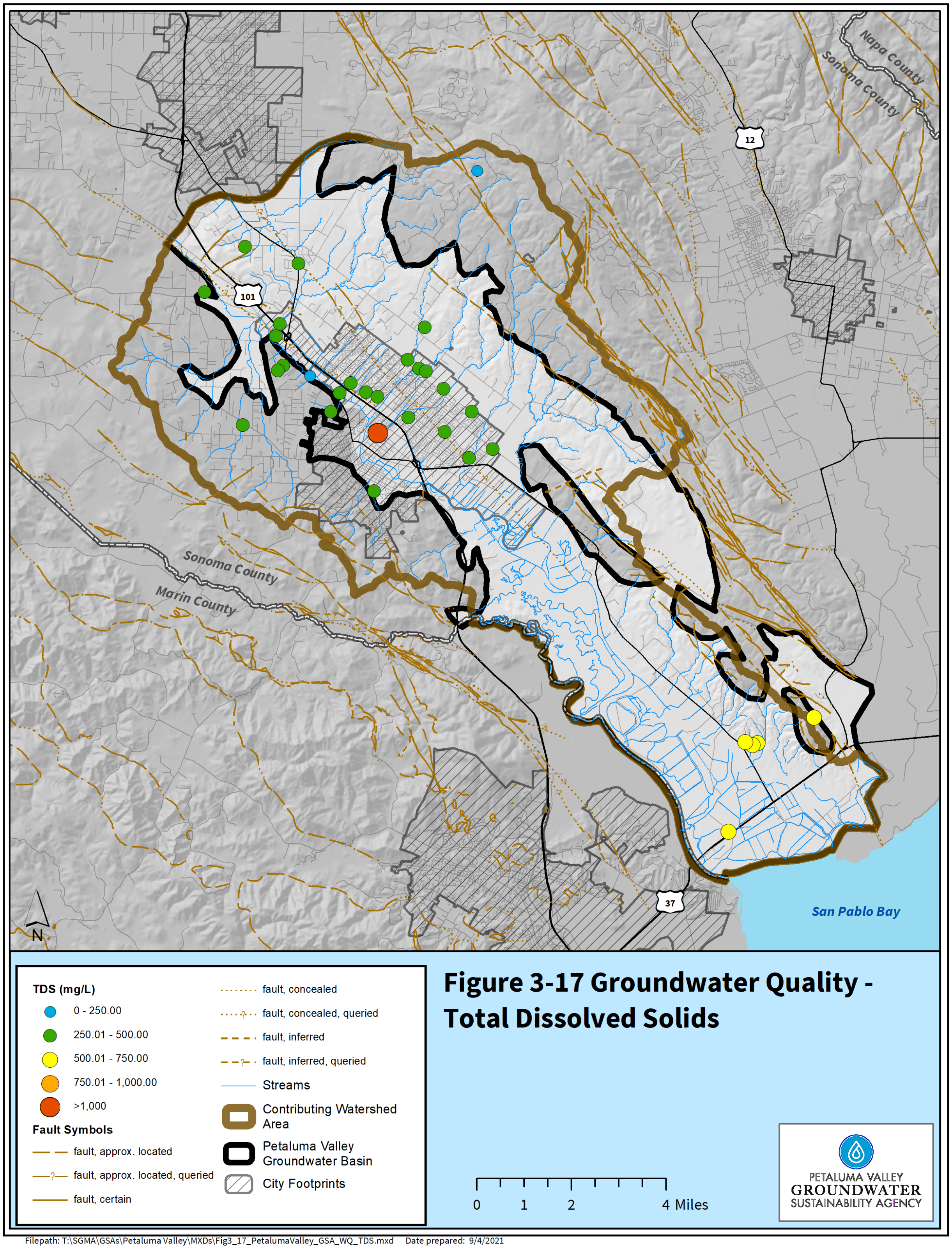
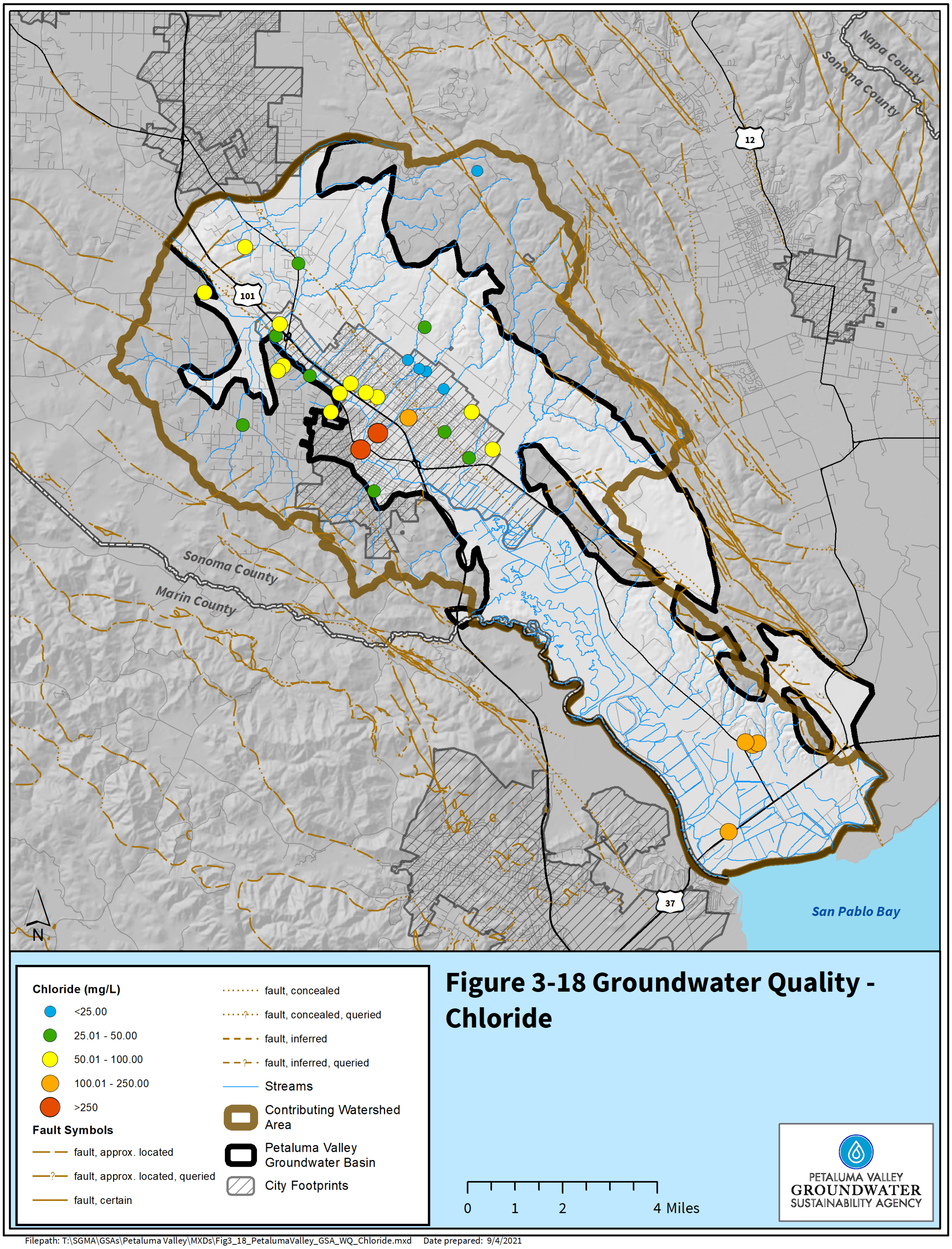


Figure 3-17 Groundwater Quality - Total Dissolved Solids

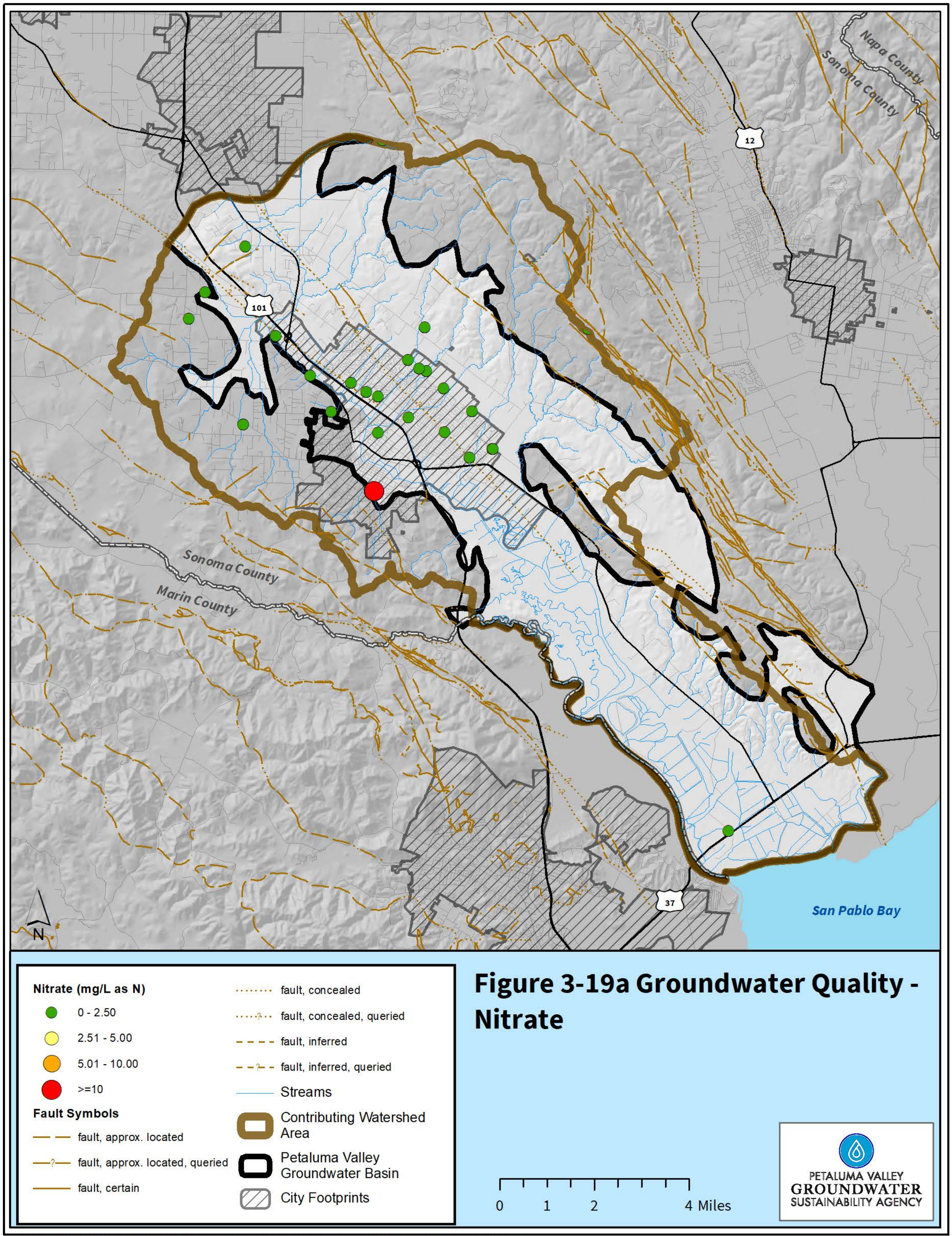
Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_17_PetalumaValley_GSA_WQ_TDS.mxd Date prepared: 9/4/2021

Figure 3-17. Groundwater Quality – TDS



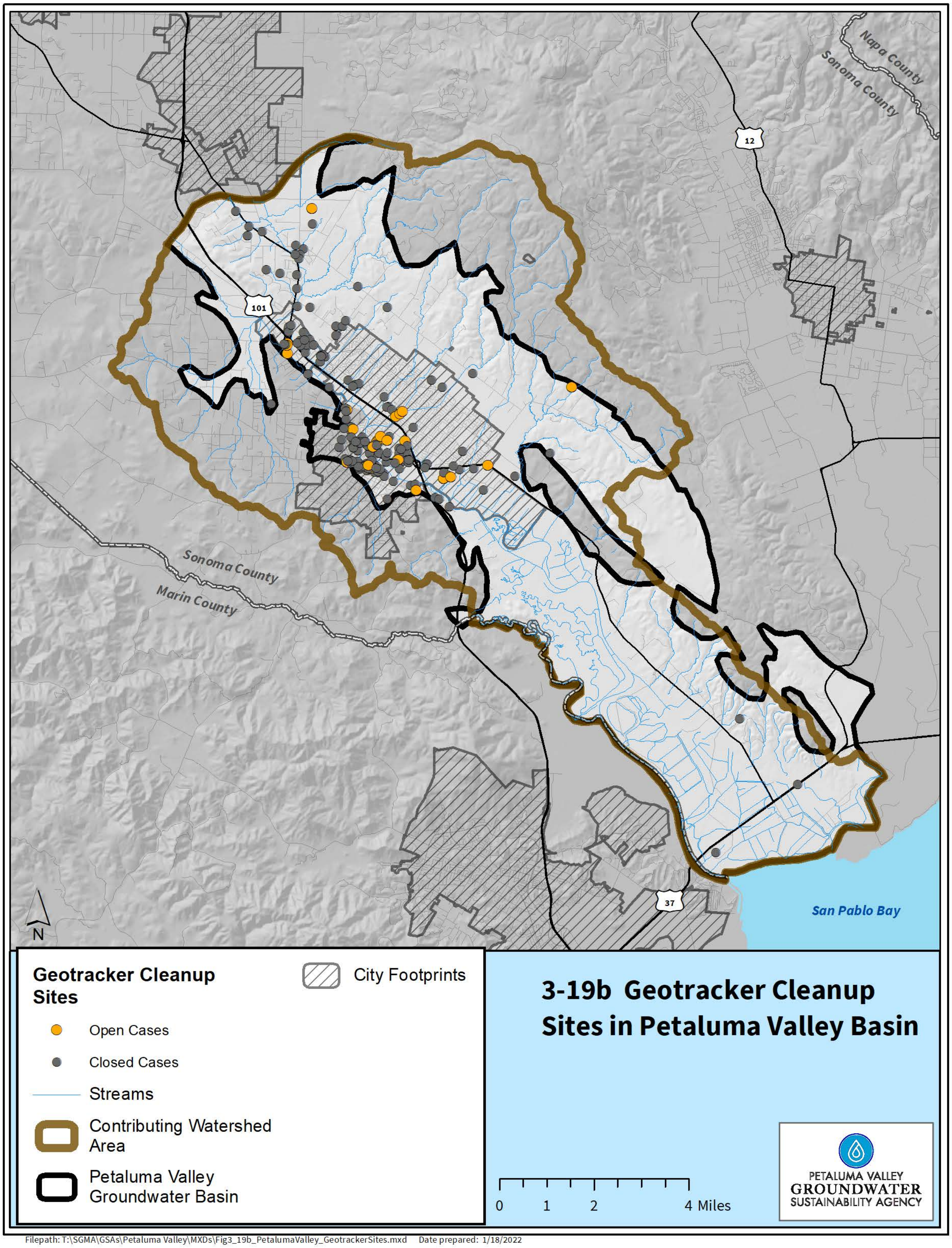
Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_18_PetalumaValley_GSA_WQ_Chloride.mxd Date prepared: 9/4/2021

Figure 3-18. Groundwater Quality – Chloride



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_19_PetalumaValley_GSA_WQ_Nitrate.mxd Date prepared: 1/14/2022

Figure 3-19a. Groundwater Quality – Nitrate



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_19b_PetalumaValley_GeotrackerSites.mxd Date prepared: 1/18/2022

Figure 3-19b. Geotracker Cleanup Sites in Petaluma Valley Basin

High nitrate concentrations historically were found in shallow (less than 200 feet below land surface) wells located in the contributing watershed area just northwest of the Basin and contamination was attributed to previous poultry and dairy operations (DWR 1982). Based on these high nitrate concentrations, the County established requirements for 100-foot seals in wells constructed in this area. Teague (Traum et al. 2022) noted that the absence of high nitrate concentrations in groundwater samples used for the purposes of the USGS study indicate that nitrate contamination has not moved deeper into the aquifer (the majority of wells analyzed as part of the study are deeper public supply wells), but these results should not be interpreted as evidence that nitrate contamination in the shallow part of the Wilson Grove Formation has been resolved in this area.

Regulated Groundwater Contaminant Sites

There are a number of currently regulated contaminant release sites located in the Basin (**Figure 3-19b**). Many of the sites are under active cleanup order by the Regional Water Quality Control Board or County of Sonoma Department of Health Services, Environmental Health and Safety. These sites include leaking underground tanks from gasoline and solvent storage. The SWRCB's GeoTracker website identifies 24 open site cases within the watershed (SWRCB 2021)**.** These releases, which include petroleum and chlorinated solvent contaminants and metals, are generally of limited areal extent. No known impacts on public water-supply wells have occurred related to these release sites.

The SWRCB GAMA Priority Basin Project study of the North San Francisco Bay Groundwater Basins has included two studies by the USGS that evaluated inorganic and organic constituents in groundwater, including constituents associated with regulated contaminant release sites (Kulongoski et al. 2010; Bennett and Fram 2014). The first study conducted in 2004 included samples from 20 public water supply wells in the watershed (Kulongoski et al. 2010). The second study conducted in 2012 included samples from three private domestic wells in the watershed (Bennett and Fram 2014). These samples were analyzed for up to 270 constituents and water-quality indicators, including volatile organic compounds, pesticides, nutrients, major and minor ions, trace elements, radioactivity, microbial indicators, dissolved noble gases, and naturally occurring isotopes (Kulongoski et al. 2010; Bennett and Fram 2014). Three of the 23 public and private wells sampled as part of the GAMA program had very low-level detections of volatile organic compounds and/or pesticides, but all detections were significantly below the contaminant's respective MCLs (Kulongoski et al. 2010; Bennett and Fram 2014).

3.2.5.4 Seawater/Freshwater Interface

The seawater/freshwater interface likely occurs beneath the tidal marshlands near the boundary with San Pablo Bay. Notwithstanding where the precise seawater/freshwater interface exists, the majority of groundwater beneath the tidal marshlands of the Baylands area is likely impacted with brackish groundwater. The poor water quality in these areas is reflected in the well density map (**Figure 2-6**), which shows that very few water wells have historically been completed in these areas.

Teague (Traum et al. 2022) identified three possible sources of saline water to groundwater in the Basin and contributing watershed areas: 1) seawater intrusion, 2) connate water, and 3) water-rock interactions. Groundwater-level data indicate that under baseflow conditions, groundwater near sea level can be vulnerable to infiltration of relatively saline water in the Basin through direct infiltration of San Pablo Bay water or tidally influenced Petaluma River water. Another possible source of saline water to groundwater in the study area is connate water (DWR 1982). Finally, the concentrations of ions dissolved in groundwater are influenced by water-rock reactions, such as dissolution, precipitation, and ionic exchange, which can increase ionic concentrations over time (Traum et al. 2022)

Teague (Traum et al. 2022) used SC and concentrations of TDS and chloride to characterize the sources of saline groundwater in the Basin and its watershed. Waters are generally classified as salinity-affected when TDS concentrations are greater than 1,000 mg/L or when chloride concentrations are greater than 100 mg/L (Tolman and Poland 1940; Iwamura 1980). Farrar et al. (2006) used an SC value of 1,000 microSiemens per centimeter (µS/cm) as the threshold for relatively saline water in the adjacent Sonoma Valley groundwater basin. Teague (Traum et al. 2022) defined salinity-affected water in the Basin and contributing watershed as water with SC values greater than 1,000 µS/cm and chloride concentrations greater than 100 mg/L.

Teague (Traum et al. 2022) identified seven saline-affected wells in the Basin. Teague (Traum et al. 2022) did not find that the source of saline water to these wells was seawater from San Pablo Bay. Five wells were deep (greater than 200 feet) or of unknown depth and located along the axis of the Basin. Because deep wells are not perforated near land surface where infiltration of tidally influenced river water should occur, Teague (Traum et al. 2022) concluded that high SC and Chloride values in these wells were likely the result of water-rock reactions as groundwater moves from recharge areas to the axis of the Basin.

Of the shallow, saline-affected wells, only one well had stable-isotope and groundwater age-dating data. These data indicated that the recharge source to this well was modern infiltration of precipitation indicating that water from land-use activities such as urban runoff or agricultural wastes from irrigation drainage (agricultural return) are affecting the shallow groundwater.

Based on interpretation of stable-isotopic and major-ion data, Teague (Traum et al. 2022) found that water sampled from the tidally influenced reach of the Petaluma River contains San Pablo Bay water that has moved upstream by tidal flow mixed with river water that originated as groundwater discharge. This tidally influenced river water has the highest SC values and chloride concentrations measured in the Basin and contributing watershed. Water sampled from upstream of the tidally influenced reach represents a mixture of groundwater inputs from the Wilson Grove Formation and Quaternary mixed unit that has undergone evaporation.

3.2.6 Surface Water and Groundwater Connectivity

This section describes the mapping of interconnected surface water and groundwater dependent ecosystems (GDEs) within the Basin.

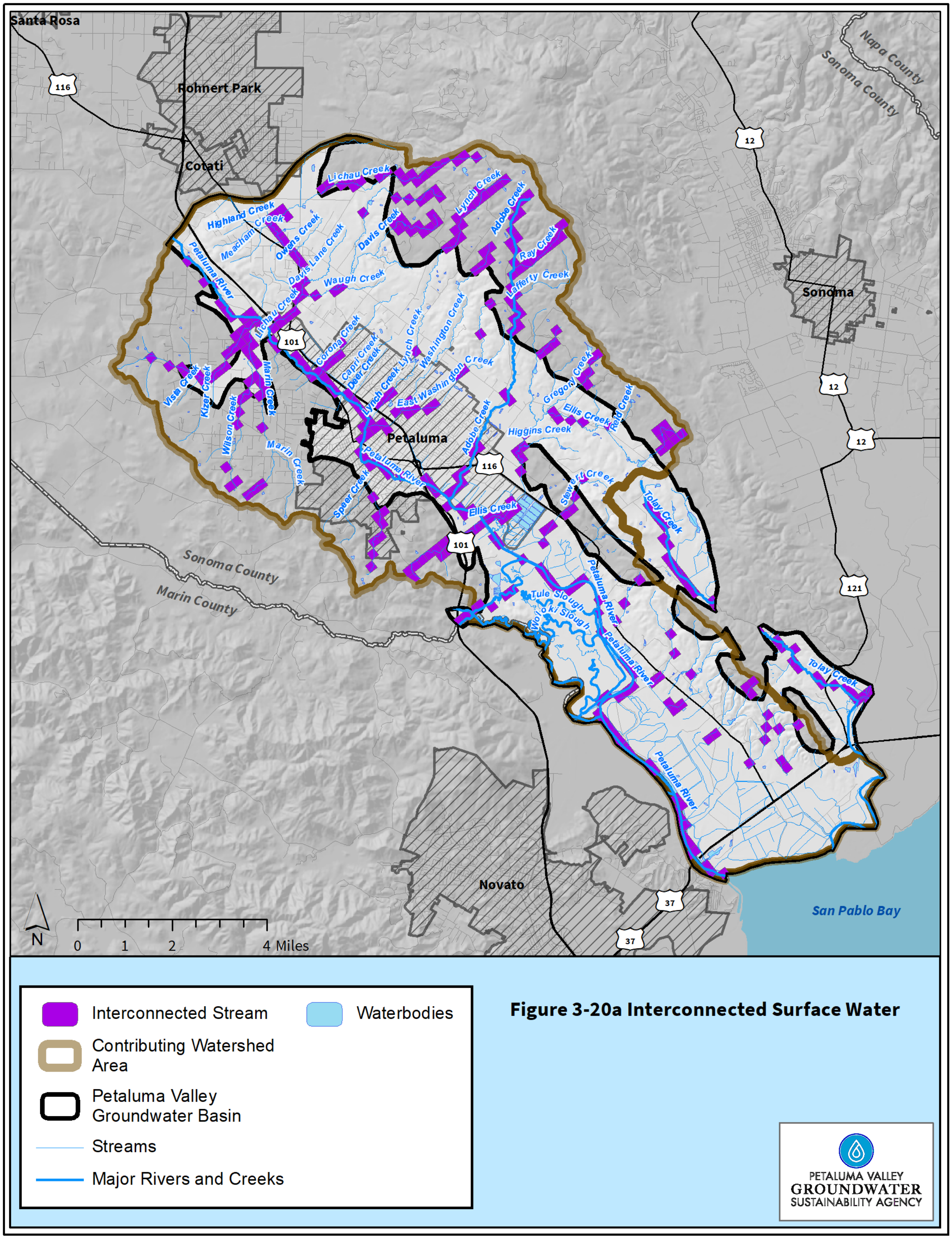
3.2.6.1 Interconnected Surface Water

Interconnected surface water is defined in the GSP Regulations as “surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted” (23 CCR 350 et seq.). Available information to map interconnected surface water is limited within the Basin and is complicated by the presence of tidal-influenced reaches of streams. Initial mapping of interconnected surface water in the Basin was informed by conditions simulated using the hydrologic model developed by the USGS (further described in **Section 3.3**). The model was used to evaluate stream reaches that are simulated to be more interconnected to shallow groundwater. Results of this analysis are provided on **Figure 3-20a** and indicate that much of the mainstem of the Petaluma River, along with the much of Tolay Creek and the lower reaches of Lichau, Lynch, Washington, Adobe, Ellis, and Capri creeks are likely interconnected surface waters. The characterization of the upper reaches of the Petaluma River (upstream of the confluence with Lynch Creek) as interconnected surface water is also supported by data from shallow monitoring well PET0172 and water quality findings by the USGS (Traum et al. 2022). Improvements to mapping of interconnected surface water has been identified as a data gap that will be addressed during implementation of the GSP.

3.2.6.2 Groundwater Dependent Ecosystems

SGMA defines an undesirable result as “depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.” To help characterize environmental beneficial users, it is necessary to identify the aquatic species and habitats that could be adversely affected by lowered groundwater levels in principal aquifers and interconnected surface water depletion. The GSA partnered with the Santa Rosa Plain and Sonoma Valley GSAs to form a practitioners’ work group to provide expert advice and perspectives, which met three times between July and November 2020. Meeting summaries and meeting materials from these meetings are included in **Appendix 4-C**. The Groundwater Dependent Ecosystems Work Group (GDE Work Group) included staff, expert biologists from Sonoma Water, and representatives from the following groups/organizations:

- San Francisco Estuary Institute (SFEI)
- County of Sonoma Ag and Open Space Preservation District
- Sonoma Ecology Center
- California Department of Fish and Wildlife
- Permit Sonoma
- The Nature Conservancy (TNC)
- NOAA National Marine Fisheries Service
- Laguna Foundation



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig3_20a_PetalumaValley_GSA_InterconnectedStreams.mxd Date prepared: 11/10/2021

Figure 3-20a. Interconnected Surface Water

SGMA defines GDEs as "ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface," which generally includes plant and animal communities that rely on shallow groundwater levels or interconnected surface water to meet all or some of their needs. The GDE Work Group focused on mapping aquatic species GDEs and vegetation GDEs that can be affected by groundwater conditions and management and are within the jurisdiction of the GSA. The methodology for mapping potential GDEs used information and guidance developed by TNC (TNC 2018) (https://groundwaterresourcehub.org/).

Aquatic Species Groundwater Dependent Ecosystems

For mapping aquatic species GDEs, species listed in Critical Species LookBook (Rohde et al. 2019) were identified and include steelhead, Chinook salmon, coho salmon, California red-legged frog, and California tiger salamander. The Critical Species LookBook is a compendium of 84 state and federally listed species that are likely to be affected by groundwater management and merit consideration by GSAs under the SGMA. Also, the federal and state endangered California freshwater shrimp was added at the request of resource agency staff. California tiger salamander was excluded because this species has "no known reliance on groundwater" (Rohde et al. 2019). The distribution of target species (species or groups of species specifically chosen for long-term monitoring) is based on Leidy et al. (2005), Salmonid Sample Frame Development for Coastal Monitoring Plan Implementation in the Russian River Watershed, and California Natural Diversity Database.

In Petaluma Valley, the following streams were identified as potential habitat for at least one target species: Adobe, Ellis, Lichau, Lynch, Wiggins, and Willow Brook Creeks and the Petaluma River. Steelhead was the most widespread species occurring in each of the streams except Ellis and Wiggins Creeks, which were identified based on the occurrence of red-legged frogs. To provide a conservative assessment whether any segment of a stream has been identified as habitat for steelhead (priority indicator species for sensitive aquatic species), the entire stream reach downstream of any interconnected reaches is included as sensitive aquatic species GDE.

Vegetation Groundwater Dependent Ecosystems

Vegetation GDEs were mapped by using the high-resolution local mapping available from the Sonoma County Veg Map (Sonoma Veg Map 2013). Classifications considered to have a potential reliance on groundwater included the following general classifications:

- Riparian Woodland
- Oak Woodland
- Freshwater Marsh and Aquatic

To identify where these vegetation classes are likely to have some connection with groundwater conditions within the Basin, the rooting depths of common tree species were compared to available depth-to-groundwater mapping.

Following guidance from TNC, potential vegetation GDEs were mapped for areas with depth to groundwater of 30 feet or less to incorporate the potential rooting depths of oak trees (TNC 2018). The depth to groundwater mapping utilized available contoured springtime datasets for the shallow aquifer system (from 2015 and 2016) and high-resolution LiDAR data. The resulting high-resolution depth-to-groundwater maps used to assess potential rooting depths are included with other GDE Work Group meeting materials and meeting summaries in **Appendix 4-C**. To address GDE Work Group member concerns that groundwater levels were generally at lower levels in 2015 and 2016 due to dry conditions, minor adjustments in some areas were made to incorporate the shallowest depth to water on record for each well based on a review of all available data from 2005 to 2020. Additionally, all riparian woodland and oak woodland habitat within 100 feet of mapped interconnected surface waters were included as potential vegetation GDEs.

Integrated Potential Groundwater Dependent Ecosystem Map

The potential aquatic species GDEs and the potential vegetation GDEs were then integrated into a single potential GDE map presented on **Figure 3-20b**.

As further described in **Section 4** and **Section 7**, additional studies and data gathering are recommended during the implementation of the GSP to better define the mapping and relationship of GDEs to groundwater conditions within the Basin.

3.3 Water Budget

This section summarizes the estimated water budgets for the Basin, including information required by the SGMA Regulations and information that is important for developing an effective plan to achieve sustainability. In accordance with the GSP Regulations Section 354.18, this water budget provides an accounting and assessment of the total annual volume of surface water and groundwater entering and leaving the Basin, including historical, current, and projected water budget conditions, and the change of the volume of groundwater in storage. Water budgets are reported in graphical and tabular formats, where applicable.

3.3.1 Overview of Water Budget Development

This section is subdivided into three subsections: (1) historical water budgets, (2) current water budgets, and (3) future water budgets. Within each subsection, a surface water budget and groundwater budget are presented. Water budgets were developed using the Petaluma Valley Integrated Groundwater Flow Model (PVIHM). The PVIHM was developed by the USGS in conjunction with Sonoma County Water Agency (Traum et al. 2022). The simulation horizon of the USGS model was WY 1960-2015; Sonoma Water subsequently extended the simulation horizon to WY 2018. An overview of the model construction and revisions made to the PVIHM for this GSP is provided in **Appendix 3-C**.

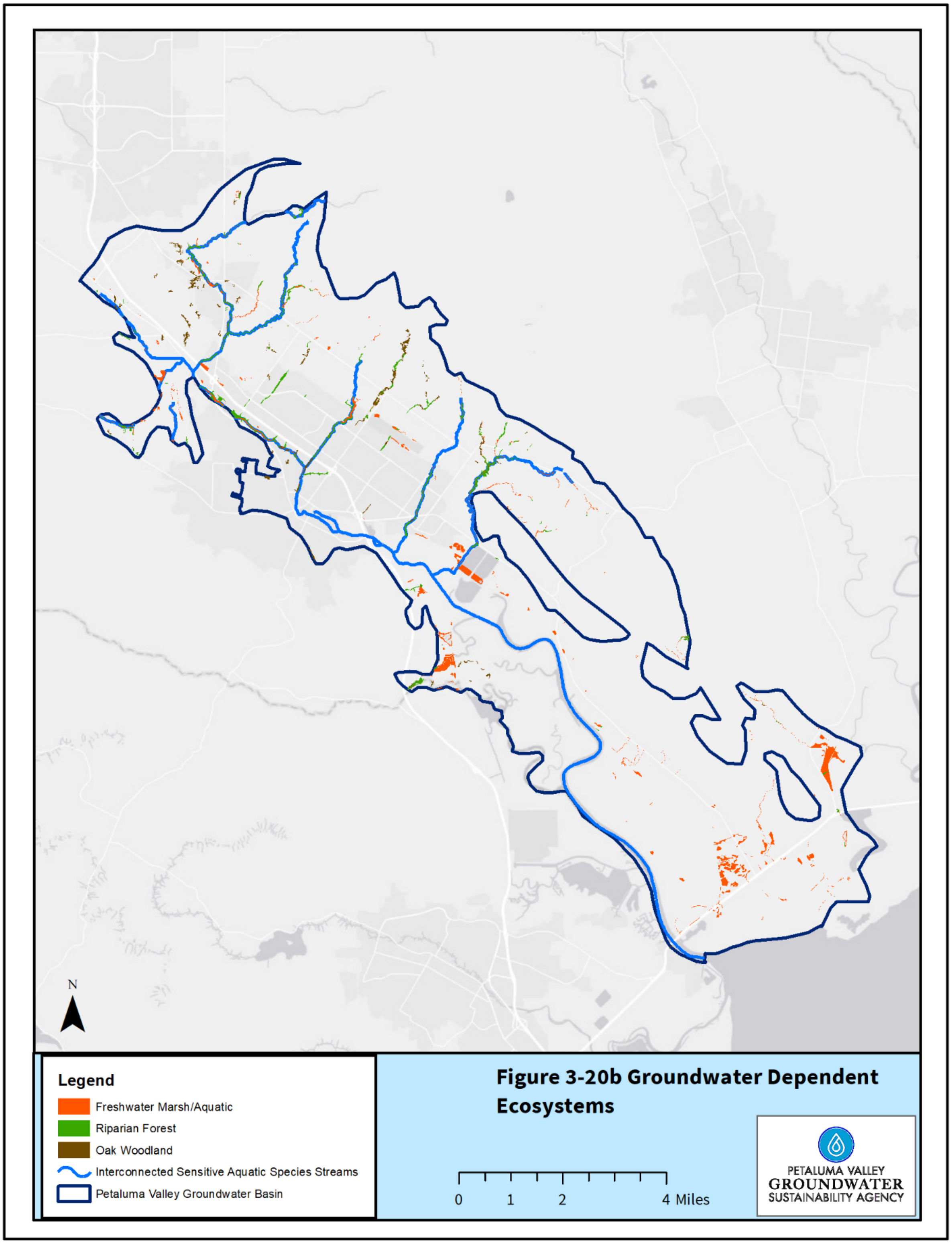


Figure 3-20b. Groundwater Dependent Ecosystems

Before presenting the water budgets, a brief overview of the inflows and outflows pertaining to the Basin is provided.

In accordance with Section 354.18 of the GSP Regulations, one integrated groundwater budget was developed for the combined inflows and outflows for the principal aquifer for each water budget period. Groundwater is pumped from the principal aquifer for beneficial use.

3.3.1.1 Water Budget Components

The water budget is an inventory of surface water and groundwater inflows (supplies) and outflows (demands) from the Basin. A few components of the water budget can be measured, such as streamflow at a gaging station or groundwater pumping from a metered well. Other components of the water budget are estimated, such as unmetered domestic groundwater pumpage and septic return flows. Additional components of the water budget are simulated by PVIHM, such as in-place recharge from precipitation and irrigation, agricultural groundwater pumping, surface water diversions, and change of groundwater in storage.

The water budgets for the Basin are calculated within the following boundaries:

- Lateral boundaries: The perimeter of the Basin relative to the PVIHM grid is shown on **Figure 3-21.**

- Bottom: Base of the groundwater Basin as described in this section. The water budget is not sensitive to the exact definition of this base elevation because it is defined as a depth below where there is not significant inflow, outflow, or change in storage.

- Top: Above the ground surface, such that surface water is included in the water budget.

The Basin includes the following inflows and outflows:

Surface Water Inflows:

- Runoff – Runoff of precipitation and excess irrigation

- Surface water boundary inflow – Lichau Creek, Willow Brook, Lynch Creek, Adobe Creek, Wiggins Hill Creek, San Antonio Creek, Petaluma River, and combination of all other smaller streams

- Groundwater discharge to streams

Surface Water Outflows:

- Stream leakage to groundwater
- Surface water boundary outflow
- Evaporation (negligible compared to other surface water outflows)
- Diversions

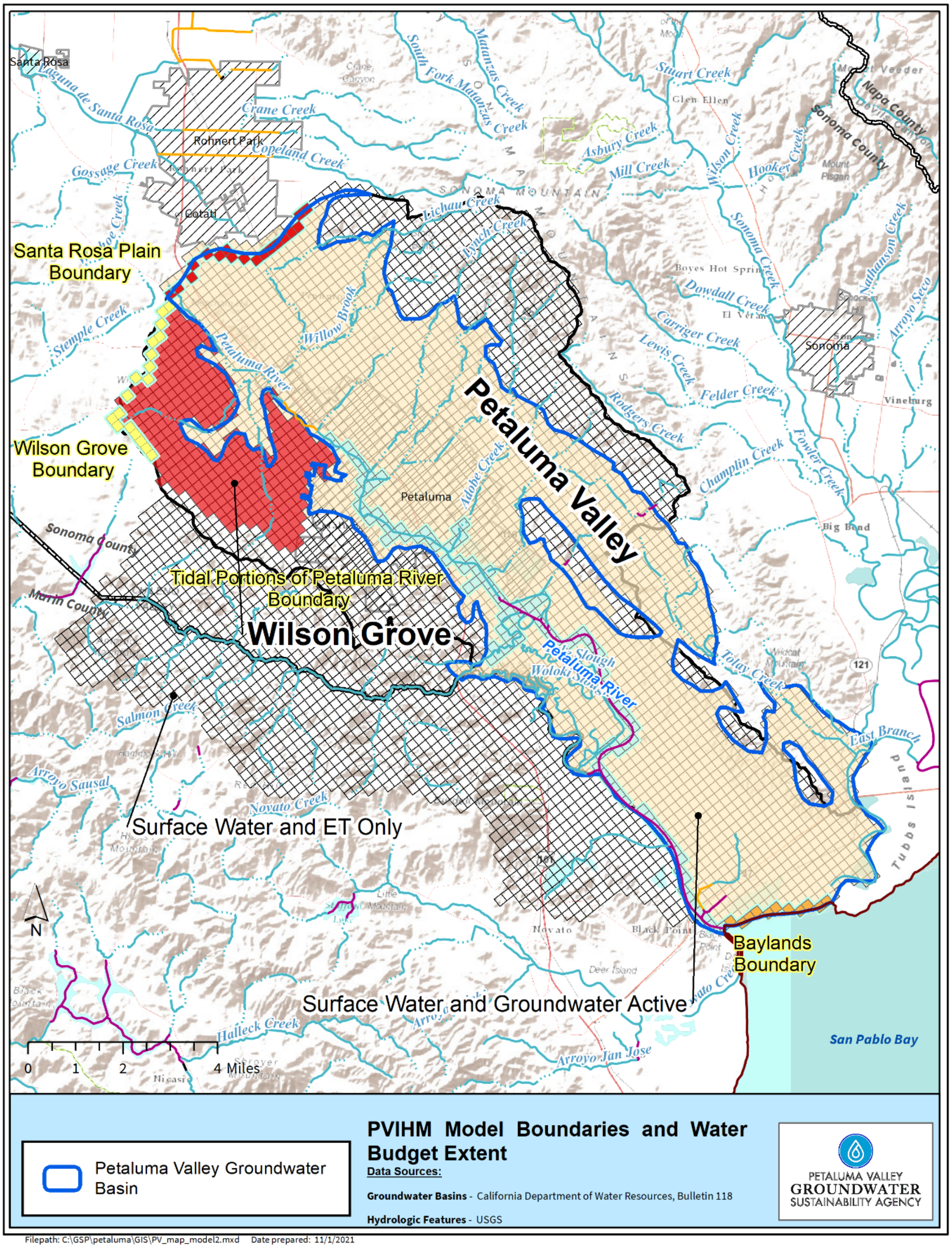


Figure 3-21. Petaluma Valley Basin and PVIHM Active Extent

Figure 3-22 presents the general schematic diagram of the hydrologic cycle that is included in the water budget BMP (DWR 2016d).

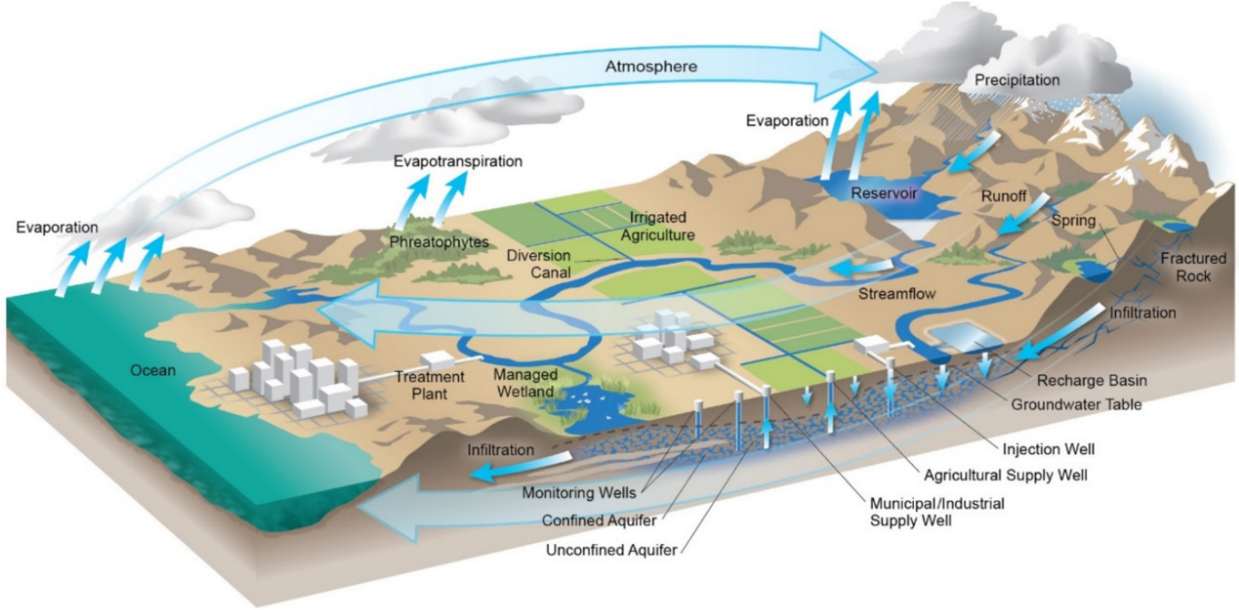


Figure 3-22. Schematic Hydrologic Cycle
Source: DWR 2016d

Groundwater Inflows:

- Septic return flows
- Subsurface Boundary Inflows:
  - Boundary flow from Santa Rosa Plain
  - Boundary flow from Baylands
  - Boundary flow from the Petaluma River
  - Groundwater Inflow from Wilson Grove Formation Highlands Basin
- Areal recharge (includes deep percolation from both precipitation and applied irrigation water)
- Stream leakage to groundwater

Groundwater Outflows:

- Groundwater pumpage (including municipal, rural domestic, and agricultural)
- Subsurface Boundary Outflows:
  - Boundary flow to Santa Rosa Plain
  - Boundary flow to the Petaluma River
  - Boundary flow to the Baylands
  - Groundwater outflow to Wilson Grove Formation Highlands Basin

- Surface Leakage – Rejected recharge occurring where phreatic water levels exceed ground surface elevation
- Groundwater ET from crops, native vegetation, and riparian vegetation
- Groundwater discharge to streams

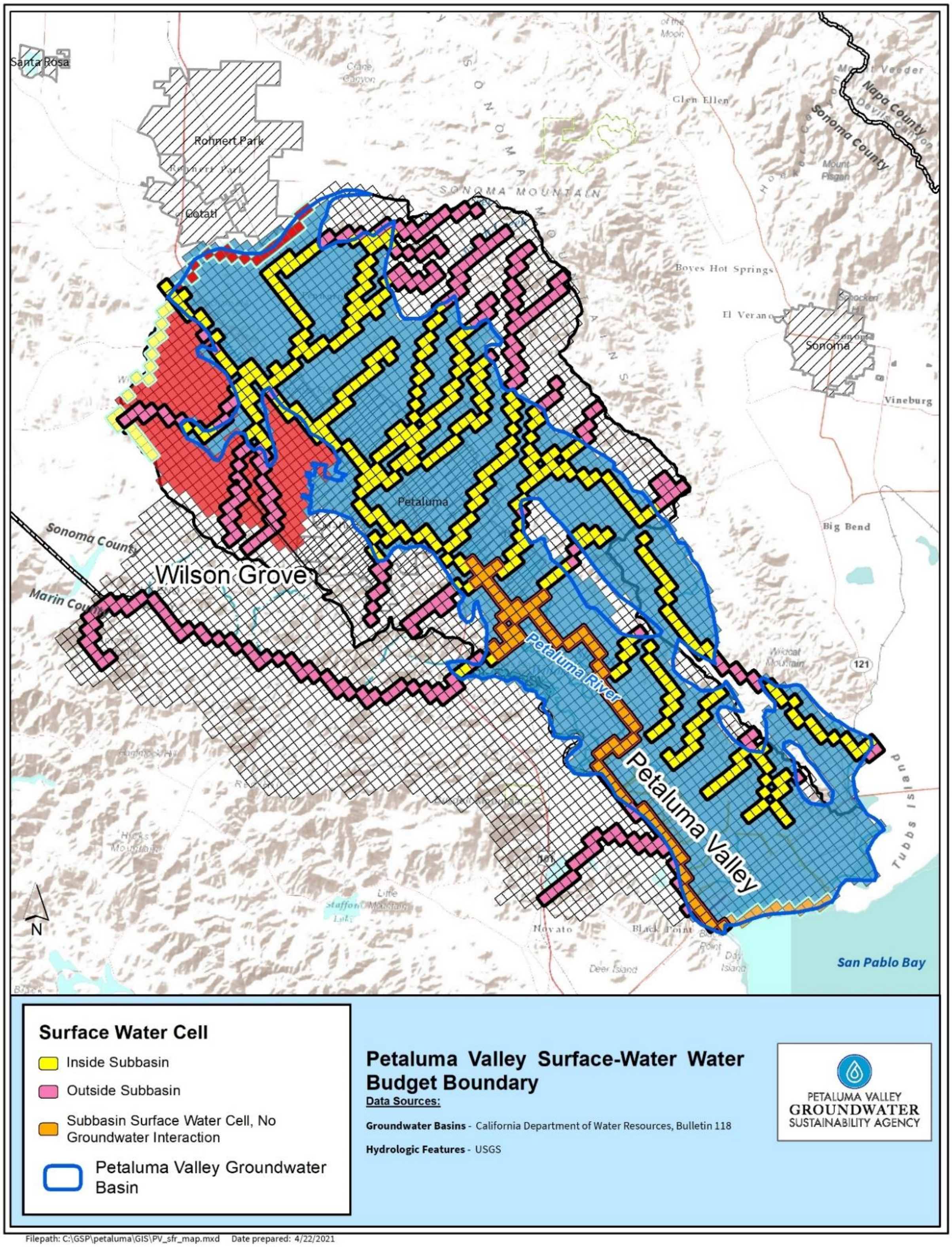
The surface water boundaries, inflow and outflow locations, and model area are shown on **Figure 3-23**. The difference between inflows and outflows is equal to the change in groundwater storage. **Figure 3-24** illustrates how the PVIHM represents the water budget components listed previously. All water budget fluxes are rounded to the nearest 100 acre-feet in each table.

3.3.1.2 Water Budget Time Frames

The GSP Regulations require water budgets for three different timeframes, representing historical conditions, current conditions, and projected conditions. Historical conditions should go back to the most reliable historical data that are available for GSP development and water budgets calculations. Current conditions are generally the "most recent conditions" for which adequate data are available. Current conditions are not well defined by DWR, but can include an average over a few recent years with various climatic and hydrologic conditions (for example, centered around the most recent drought in 2015, which is also the effective date of SGMA). Projected conditions should include a timeframe of 50 years into the GSP planning and implementation horizon, including projected climate change, population, and land use changes.

In accordance with the GSP Regulation 23 CCR Section 354.18(c), the GSP quantifies a historical, current, and projected water budget for the Basin, as follows:

- The historical water budget is intended to evaluate how past water supply availability has affected aquifer conditions and the ability of groundwater users to operate within the sustainable yield. GSP Regulations require that the historical water budget include at least the most recent 10 years of water budget information.
- The current water budget is intended to allow the GSA and DWR to understand the existing supply, demand, and change in storage under the most recent population, land use, and hydrologic conditions.
- The projected water budget is intended to quantify the estimated future baseline conditions without implementation of GSP projects and management actions. The projected water budget is based on information from the historical budget and includes an assessment of uncertainty. The projected water budget estimates the future baseline conditions concerning hydrology, water demand, and surface water supply over a 50-year planning and implementation horizon. It is based on historical trends in hydrologic conditions, which are used to project forward 50 years while considering projected climate change and sea level rise (if applicable).



Filepath: C:\GSP\petaluma\GIS\PV_sfr_map.mxd Date prepared: 4/22/2021

Figure 3-23. Surface Water Budget Boundaries

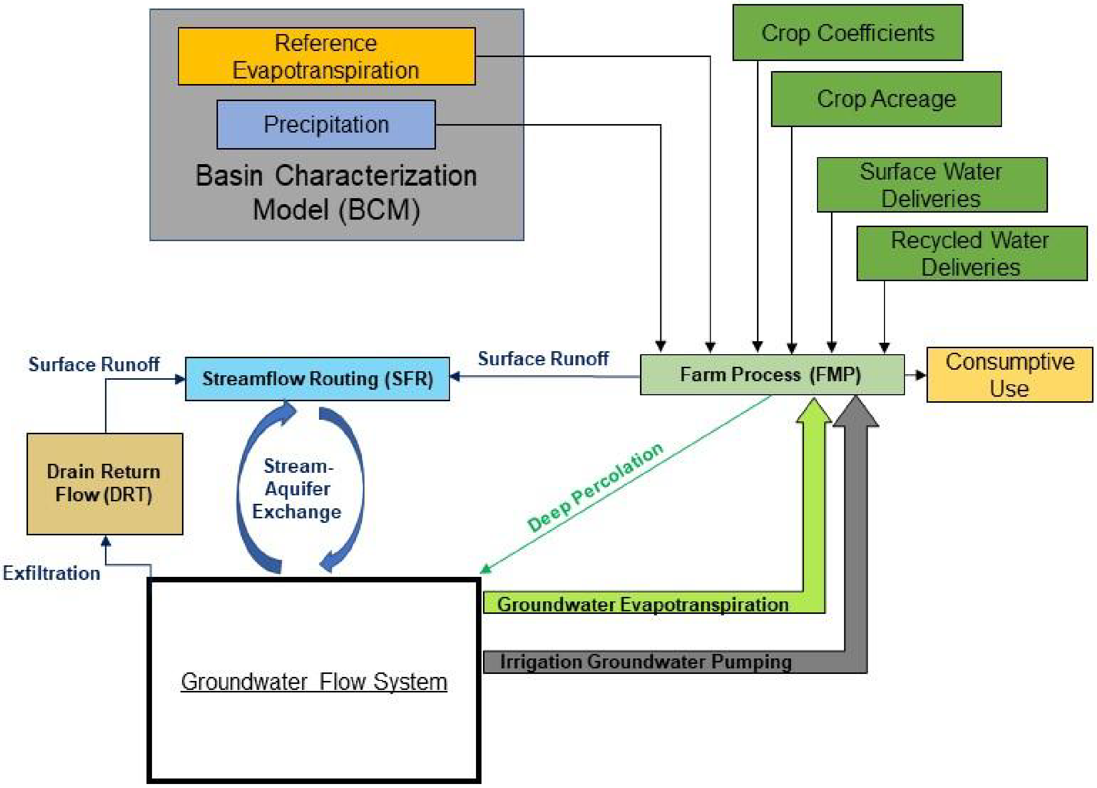


Figure 3-24. Representation of Water Budget Components in Petaluma Valley Integrated Groundwater Flow Model

Although there is a significant seasonal variation between wet and dry seasons in the Basin, the GSP does not consider seasonal water budgets. All water budgets are developed for complete WY(s). The historical and current water budget periods are described in **Table 3-2** and shown on **Figure 3-25**.

Table 3-2. Summary of Historical and Current Water Budget Time Periods

Time Period	Proposed Date Range	WY Types Represented in Time Period	Rationale
Historical	WYs 1969 through 2018	Very dry: 1 Dry: 7 Normal: 23 Wet: 15 Very wet: 2	Based on entire model timeframe (after a 1-year model spin-up period). Provides insights on water budget response to a wide range of variations in climate and groundwater use over an extensive period of record.
Current	WYs 2012 through 2018	Very dry: 0 Dry: 2 Normal: 4 Wet: 1 Very wet: 0	Best reflection of current land use and water use conditions with a range of recent climate variability.

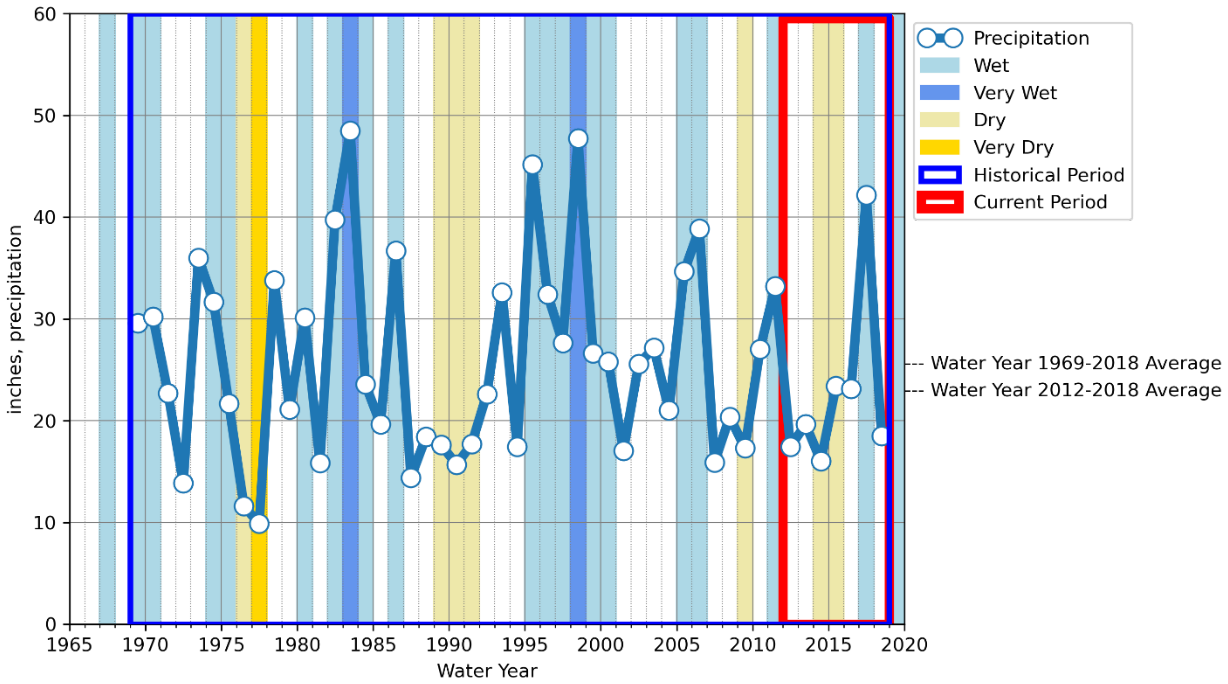


Figure 3-25. Climate and Precipitation for Historical and Current Water Budget Time Periods for the Basin. Precipitation data from PRISM (October 2020) near the Petaluma Airport.

Historical Water Budgets Time Period

The only specific GSP guideline requirement is that the historical water budget be at least 10 years.

> **From Section 354.18. Water Budget:** “A quantitative assessment of the historical water budget, starting with the most recently available information and extending back a minimum of 10 years, or as is sufficient to calibrate and reduce the uncertainty of the tools and methods used to estimate and project future water budget information and future aquifer response to proposed sustainable groundwater management practices over the planning and implementation horizon.”

The historical water budget is computed using the revised PVIHM. As stated previously, the PVIHM simulates the time period from WY 1960 through WY 2018. For consistency with GSPs in neighboring subbasins, the historical period is selected to encompass WY 1969 to WY 2018 (a 50-year period). Selecting a later starting point for the water budget period allows for the removal and dissipation of the influence of the initial conditions on model results.

Current Water Budgets Time Period

The current water budget is based on the average of conditions between WY 2012 and WY 2018 in order to include the entire recent drought period of WY 2012 to WY 2016. In addition, this period includes some post-drought WYs so that a variety of WY types are covered in the current average.

Future Projected Water Budgets Time Period

Future projected conditions are based on model simulations using the revised PVIHM and using projected land use changes, population growth estimates, and a projected climate change scenario. Projected climate based on the selected general circulation model (GCM) will represent WY 2021 through WY 2070.

3.3.2 Overview of Model Assumptions for Water Budget Development

All groundwater models contain assumptions and some level of uncertainty, particularly when predicting future conditions. Model uncertainty stems from heterogeneity in the Basin and the surrounding watershed geology, hydrology, and climate, in addition to assumptions regarding unmetered groundwater pumping. However, inputs to the PVIHM were carefully selected using best available data, resulting in a model well suited to simulate Basin hydrogeologic conditions. As the GSP implementation proceeds, the PVIHM will be updated and recalibrated with new data to better inform model simulations of current and projected water budgets.

Figure 3-24 depicts the PVIHM modules that contribute to the various water budget components. **Table 3-3** provides the detailed water budget components and model assumptions and limitations for each.

Table 3-3. Petaluma Valley Integrated Groundwater Flow Model - Summary of Water Budget Component Data Sources

Water Budget Component	Source of Model Input Data	Limitations
Precipitation	Monthly, spatially distributed precipitation, interpolated to model grid using PRISM. (PRISM Climate Group 2021)	Spatial precipitation distribution may change with changing climate
ET	Monthly, spatially distributed potential ET surfaces computed by BCM v65 (Flint et al. 2013)	Not simulated from surface water bodies or riparian vegetation
Surface Water Inflows		
Surface-Water Boundary Inflows	Simulated from calibrated model	Based on rainfall-runoff process simulated in FMP
Groundwater Discharge to Streams	Simulated from calibrated model	Based on calibration of streamflow with available data from gaged creeks
Runoff	Simulated from calibrated model	Based on calibration of streamflow with available data from gaged creeks
Surface Water Outflows		
Stream Leakage to Groundwater	Simulated from calibrated model	Based on calibration of streamflow with available data from gaged creeks
Diversions	Simulated from calibrated model	Based on estimates of delivered surface-water from the Electronic Water Rights Information Management System (eWRIMS) database

Water Budget Component	**Source of Model Input Data**	**Limitations**
Surface-water Boundary Outflow	Simulated from calibrated model	Based on calibration of streamflow with available data from gaged creeks
Water Budget Component	Source of Model Input Data	Limitations
Groundwater Inflows		
Areal Recharge	Portion from precipitation calculated based on monthly precipitation in excess of effective precipitation Irrigation return flows calculated based on assumed irrigation efficiency	Based on calibrated fraction of inefficient losses to surface water
Stream Leakage to Groundwater	Simulated from calibrated model	Based on calibration of streamflow with available data from gaged creeks
Septic System Return Flows	Locations match rural domestic pumpage and is calculated as a fraction of groundwater pumpage to satisfy indoor water use	Based on rural domestic pumping estimates and assumed return flow fraction
Subsurface Inflow from Adjacent Basins	Based on measured groundwater levels at boundaries with adjacent basins	Dependent on sparse measured data, must be estimated for projected water budget
Inflow from Tidally-influenced Petaluma River and San Pablo Bay	Calculated by the calibrated model given freshwater equivalent head of San Pablo Bay	Based on calibration with groundwater levels
Groundwater Outflows		
Groundwater Pumpage	Metered for historical municipal pumpage and some small water systems	Agricultural and rural domestic pumping is unmetered
	Estimated for non-municipal domestic pumping	
	Simulated for agricultural and large-scale turf irrigation	
Groundwater Discharge to Streams	Simulated from calibrated model	Based on calibration of streamflow with available data from gaged creeks
Subsurface Outflows to Adjacent Basins	Based on measured groundwater levels at boundaries with adjacent basins	Dependent on sparse measured data, must be estimated for projected water budget
ET by Crops, Riparian, and Native Vegetation	Simulated from calibrated model	Based on assumed areal extent, rooting depth, crop coefficients, and available irrigation water supply
Flow to Soil Zone	Simulated from calibrated model	Based on assumed distribution of drainage features in Petaluma Valley lowlands

Some of the more significant model limitations are the following:

- Estimates of agricultural and rural domestic pumpage
- Aquifer hydraulic properties due to complexity of geology
- Data gaps on vertical distribution of hydraulic head in deeper aquifer zones

3.3.3 Historical and Current Water Budgets

3.3.3.1 Surface Water Budget

The surface water budget shows the inflows and outflows of the streams within the Basin. This includes inflow from streams that enter the Basin. Surface water budget inflows include inflow from streams entering the Basin, overland runoff to streams, and groundwater discharge to streams. Surface water budget outflows include streambed recharge to groundwater, surface-water diversions, and stream discharge outside of the Basin. **Figure 3-26** shows the surface water inflows and outflows from streams for the historical period and the current period. The lower panel of **Figure 3-26** shows surface water inflows and outflows from groundwater as well as the net groundwater and surface water exchange for the historical period and current period. **Table 3-4** shows summary statistics of surface water inflows for the historical and current periods.

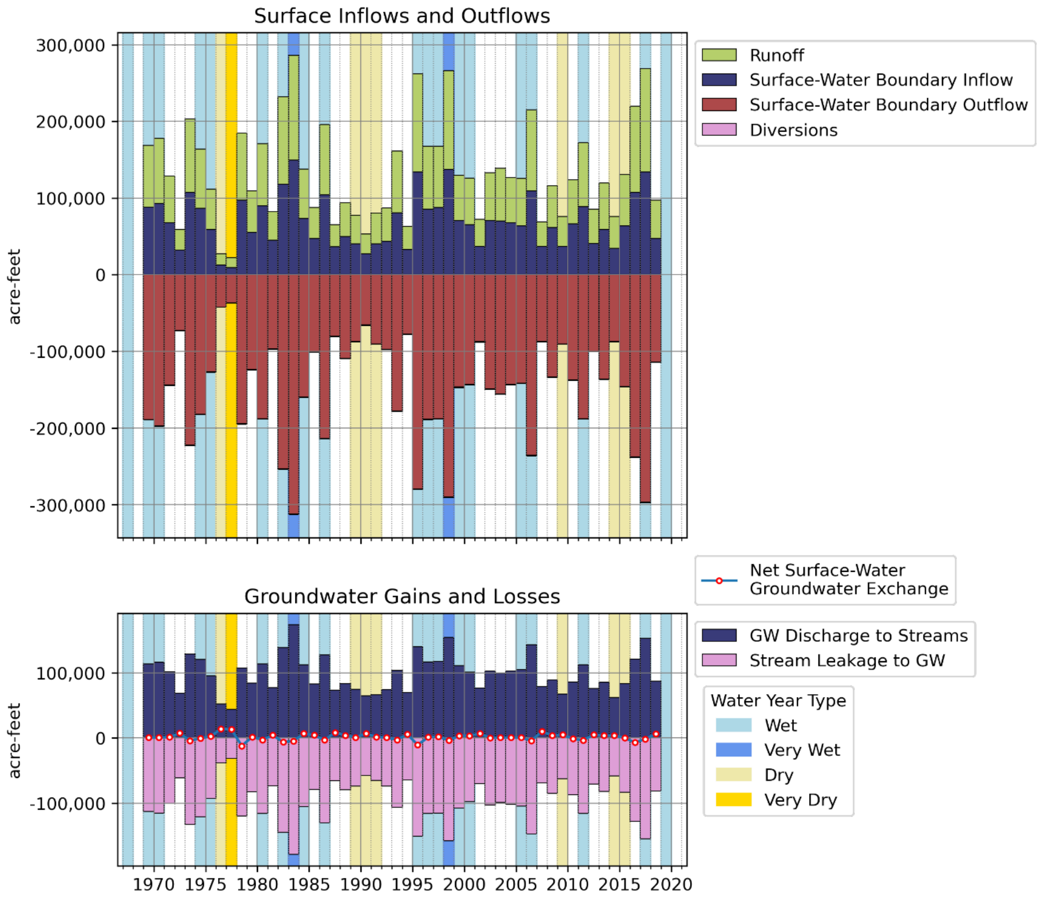


Figure 3-26. Historical and Current Surface Water Inflows, Outflows, and Groundwater Gains and Losses

Table 3-4. Historical (WY 1969 through WY 2018) and Current (WY 2012 through WY 2018) Surface Water Budget Inflows (AFY)[a]

	Historical (WY 1969 through WY 2018)			Current (WY 2012 through WY 2018)		
	Surface-Water Boundary Inflow	Runoff	Groundwater discharge to streams	Surface-Water Boundary Inflow	Runoff	Groundwater discharge to streams
Mean	69,300	65,100	98,800	69,500	73,100	95,500
Minimum	9,200	13,000	43,900	34,600	41,100	62,300
Maximum	149,700	136,000	173,600	133,800	135,300	153,000
Median	65,900	60,700	100,000	58,800	60,800	85,400

[a] Values are rounded to the nearest 100 acre-feet.

Table 3-5 shows summary statistics of surface water outflows for the historical and current periods.

Table 3-5. Historical (WY 1969 through WY 2018) and Current (WY 2012 through WY 2018) Surface Water Budget Outflows (AFY)[a]

	Historical (WY 1969 through WY 2018)			Current (WY 2012 through WY 2018)		
	Surface-Water Boundary Outflow	Diversions	Stream Leakage to Groundwater	Surface-Water Boundary Outflow	Diversions	Stream Leakage to Groundwater
Mean	-150,700	-700	-97,200	-159,600	-600	-93,900
Minimum	-312,100	-900	-178,200	-296,800	-800	-154,500
Maximum	-36,500	-400	-30,800	-87,200	-400	-58,300
Median	-143,100	-700	-97,900	-136,200	-600	-81,800

[a] Values are rounded to the nearest 100 acre-feet.

Figure 3-26 presents the net stream leakage of the Basin. Net stream leakage is calculated as the difference between groundwater discharge to streams and stream leakage to groundwater. Positive net stream leakage values represent conditions where the streams are gaining water from the groundwater system. Negative net stream leakage values represent conditions where streams are losing water to the groundwater system. Net stream leakage varies with climatic variations, and the degree of interconnection between streams and the underlying water table, ranging from nearly -12,000 acre-feet in WY 1978 up to 14,000 acre-feet in WY 1976.

3.3.3.2 Land Surface Budget

The land surface water budget shows the inflows and outflows for the land surface within the Basin. Inflows to the land surface water budget include precipitation, surface water deliveries from stream diversions, recycled water deliveries, and groundwater pumpage deliveries. Outflows from the land surface water budget include consumptive uses such as evaporation and transpiration of precipitation, groundwater (phreatic uptake by plant roots), and irrigation water. Additionally, runoff and deep percolation of precipitation and excess irrigation water are considered outflows from the land surface water budget.

Figure 3-27 shows the land surface sources, consumptive uses of water, and outflows from the land surface water budget for the historical and current periods. **Table 3-7** and **Table 3-8** show summary statistics of land surface water budget outflows for the historical and current periods, respectively.

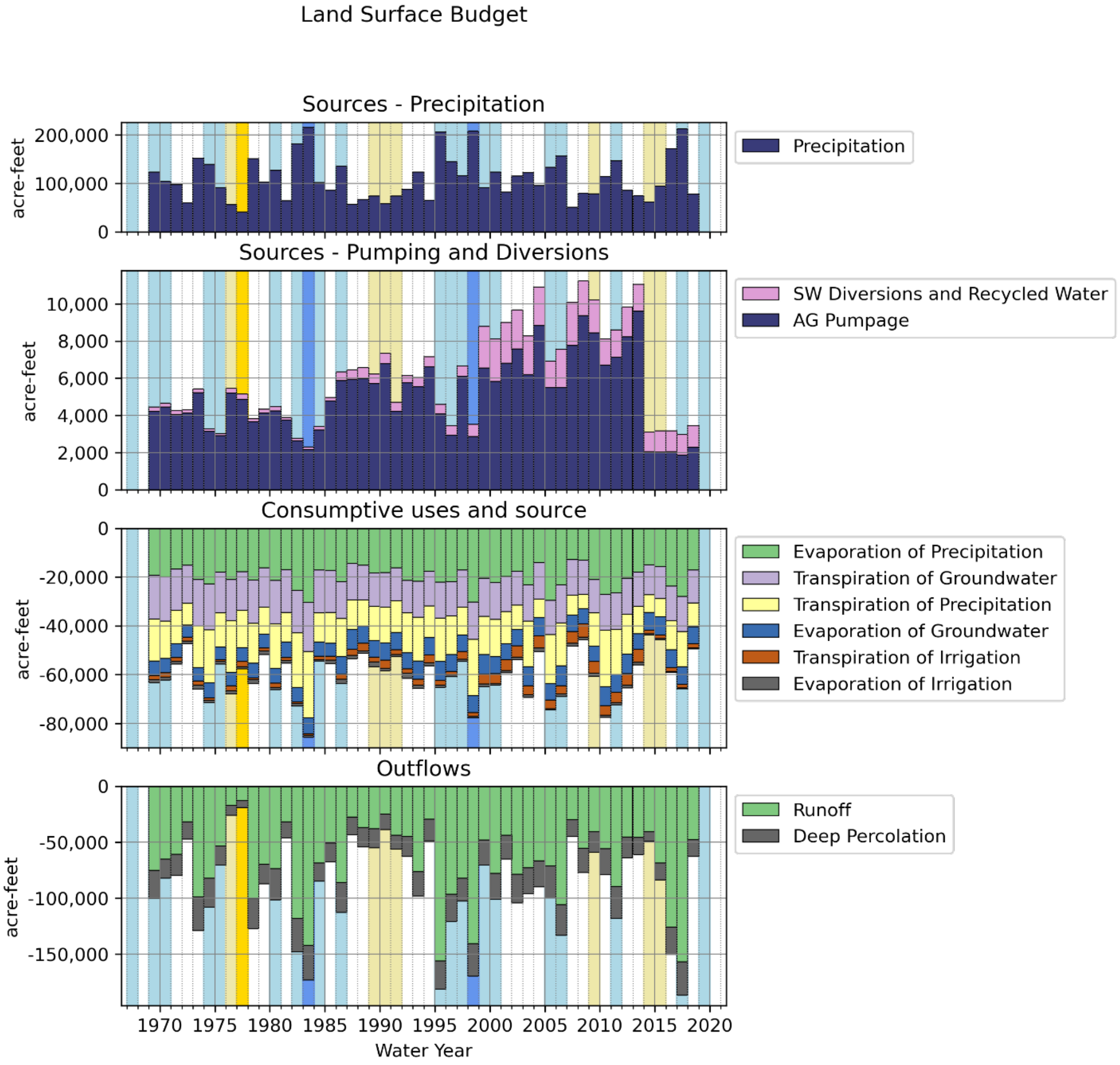


Figure 3-27. Historical and Current Land Surface Budget Inflows and Outflows

Table 3-6. Historical (WY 1969 through WY 2018) and Current (WY 2012 through WY 2018) Land Surface Budget Inflows (AFY)[a]

	Historical (WY 1969 to WY 2018)			Current (WY 2012 to WY 2018)		
	Precipitation	Surface-Water Diversions and Recycled Water	Agricultural Pumpage	Precipitation	Surface-Water Diversions and Recycled Water	Agricultural Pumpage
Mean	109,600	900	5,100	111,300	1,200	4,000
Minimum	41,400	100	1,900	61,300	1,000	1,900
Maximum	215,500	2,300	9,600	212,900	1,600	9,600
Median	99,400	500	5,200	85,800	1,100	2,100

[a] Values are rounded to the nearest 100 acre-feet.

Table 3-7. Historical (WY 1969 through WY 2018) Land Surface Budget Outflows (AFY)[a]

	Evaporation of Precipitation	Transpiration of Groundwater	Transpiration of Precipitation	Evaporation of Groundwater
Mean	20,100	15,400	14,800	6,700
Minimum	30,500	19,900	27,400	8,300
Maximum	12,900	12,100	6,000	4,900
Median	19,900	14,900	14,500	6,800

	Transpiration of Irrigation	Evaporation of Irrigation	Runoff	Deep Percolation
Mean	2,600	1,000	68,200	20,700
Minimum	5,500	2,000	156,900	30,800
Maximum	600	300	12,900	6,200
Median	1,900	1,000	66,000	20,900

[a] Values are rounded to the nearest 100 acre-feet.

Table 3-8. Current (WY 2012 through WY 2018) Land Surface Budget Outflows (AFY)[a]

	Evaporation of Precipitation	Transpiration of Groundwater	Transpiration of Precipitation	Evaporation of Groundwater
Mean	19,700	13,700	11,300	7,200
Minimum	27,900	14,700	16,500	8,000
Maximum	15,100	12,100	7,500	6,300
Median	18,000	14,100	11,200	7,200

	Transpiration of Irrigation	Evaporation of Irrigation	Runoff	Deep Percolation
Mean	2,500	600	75,900	18,300
Minimum	5,300	1,200	156,900	30,000
Maximum	1,500	300	40,700	8,800
Median	1,500	400	47,800	15,800

[a] Values are rounded to the nearest 100 acre-feet.

The difference between deep percolation and combined evaporation and transpiration of groundwater is referred to as "Farm Net Recharge" in the MODFLOW-OWHM model outputs. Positive values of farm net recharge mean that areal recharge exceeds groundwater ET, whereas negative values of farm net recharge mean the opposite. Farm Net Recharge during the historical and current periods is equal to -1,400 and -2,600 AFY, respectively.

3.3.3.3 Groundwater Budget

The groundwater budget shows the inflows and outflows for the saturated aquifer system of the Basin. This includes inflows and outflows of groundwater at the Basin boundaries, areal recharge, pumping, and flows of groundwater to and from streams, the surface, and ET.

Figure 3-28 shows inflows to the groundwater system for the historical and current time periods. **Tables 3-9** and **3-10** display summary statistics for groundwater inflows for the historical and current periods, respectively. The largest inflow is stream leakage to groundwater, which, when combined with boundary flow from the Petaluma River, constitutes about 75 percent of total inflows on average during the historical period. Stream leakage diminishes by approximately 3,000 acre-feet per year on average during the current period as compared to the historical period. Combined inflow from the Santa Rosa Plain and from Wilson Grove constitutes 12 percent of total inflows during the historical period; this value decreases by approximately 1,300 acre-feet per year on average during the current period as compared to the historical period.

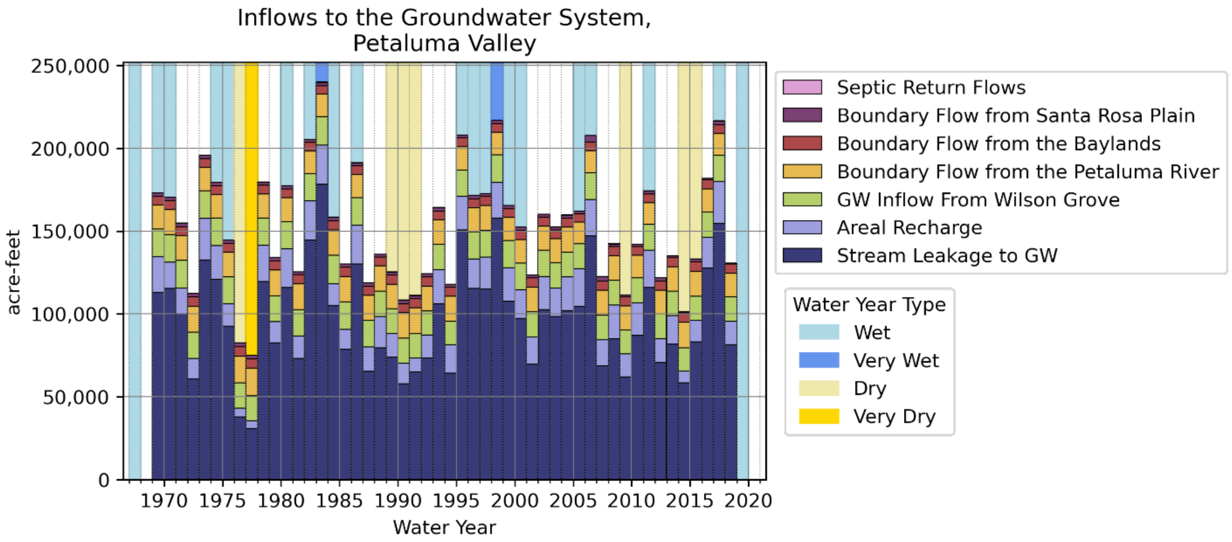


Figure 3-28. Inflows to the Groundwater System

Table 3-9. Historical (WY 1969 through WY 2018) Groundwater Inflows Budget Summary (AFY)[a]

	Septic Return Flows	Boundary Flow from Santa Rosa Plain	Boundary Flow from the Baylands	Boundary Flow from the Petaluma River	Groundwater Inflow from Wilson Grove	Areal Recharge	Stream Leakage to Groundwater
Mean	100	1,800	5,400	14,600	15,700	17,200	97,200
Minimum	100	600	5,100	13,100	14,100	4,900	30,800
Maximum	100	3,900	5,700	16,800	17,300	25,500	178,200
Median	100	1,800	5,500	14,600	15,700	17,300	97,900

[a] Values are rounded to the nearest 100 acre-feet.

Table 3-10. Current (WY 2012 through WY 2018) Groundwater Inflows Budget Summary (AFY)[a]

	Septic Return Flows	Boundary Flow from Santa Rosa Plain	Boundary Flow from the Baylands	Boundary Flow from the Petaluma River	Groundwater Inflow from Wilson Grove	Areal Recharge	Stream Leakage to Groundwater
Mean	100	1,300	5,500	14,400	14,900	15,700	93,900
Minimum	100	600	5,200	13,100	14,100	7,200	58,300
Maximum	100	2,300	5,700	15,300	15,700	25,500	154,500
Median	100	900	5,500	14,300	14,800	14,700	81,800

[a] Values are rounded to the nearest 100 acre-feet.

Figure 3-29 shows simulated outflows from the groundwater system for the historical and current time periods. **Table 3-11** and **Table 3-12** provide summary statistics for groundwater outflows of the historical and current period, respectively. Groundwater discharge to streams is the largest groundwater outflow for the historical and current time periods. Total groundwater pumpage, including municipal and industrial (M&I), rural domestic, and agricultural constitutes approximately 4 percent of the total outflow from the groundwater system during the historical period, and 3 percent during the current period.

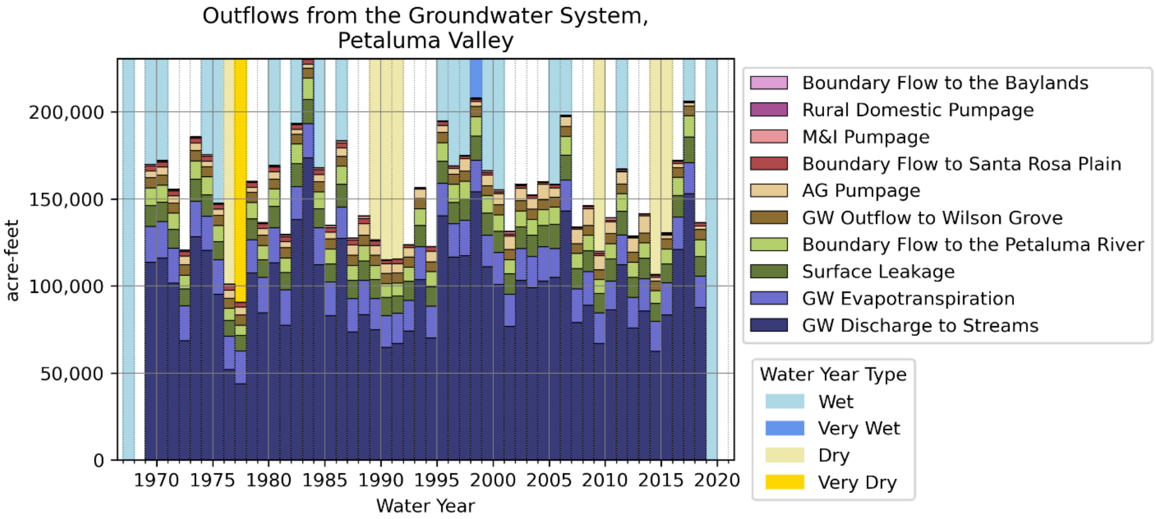


Figure 3-29. Simulated outflows from the Groundwater System

Table 3-11. Historical (WY 1969 through WY 2018) Groundwater Outflows Budget Summary (AFY)[a]

	Boundary Flow to the Baylands	Rural Domestic Pumpage	M&I Pumpage	Boundary Flow to Santa Rosa Plain	Agricultural Pumpage
Mean	0	200	500	1,900	5,100
Minimum	0	100	0	400	1,900
Maximum	0	300	1,400	3,100	9,900
Median	0	300	500	1,800	4,800

	Groundwater Outflow to Wilson Grove	Boundary Flow to the Petaluma River	Surface Leakage	Groundwater ET	Groundwater Discharge to Streams
Mean	5,800	9,300	11,700	18,800	98,800
Minimum	5,600	5,700	9,100	16,500	43,900
Maximum	6,000	12,100	14,800	21,100	173,600
Median	5,800	9,200	11,800	18,600	100,000

[a] Values are rounded to the nearest 100 acre-feet.

Table 3-12. Current (WY 2012 through WY 2018) Groundwater Outflows Budget Summary (AFY)[a]

	Boundary Flow to the Baylands	Rural Domestic Pumpage	M&I Pumpage	Boundary Flow to Santa Rosa Plain	Agricultural Pumpage
Mean	0	300	200	1,000	4,000
Minimum	0	300	0	500	1,900
Maximum	0	300	400	1,700	9,900
Median	0	300	200	900	2,200

	Groundwater Outflow to Wilson Grove	Boundary Flow to the Petaluma River	Surface Leakage	Groundwater ET	Groundwater Discharge to Streams
Mean	5,700	9,400	11,800	18,000	95,500
Minimum	5,600	7,400	10,000	17,500	62,300
Maximum	5,700	12,000	14,800	18,500	153,000
Median	5,700	8,900	11,400	18,000	85,400

[a] Values are rounded to the nearest 100 acre-feet.

The MODFLOW-OWHM code prints Farm Net Recharge to gridded model outputs. Areal recharge listed in **Table 3-11** is equal to the total Farm Net Recharge in cells where the value of Farm Net Recharge is positive. Conversely, groundwater ET listed in **Table 3-12** is equal to total Farm Net Recharge in cells where the value of Farm Net Recharge is negative. The difference between areal recharge (**Table 3-11**) and groundwater ET (**Table 3-12**) is equal to Farm Net Recharge over the Basin.

Farm Net Recharge for the historical and current periods is equal to -1,600 AFY and -2,300 AFY, respectively. Minor discrepancies in Farm Net Recharge between the Land Surface Water Budget (**Section 3.3.3.2**) and the Groundwater Budget are due to the way that those terms are printed to MODFLOW-OWHM output files.

Figure 3-30 shows groundwater pumpage by water use sector for the historical and current periods. **Table 3-13** provides summary statistics for groundwater pumpage by water use sector during the historical and current periods. Mean annual groundwater pumpage is 1,300 AFY lower during the current period compared to the historical period. This reduction is due primarily to changes in irrigated pasture acreage that occurred during the current period. Changes in total groundwater pumping between the historical and current periods also reflect reductions in M&I pumping.

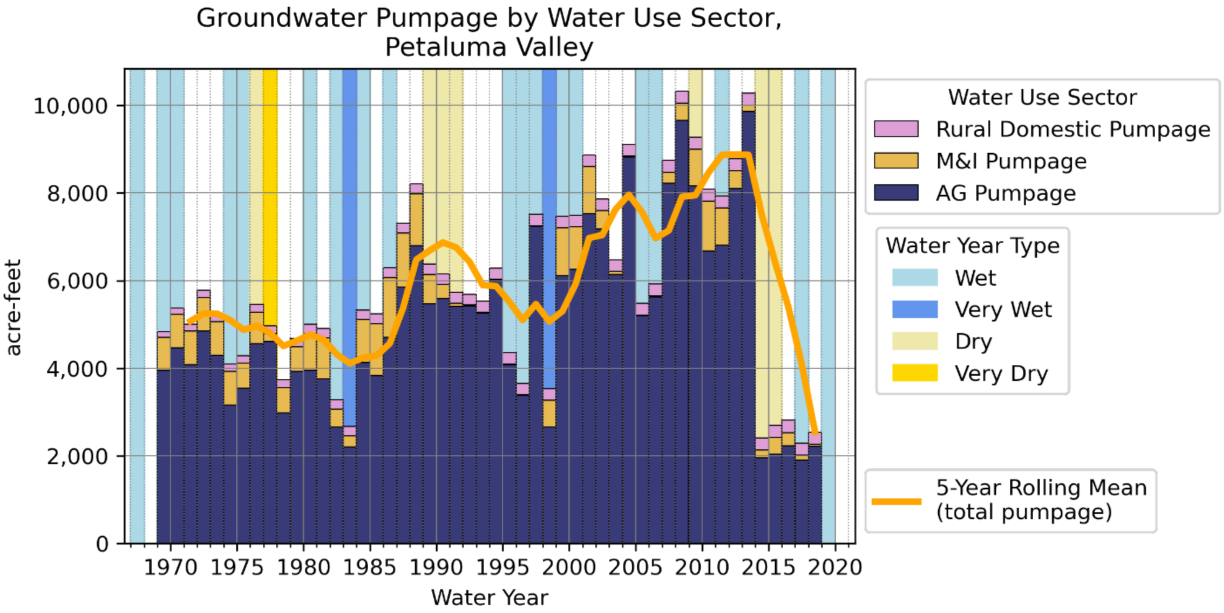


Figure 3-30 Groundwater Pumpage by Water Use Sector

Table 3-13. Historical (WY 1969 through WY 2018) Groundwater Pumpage by Water Use Sector (AFY)[a]

	Historical (WY 1969 through WY 2018)			Current (WY 2012 through WY 2018)		
	M&I Pumpage	**Rural Domestic Pumpage**	**Agricultural Pumpage**	**M&I Pumpage**	**Rural Domestic Pumpage**	**Agricultural Pumpage**
Mean	500	200	5,100	200	300	4,000
Minimum	0	100	1,900	0	300	1,900
Maximum	1,400	300	9,900	400	300	9,900
Median	500	300	4,800	200	300	2,200

[a] Values are rounded to the nearest 100 acre-feet.

3.3.3.4 Groundwater Storage Change

Figure 3-31 shows the entire groundwater water budget and also includes the annual change in groundwater storage. Change in groundwater storage is equal to total inflow minus total outflow in the groundwater budget. A negative change in groundwater storage indicates groundwater-storage depletion while a positive value indicates groundwater-storage accretion. **Table 3-14** shows the mean annual change in groundwater storage, as well as the minimum, maximum, and median for the historical and current time periods. The mean annual groundwater storage change over the historical period is about -40 AFY, but is rounded and reported as 0 AFY in **Table 3-14**. The current period, which includes the recent drought, shows a mean annual decline of 100 AFY in groundwater storage. The two largest drops in groundwater storage occurred in the drought of 1976–1978 and the largest increase in groundwater storage was the year following that drought (**Figure 3-31**). By about WY 1982 groundwater storage rebounded to the initial storage from WY 1970. From WY 1982 through WY 1992 groundwater storage declined, followed by a period of recovery associated with relatively wet conditions during WY 1995 through WY 2002. Cumulative storage change at the end of WY 2018 is a total change of -2,000 acre-feet.

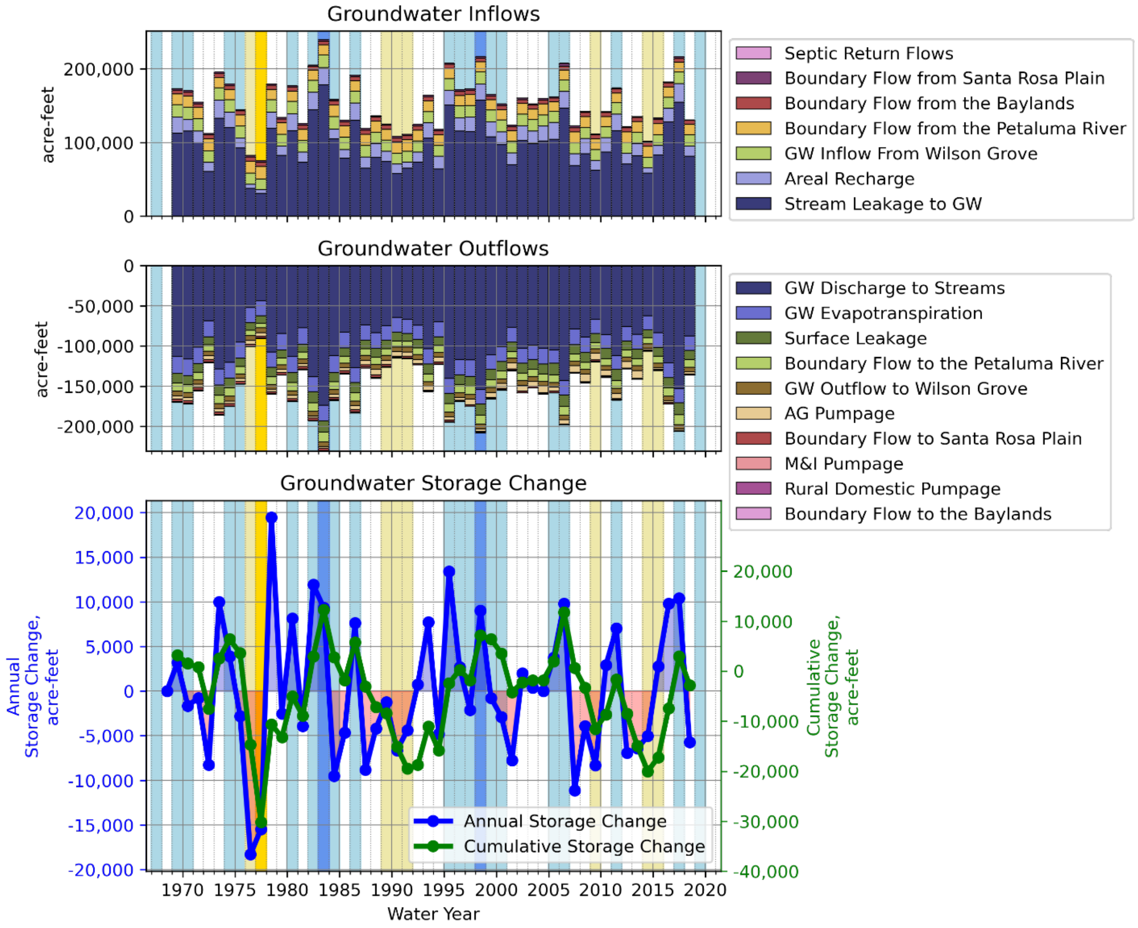


Figure 3-31. Simulated Historical and Current Groundwater Budget: Groundwater Inflows, Groundwater Outflows, and Change in Groundwater Storage

Table 3-14. Average and Annual Change of Groundwater in Storage (AFY)[a] {b]

	Historical (WY 1969 through 2018)	**Current (WY 2012 through 2018)**
Mean	0	-100
Minimum	-18,300	-6,900
Maximum	19,500	10,400
Median	-1,000	-5,000

[a] Values may not equal inflows minus outflows due to rounding.

[b] Values are rounded to the nearest 100 acre-feet.

3.3.3.5 Water Budget Summary

For the historical and current periods, the main groundwater inflows into the Basin are (1) stream leakage to groundwater, (2) areal recharge, and (3) groundwater inflow from the Wilson Grove Formation Highlands Basin. Together these inflows constitute 86 percent of inflows into the Basin during the historical period. Subsurface inflow from the Petaluma River is comparable to subsurface inflow from Wilson Grove. Subsurface inflow from the Baylands, subsurface inflow from the Santa Rosa Plain, and septic return flows are smaller inflows when compared to the others. The primary groundwater outflow component is the groundwater discharge to streams, which is approximately 65 percent of the total outflows from the Basin. Agricultural pumpage, surface leakage, and groundwater ET comprise about 23 percent of groundwater outflows. The smaller outflow terms are rural domestic and M&I pumpage, subsurface outflow to adjacent areas outside of the Basin, and groundwater outflow to the Petaluma River.

From 1969 to 2013, total groundwater pumpage increased from 4,900 AFY to 10,300 AFY. Since 2013, total groundwater pumpage has decreased to an average of approximately 2,500 AFY. Reductions in groundwater pumping are due primarily to changes in irrigated pasture acreage that occurred during the current period.

Areal recharge ranged from a low of approximately 5,300 AFY in WY 1976 to a high of approximately 25,500 AFY in WY 2017. Areal recharge declined to about 10,100 AFY during WY 2014 and WY 2015, but has subsequently recovered to near average inflow rates during WY 2016 through WY 2018.

There was negligible net change in groundwater storage simulated over the historical period, while a net loss of about 100 AFY of groundwater storage was simulated over the current period (**Table 3-1**).

3.3.4 Basin Water Supply Reliability

Based on analysis conducted for Sonoma Water's 2020 UWMP (Sonoma Water 2021), Sonoma Water has adequate water supply to deliver imported surface water through the 2045 planning horizon analyzed in the 2020 UWMP. The exception are single-dry years, starting after 2025. For single-dry years, model simulations predict that storage levels in Lake Sonoma will drop below 100,000 AF prior to July 15th, thus requiring demand curtailments by Sonoma Water customers per SWRCB Decision 1610 (SWRCB 1986) for some portion of the year. In these circumstances, Sonoma Water will work with its customers to reduce demands on the imported surface water. Based on efforts over the last 5 years during dry conditions, Sonoma Water does not anticipate any difficulty in maintaining an adequate supply of imported surface water during the single-dry year. The magnitude of these single-dry year potential shortfalls is estimated to be about 19 percent of average annual demand by 2045. This condition is accounted for in the baseline projected water budget developed for this GSP by assuming higher levels of groundwater demands from Sonoma Water contractors during dry conditions.

3.3.5 Uncertainties in Water Budget Calculations

The level of accuracy and certainty is highly variable among water budget components. A few water budget components are directly measured, but most water budget components are estimated as input to the model or simulated by the model. Both estimated and simulated values are based on assumptions and there is additional model uncertainty for simulated results. Model uncertainty stems from an imperfect representation of natural conditions and is reflected in model calibration error. However, inputs to the model are carefully selected using best available data, the model's calculations represent established science for groundwater flow, and the model calibration error is within acceptable bounds. Therefore, the model is the best available tool for estimating water budgets.

The following lists groups of water budget components in order from least to most uncertain. Simulated components based on the calibrated model have the greatest uncertainty because those simulated results encompass the uncertainty of other water budget components used in the model in addition to model calibration error.

- Measured: metered municipal and some small water system pumpage
- Estimated: non-municipal domestic pumpage and septic system return flow, including depth and location
- Simulated by external BCM (Flint et al. 2013) based on climate data: precipitation, reference ET
- Simulated based on calibration model: actual ET and irrigation pumpage, including depth and location
- Simulated based on calibrated model: all other water budget components

3.3.6 Projected Water Budgets

SGMA legislation and GSP Regulation requirements for projected water budgets are as follows:

- Simulate projected groundwater conditions 50 years into the future
- Incorporate projections of land use change, climate change, and other changes in groundwater demands (such as population increase)

The results of the simulation will be used to assess how the sustainability indicators respond to changing climate and groundwater demands in the future. If undesirable results are simulated to occur, the GSP will need to plan for projects and management actions that respond to the undesirable results.

Projected water budgets will be useful for showing that sustainability will be achieved in the 20-year implementation period and maintained over the 50-year planning and implementation horizon.

The predictive simulation used to develop projected water budgets covers the time period from WY 2021 through WY 2070. The projected water budget is developed using a predictive simulation from the PVIHM that incorporates a climate change scenario.

3.3.6.1 Method and Assumptions used to Develop Projected Water Budgets

Future projected conditions are based on model simulations using the updated PVIHM numerical flow model and using estimates of:

- Projected land use changes
- Projected population growth
- Projected climate change

Future Projected Land Use Change and Water Demand Assumptions

Assumptions for future projected land use changes and water demands were estimated for rural residential groundwater pumping, the agricultural land use footprint, and municipal demands. Several workgroups and surveys helped develop the data used in the projected model. Assumptions for each set of data are described and numbers are provided in **Appendix 3-D.**

Municipal purveyors provided ranges of projected demands based on a combination of historical and potential future use. The projections included higher-end ranges for GSP planning that are generally higher in comparison with planning projections for urban water management plans.

To capture these ranges and incorporate potential climate variability in the model:

- For the City of Petaluma, with both delivered water and groundwater sources, varied annual future pumpage based on projected future climate year classifications (very dry, dry, normal, wet, very wet) using calculated standard deviation from historical pumpage records

- Applied patterns of seasonality of groundwater production based on historical wellfield operations

The PVIHM historical period simulation assumes that water levels are maintained at or below ground surface in the lower part of the Basin near San Pablo Bay. This assumption was carried forward into the future period. The projected simulation does account for sea level rise (refer to the following section).

Projected Climate Change Simulation Approach

SGMA requires the incorporation of climate change and sea level rise into projected future simulation scenarios for purposes of assessing the impact of climate change on groundwater conditions, demands, and availability, and for identifying uncertainties in future conditions when including projects and management actions and identifying SMC. For the GSP, after a review of DWR climate change guidance and recommendations, the GSA decided to choose one potential climate change scenario representative of regional conditions to limit the number of simulations and provide better comparability between various potential projects and actions. During the 5-year GSP update, the status of climate change science will be assessed and the use of different climate futures will be considered, as appropriate.

Projections of future climate conditions are generally performed through GCMs forced with specific global greenhouse gas (GHG) emissions scenarios (IPCC 2013). A description of GCM selection is provided in **Appendix 3-E**. Sea level rise assumptions were developed and applied separately.

The overall approach for selecting and simulating projected climate change can be summarized as follows:

1. Chose a projected climate future by selecting regionally representative GCM and then selecting a specific GHG emissions scenario
    a. Review DWR-recommended GCMs and chose one GCM and emissions scenario that best represents projected median conditions in the Russian River Watershed area (including groundwater basins)
2. Updated model inputs for:
    a. Precipitation
    b. Temperature/ET
    c. Groundwater inflow
    d. Sea level rise boundary conditions at San Pablo Bay
3. Used climate data in the model to:
    a. Define precipitation and calculate potential ET and actual evaporation and transpiration
    b. Calculate projected irrigation water demands and groundwater pumping
    c. Evaluate the effects of projected sea level rise on groundwater levels

Selection of Regional Representative General Circulation Model

The projections reviewed for purposes of developing this GSP relied upon available climate projections using the models and emissions scenarios included in the Coupled Model Intercomparison Project 5 (CMIP5). Twenty individual downscaled GCM projections were reviewed using ten different GCMs and two different Representative Concentration Pathways (RCPs), RCP 4.5 and RCP 8.5 for each model (**Appendix 3-E**). The 10 GCMs were chosen by the DWR Climate Change Technical Advisory Group based on a regional evaluation of climate model ability to reproduce a range of historical climate conditions (DWR CCTAG 2015) and are contained in the California Fourth Climate Change Assessment.

For GSP planning purposes, it is desirable to identify projected climate scenarios that best represent the climate and hydrologic conditions within the Russian River watershed and Sonoma County. To identify the model that was most representative of the Russian River watershed, a technical analysis was conducted to compare how well each model performed relative to historical data for objective metrics (for example, river flow and reservoir storage). The evaluation identified the HadGEM2-ES GCM as best representing the middle of the ensemble for mean climate and hydrologic metrics for the Russian River watershed and did not stray to any of the extremes for other metric rankings.

Greenhouse Gas Emissions Scenario

Upon selection of the HadGEM2-ES model, the next step focused on selection of an emissions scenario. Emissions scenarios are possible pathways that society might take regarding the emission of GHG in the future. Each pathway is categorized as an RCP. DWR has recommended the use of two potential RCPs: RCP 4.5 and RCP 8.5. RCP 4.5 is sometimes considered “most likely” based on current projections of GHG emissions, and RCP 8.5 is often known as “worst-case scenario.” Experts and scientists contacted by GSA staff have differing views on which emissions scenario is more likely, although many acknowledge that selection of an emissions scenario is not a technical or scientific issue but rather a societal issue. Accordingly, the process to select which emissions scenario to use was based on several Advisory Committee and GSA Board meetings in addition to a focused workshop for the three Sonoma County SGMA basins and subbasins. As part of this effort, the model results for both RCP 4.5 and RCP 8.5 for the Santa Rosa Plain Subbasin were presented and discussed. In general, the model results indicated that RCP 8.5 was the worst-case scenario (relative to RCP 4.5) in terms of groundwater storage, groundwater recharge, groundwater discharge to streams, and pumping. RCP 8.5 provided a stiffer stress test for groundwater resources due to a forecasted sustained period of several dry years after the mid-21st century and the increased temperature associated with this higher emissions scenario (increased pumping and ET). Based on this review of groundwater model results from simulating the combination of each RCP with the chosen HadGEM2-ES GCM, the majority of Advisory Committee members supported RCP 8.5 and the GSA Board affirmed that recommendation.

Sea Level Rise Assumptions

Future sea level rise due to climate change may impact groundwater conditions in the Basin near San Pablo Bay. Sea level rise guidance provided by the California Natural Resources Agency (CNRA 2018) was used to identify the sea level rise trajectory to be simulated. The PVIHM was modified to simulate the 1-in-200 chance (0.5 percent probability) sea level rise trajectory under the high emissions scenario, which results in a projected sea level rise of 3.5 feet at the end of the projected 50-year simulation (WY 2070). The choice of the 1-in-200 change scenario is consistent with (1) the choice of RCP 8.5, and (2) sea level rise assumptions used for the Sonoma Creek Baylands Strategy (Sonoma Land Trust and San Francisco Bay Restoration Authority, 2020). Exchanges between the aquifer and San Pablo Bay, and between the aquifer and the tidally influenced Petaluma River are simulated in both the historical and future period as a head-dependent flow using the General Head Boundary package. Future sea level rise was simulated by converting the sea level rise trajectory to freshwater equivalent head, and adding to the historic freshwater equivalent head used to represent both the bay and the tidally influenced Petaluma River in the PVIHM future simulation. Projected climate based on the selected GCM will represent WY 2021 through WY 2070.

Modifications to Modeling Platform to Simulate Future Projected Conditions

The PVIHM input files were modified to simulate future projected land use and climate as described in the previous section. **Appendix 3-C** provides a summary of how future conditions were incorporated into the model, including projected climate summaries.

3.3.6.2 Projected Surface Water Budget

Precipitation is the main input that drives the changes to the surface water budget in the projected simulation compared to historical simulation.

Figure 3-32 shows historical and projected precipitation for the Basin. Projected mean annual precipitation is slightly higher than the historical mean annual precipitation. because the projected precipitation from WY 2021 through WY 2050 includes a number of years with above-average precipitation. However, from WY 2050 through WY 2070, only 1 year has a wet water type and 13 years are characterized as dry (**Figure 3-32**).

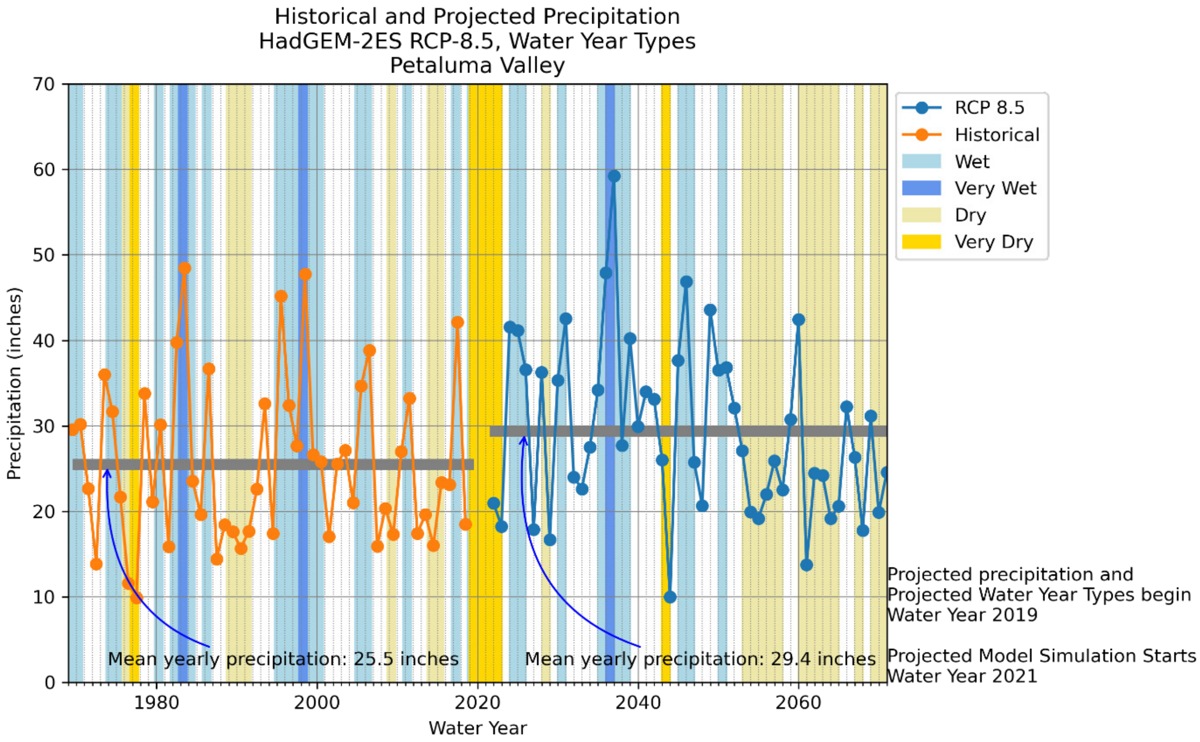


Figure 3-32. Historical and Projected Precipitation

Figure 3-33 shows the surface water inflows, outflows, and groundwater gains and losses from streams for the projected period. **Table 3-15** shows summary statistics of surface water inflows for the projected period. **Table 3-16** shows summary statistics of surface water outflows for the projected period.

The mean annual projected groundwater discharge to streams (**Table 3-15**) exceeds projected stream leakage to groundwater (**Table 3-16**) by about 6,800 AFY; this is the mean annual projected net groundwater/surface-water exchange. Mean annual net groundwater/surface-water exchange is greater during the projected period than either the historical period (**Table 3-4**, **Table 3-5**), due to a combination of increasing precipitation (**Figure 3-32**) and decreasing groundwater pumpage, as discussed in **Section 3.3.6.4**.

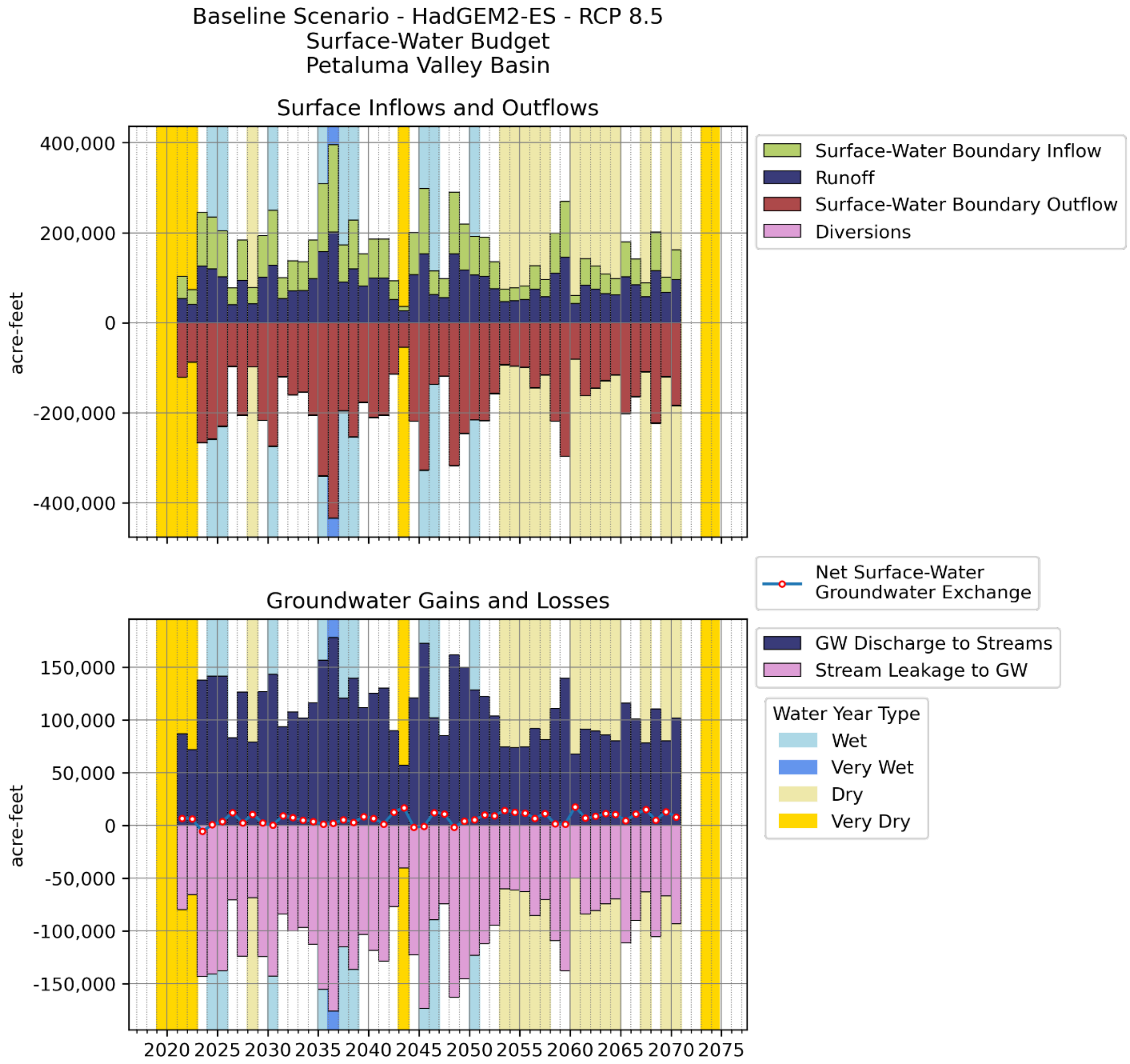


Figure 3-33. Projected Surface Water Inflows, Outflows, and Groundwater Gains and Losses

Table 3-15. Projected Surface Water Budget Inflows (AFY)[a]

	Projected (WY 2021 through WY 2070)		
	Surface Water Boundary Inflow	**Runoff**	**Ground Water Discharge to Streams**
Mean	72,900	87,800	109,200
Minimum	10,300	25,900	57,200
Maximum	193,000	202,000	178,000
Median	66,200	83,700	105,700

[a] Values are rounded to the nearest 100 acre-feet.

Table 3-16. Projected Surface Water Budget Outflows (AFY)[a]

	Projected (WY 2021 through WY 2070)		
	Surface-Water Boundary Outflow	**Diversions**	**Stream Leakage to Groundwater**
Mean	182,400	700	-102,400
Minimum	54,600	800	-176,000
Maximum	433,400	300	-40,200
Median	170,300	700	-98,400

[a] Values are rounded to the nearest 100 acre-feet.

3.3.6.3 Projected Land Surface Budget

Figure 3-34 shows the land surface inflows (precipitation, agricultural pumpage, surface-water diversions, and recycled water), consumptive uses of water, and outflows from the land surface water budget. **Table 3-17** presents summary statistics of land surface water budget sources (inflows) for the projected period. **Table 3-18** shows summary statistics of land surface water budget outflows for the projected period. Projected Farm Net Recharge during 2021-2070 is -8,600 AFY (**Table 3-18**).

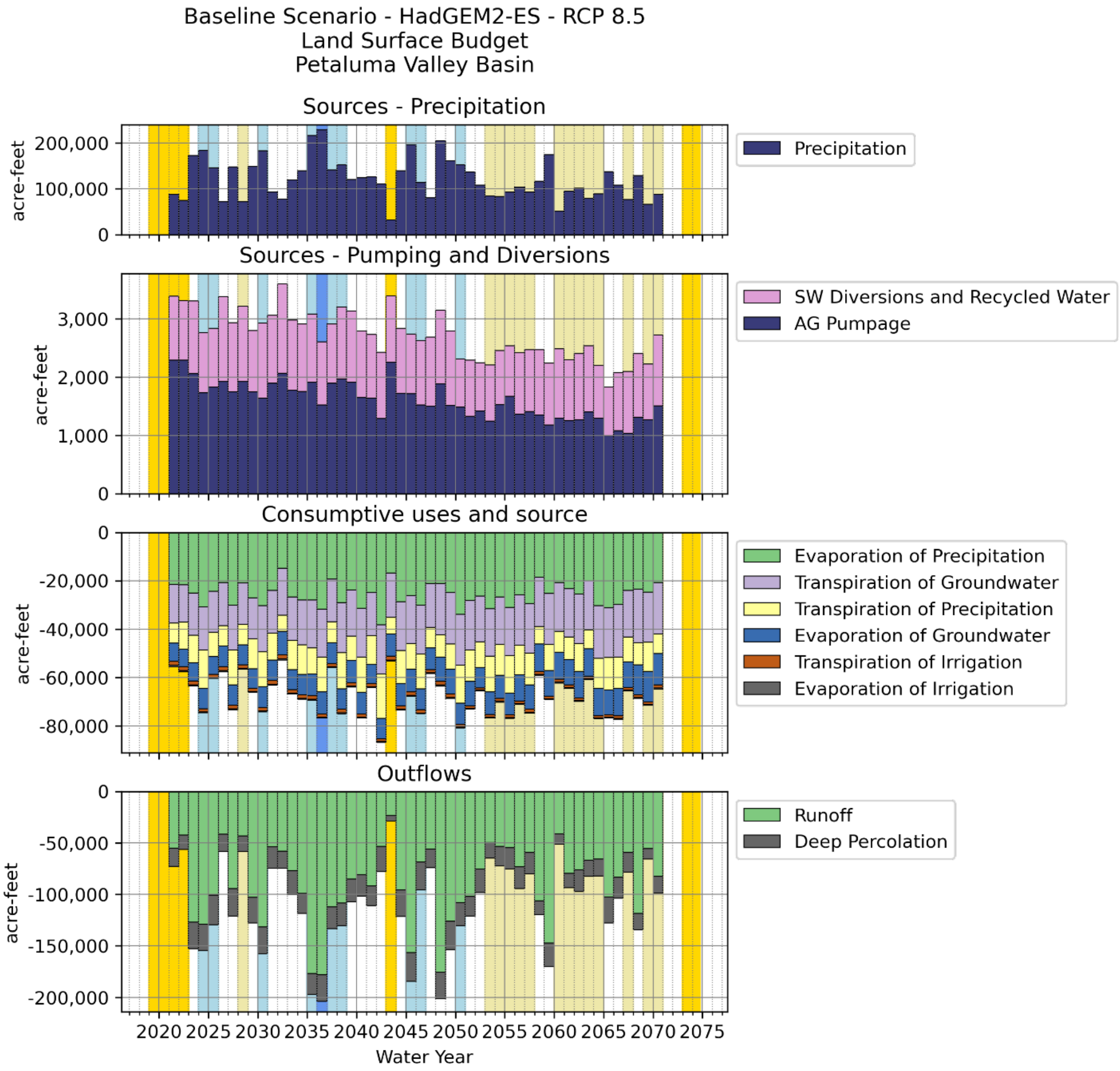


Figure 3-34. Projected Land Surface Water Budget: Precipitation, Pumping and Diversions, Consumptive Use and Source, and Outflows

Table 3-17. Projected Land Surface Budget Inflows (AFY)[a]

	Projected (WY 2021 through WY 2070)		
	Precipitation	**Surface-Water Diversions and Recycled Water**	**Agricultural Pumpage**
Mean	120,600	1,100	1,600
Minimum	32,600	800	1,000
Maximum	228,500	1,500	2,300
Median	115,100	1,100	1,600

[a] Values are rounded to the nearest 100 acre-feet.

Table 3-18. Projected Land Surface Water Budget Outflows (AFY)[a]

Projected (WY 2021 through WY 2070)	Evaporation of Precipitation	Transpiration of Groundwater	Transpiration of Precipitation	Evaporation of Groundwater
Mean	25,900	19,500	11,500	9,500
Minimum	38,300	22,100	18,400	13,000
Maximum	14,900	15,500	6,700	7,300
Median	25,600	19,900	11,500	9,100

	Transpiration of Irrigation	Evaporation of Irrigation	Runoff	Deep Percolation
Mean	1,300	400	88,100	20,400
Minimum	1,700	500	178,100	28,400
Maximum	800	300	23,200	5,500
Median	1,300	400	81,500	20,700

[a] Values are rounded to the nearest 100 acre-feet.

3.3.6.4 Projected Groundwater Budget

Figure 3-35 shows inflows to the groundwater system for the projected time period. **Table 3-19** shows summary statistics for groundwater inflows for the projected time period. Combined inflow from the Baylands and from the tidally influenced Petaluma River is projected to increase by 18,800 AFY relative to the current period. This increase reflects the assumptions about future sea level rise described in the Sea Level Rise Assumptions Section. Stream leakage to groundwater is projected to increase by 8,500 AFY relative to the current period. This reflects increased surface water flows associated with projected changes in precipitation, with the largest increases in both precipitation and stream leakage occurring during 2021-2050.

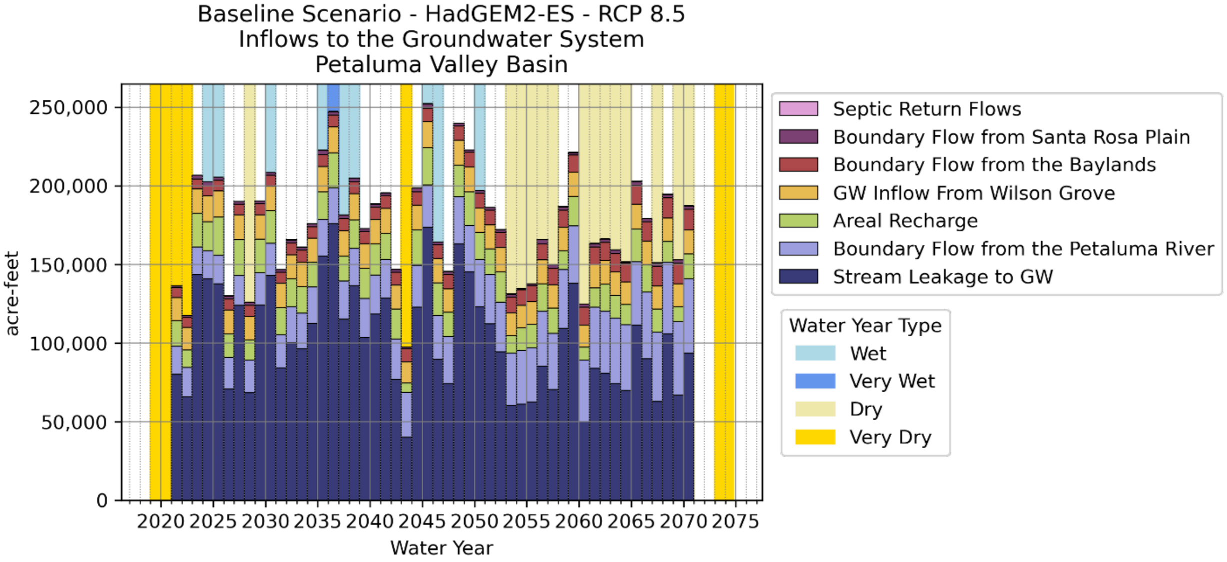


Figure 3-35. Projected Inflows to the Groundwater System

Table 3-19. Projected (WY 2021 through WY 2070) Groundwater Budget Inflow Summary (AFY)[a]

	Septic Return Flows	Boundary Flow from Santa Rosa Plain	Boundary Flow from the Baylands	Boundary Flow from the Petaluma River	Groundwater Inflow from Wilson Grove	Areal Recharge	Stream Leakage to Groundwater
Mean	200	1,800	9,100	29,600	15,300	16,900	102,400
Minimum	100	700	6,400	17,600	13,500	5,600	40,200
Maximum	200	2,700	13,400	47,500	16,700	24,300	176,000
Median	200	1,900	8,700	28,200	15,200	17,300	98,400

[a] Values are rounded to the nearest 100 acre-feet.

Figure 3-36 shows outflows from the groundwater system for the projected time period. **Table 3-20** provides summary statistics for groundwater outflows for the projected time period.

Groundwater discharge to streams is projected to increase by 13,700 AFY in the future period relative to the current period. This increase is due in part to projected wetter conditions in the future period, increased inflow from the Baylands and tidally influenced Petaluma River (**Table 3-19**), and reductions in agricultural pumpage. Projected Farm Net Recharge during 2021-2070 is -8,600 AFY (**Table 3-19; Table 3-20**).

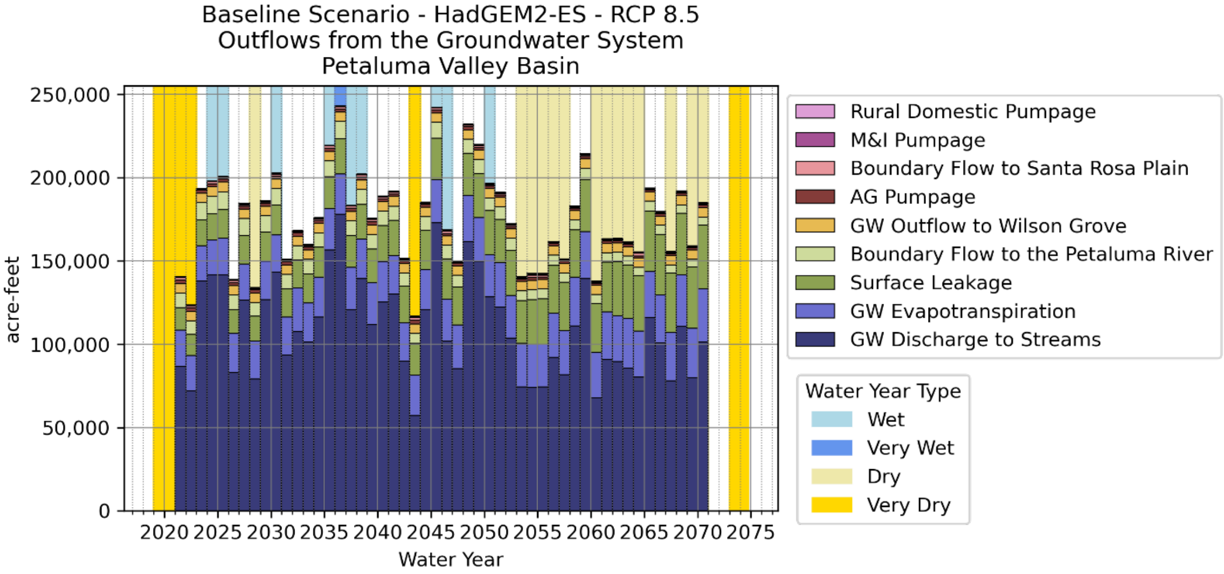


Figure 3-36. Projected Outflows from the Groundwater System

Table 3-20. Projected (WY 2021 through WY 2070) Groundwater Outflows Budget Summary (AFY)[a]

	Boundary Flow to the Baylands	Rural Domestic Pumpage	M&I Pumpage	Boundary Flow to Santa Rosa Plain	Agricultural Pumpage
Mean	0	300	400	900	1,600
Minimum	0	300	0	300	1,100
Maximum	0	400	500	1,600	2,400
Median	0	300	400	900	1,600

	Groundwater Outflow to Wilson Grove	Boundary Flow to the Petaluma River	Surface Leakage	Groundwater ET	Groundwater Discharge to Streams
Mean	5,600	7,600	24,200	25,500	109,200
Minimum	5,600	4,500	12,700	20,800	57,200
Maximum	5,700	10,900	38,400	31,600	178,000
Median	5,600	8,100	24,000	25,500	105,700

[a] Values are rounded to the nearest 100 acre-feet.

Figure 3-37 shows annual projected groundwater pumpage by water use sector, and the 5-year running mean of the total projected pumpage. **Table 3-21** provides summary statistics for projected groundwater pumpage by sector during the future period. Mean total groundwater pumpage is projected to decline by 2,200 AFY during the future period relative to the current period. Agricultural pumpage is projected to decline by 2,400 AFY in the future period relative to the current period, due primarily to projected reductions in irrigated pasture acreage. Rural domestic pumpage is projected to increase gradually from year to year during the future period due to population growth.

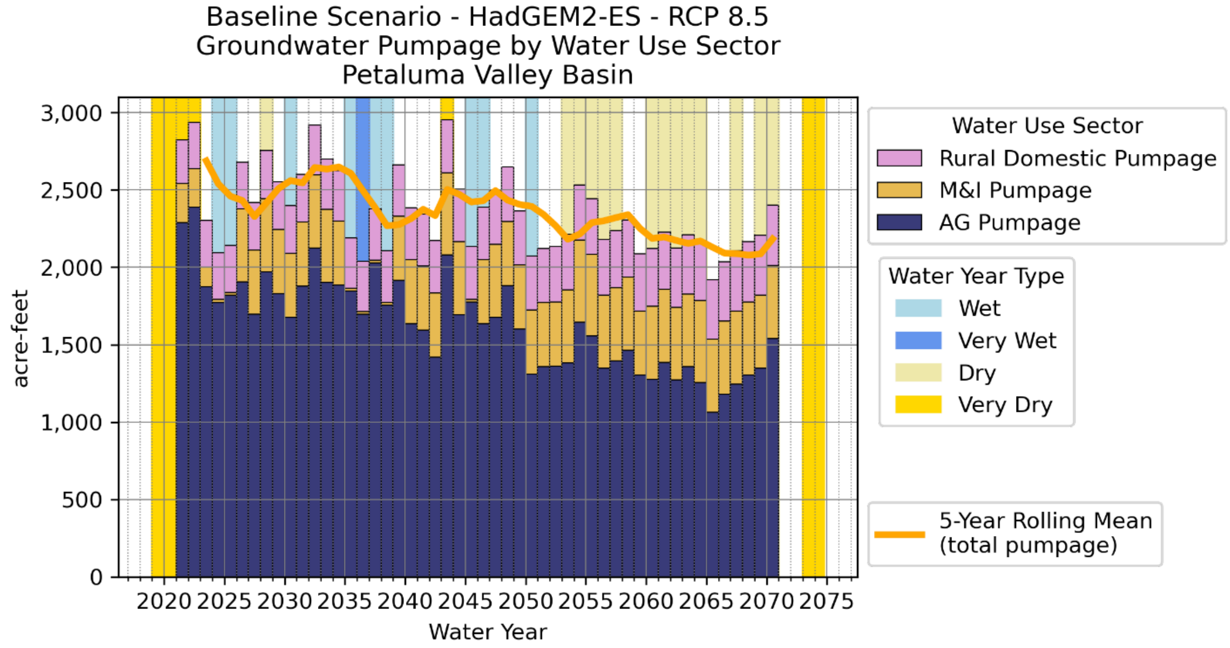


Figure 3-37. Projected Groundwater Pumpage by Water Use Sector

Table 3-21. Projected Groundwater Pumpage by Water Use Sector (AFY)[a]

		Future (WY 2021 through WY 2070)	
	AG Pumpage	**M&I Pumpage**	**Rural Domestic Pumpage**
Mean	1,600	400	300
Minimum	1,100	0	300
Maximum	2,400	500	400
Median	1,600	400	300

[a] Values are rounded to the nearest 100 acre-feet.

3.3.6.5 Projected Storage Change

Figure 3-38 shows the entire projected groundwater budget and also includes the annual change of groundwater in storage. **Table 3-22** shows the annual change in groundwater in storage for the future, historical and current time periods. The projected water budget is characterized by an initial 30-year period of increased precipitation and temperatures, rising sea levels, and declining total groundwater pumpage. Together, these changes result in a stable trend in groundwater storage. Below-average precipitation beginning in 2050 causes reduced surface water runoff into the Basin and reduced areal recharge and consequently groundwater storage depletion from 2050 through 2070. Groundwater storage is projected to decrease by about 200 AFY on average over the entire future period, resulting in a cumulative storage loss of about 10,000 AFY relative to the end of the historical period.

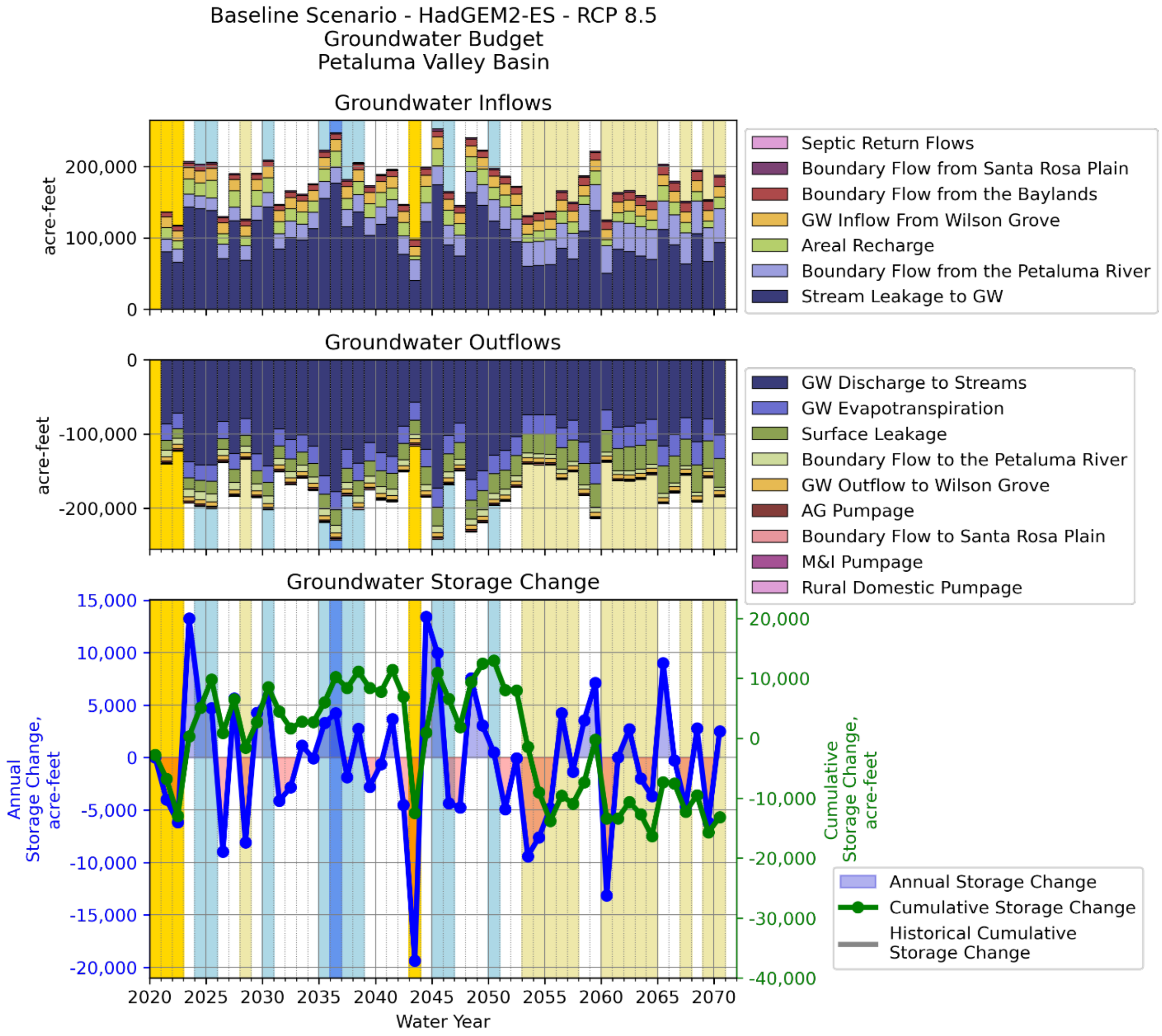


Figure 3-38. Projected Groundwater Budget: Groundwater Inflows, Groundwater Outflows, and Change in Groundwater Storage

Table 3-22. Average Annual Change of Groundwater in Storage (AFY)[a]

	Projected (WY 2021 through WY 2070)
Mean	-200
Minimum	-19,400
Maximum	13,400
Median	-100

[a] Values are rounded to the nearest 100 acre-feet.

3.3.6.6 Projected Water Budget Summary

The projected water budget is characterized by an initial 20-year period of increased precipitation and temperatures, rising sea levels, and declining total groundwater pumpage.

Together, these changes result in a stable trend in groundwater storage. However, due to rising sea levels, inflows from the Baylands are expected to increase. Changes in the projected water budget relative to the current water budget are primarily due to:

- Changes in precipitation and ET as part of the future climate scenario
- Projected changes in agricultural land use
- The effect of sea level rise on aquifer exchange with Baylands and the tidally influenced Petaluma River

Surface Water Budget

Figure 3-39 shows a comparison of historical, current, and projected surface water budget terms for the Basin. Surface-water diversions are assumed to remain at historical average levels under projected conditions.

Runoff, surface water boundary inflows, and surface water boundary outflows are all projected to increase under projected conditions due to wetter climate conditions.

Net surface-water groundwater exchange is defined here as net groundwater discharge to streams, calculated as groundwater discharge to streams less stream leakage to groundwater. **Figure 3-39** shows the mean net surface water groundwater exchange increasing from less than 2,000 AFY during the period 1976 to 2018, to greater than 6,000 AFY during the projected period. This projected increase is due to a combination of increased runoff, reduced groundwater pumpage, and increased inflow from the Baylands and tidally influenced Petaluma River.

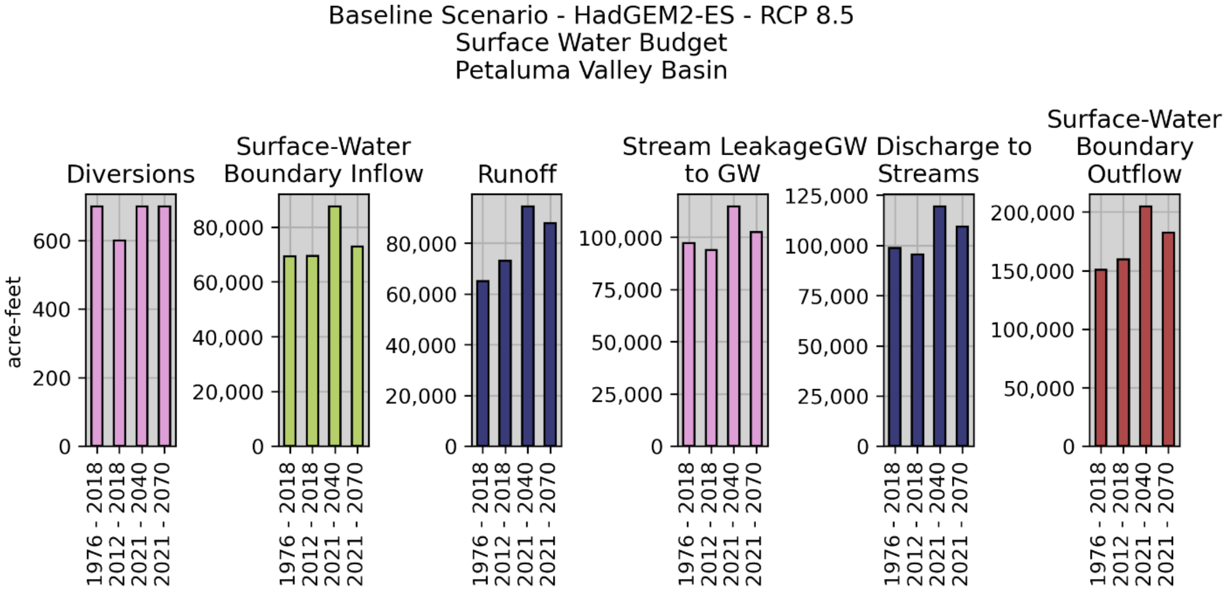


Figure 3-39. Comparison of Historical, Current, and Projected Surface Average Annual Water Budget Terms

Groundwater Budget

Figure 3-40 and Figure 3-41 show comparisons of the mean annual historical, current, and projected groundwater inflow and outflow terms, respectively, for the Basin. Inflows to groundwater from the Petaluma River and Baylands are projected to increase during the future period relative to the current period due to the projected sea level rise **(Figure 3-40).** Areal recharge during the future period exceeds areal recharge during the current period; however, relatively dry conditions during the second half of the future period lead to small reductions in areal recharge relative to the first half of the future period (**Figure 3-40)**.

As shown on **Figure 3-41**, M&I pumping is projected to increase over the future period, but remains below the average pumping levels during the historical period. Agricultural pumping declined during the current period relative to the historical period, and is projected to continue declining over the future period. Surface leakage and groundwater ET are projected to increase relative to the current period due to the combination of wetter climate conditions and the effects of sea level rise. Groundwater discharge to streams is projected to increase relative to the current period due to wetter climate conditions and sea level rise.

During the future period, groundwater inflows are projected to exceed groundwater outflows through WY 2045, due to a projected wetter period (**Figure 3-38**). Consequently, groundwater storage is projected to increase at a rate of 500 AFY from WY 2021 through WY 2040. After WY 2045, projected groundwater outflows exceed projected groundwater inflows, due to the projected severe longer drought, and groundwater storage then decreases at a rate of 700 AFY from WY 2041 through WY 2070. Overall, the groundwater storage is projected to decrease by 200 AFY on average over the future period.

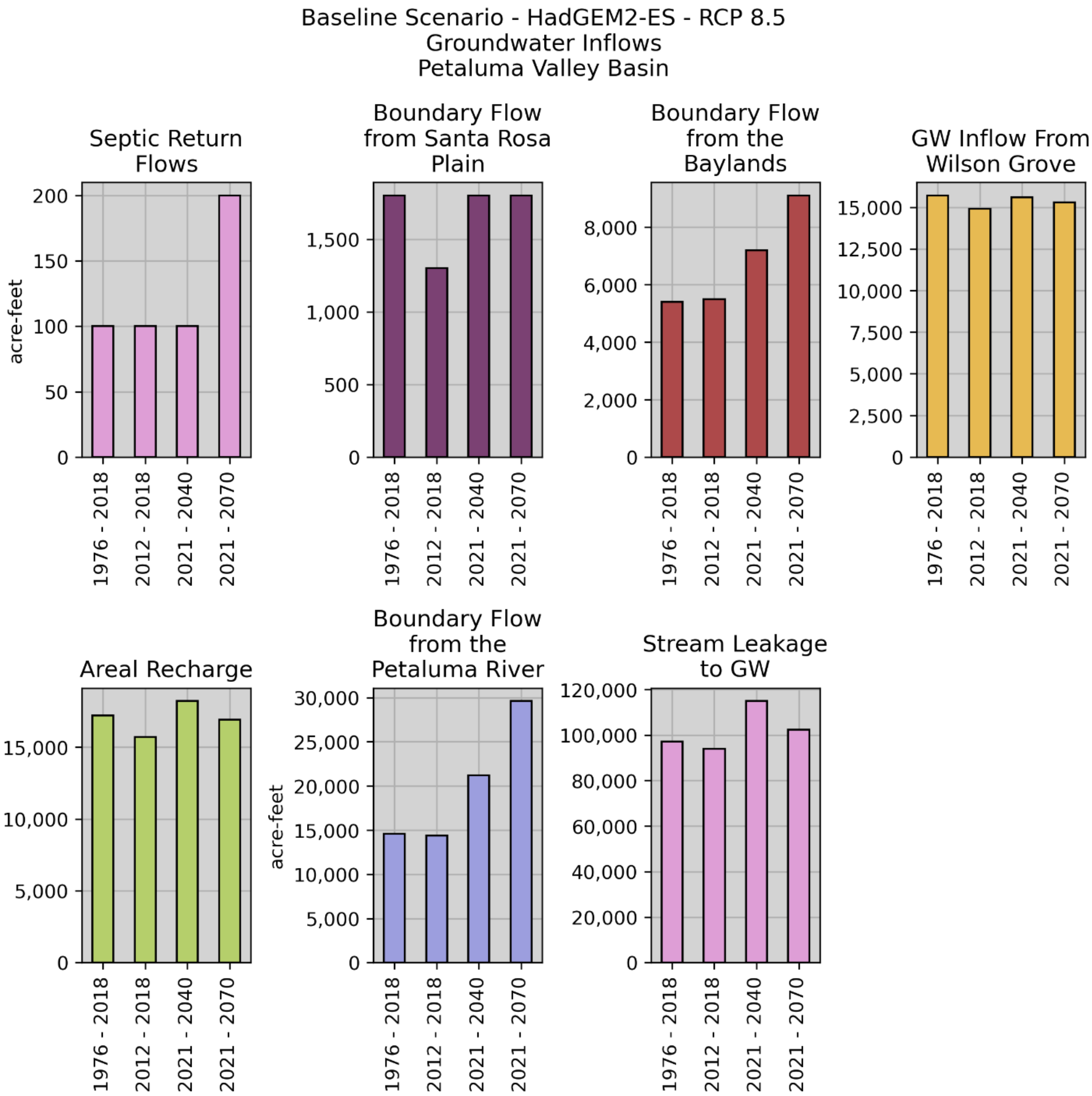


Figure 3-40. Comparison of Historical, Current, and Projected Groundwater Budget Inflow Terms

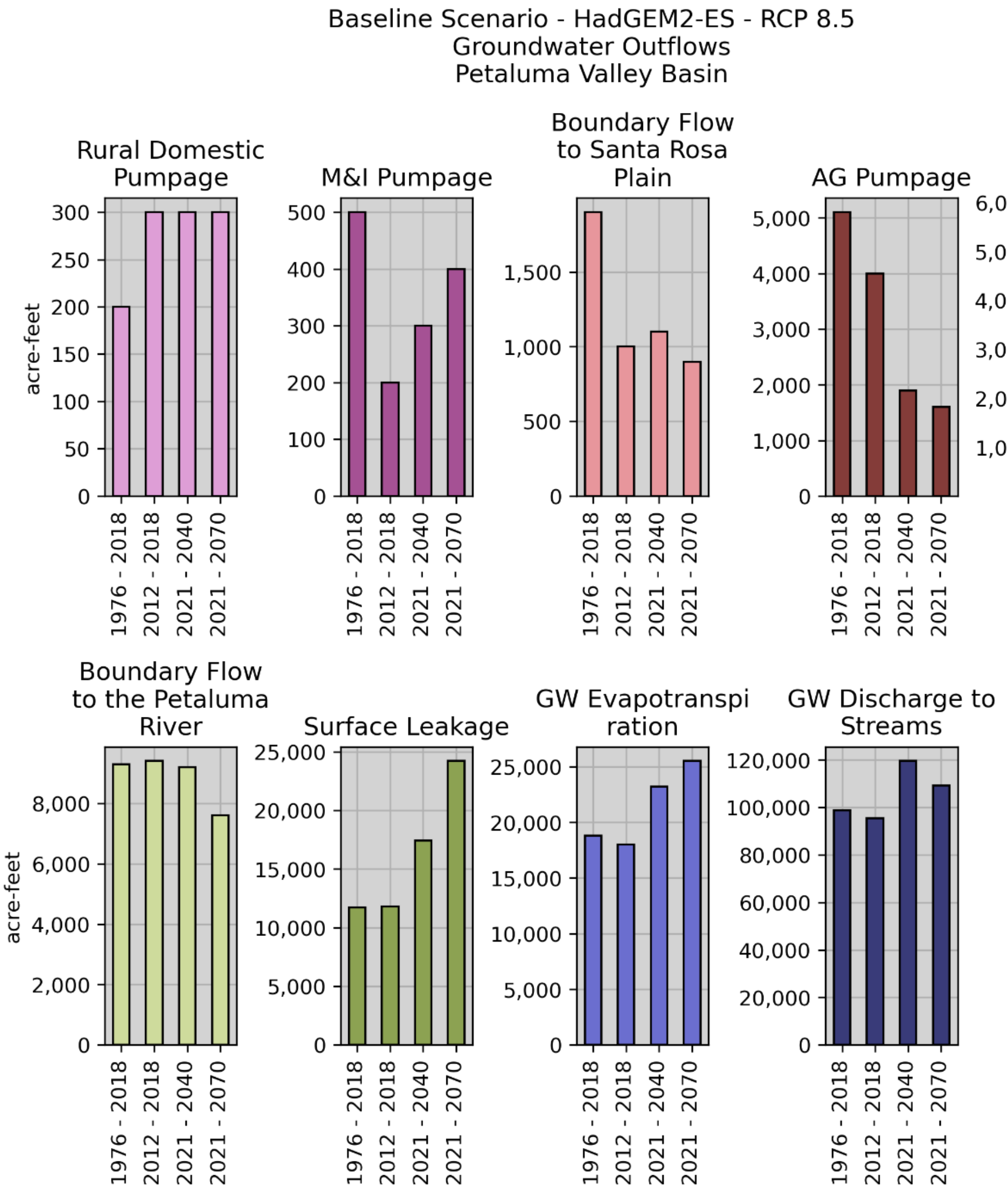


Figure 3-41. Comparison of Historical, Current, and Projected Groundwater Budget Outflow Terms

3.3.6.7 Uncertainties in Projected Water Budget Simulations

- Projected climate variability presents one possible future sequence of wet and dry periods and should not be considered an forecast of what will occur in the near or long-term future

- Trends in projected climate are subject to assumptions on future carbon emissions, the selection of GCM to simulate future climate conditions, and choice of spatial and temporal downscaling method

- Projected municipal demands have been standardized to reflect annual pumping based on climate year classifications and may not reflect actual timing and magnitude of groundwater pumpage
- Projected rural domestic and agricultural demands are subject to uncertainty due the projection of land use development and crop expansion and contraction, and due to the uncertainty in how users' habits and irrigation practices will change. Though cannabis cultivation is currently not a significant groundwater user in the Basin, projected cannabis acreage and associated water use is uncertain and may be a source of increased groundwater use in the future. Cannabis cultivation will continue to be monitored in the future to determine if adding it to the model is warranted.

3.4 Sustainable Yield

The sustainable yield of the Basin is an estimate of the quantity of groundwater that can be pumped on a long-term average annual basis without causing undesirable results. Basinwide pumping within the sustainable yield estimate is neither a measure of, nor proof of, sustainability. Sustainability under SGMA is only demonstrated by avoiding undesirable results for the six applicable sustainability indicators in the Basin. However, estimates of sustainable yield using the historical simulations may prove useful in estimating the need for projects and management actions to help achieve sustainability.

The role of sustainable yield estimates in SGMA, as described in the Sustainable Management Criteria (SMC) BMP (DWR 2017), are as follows:

> "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.
>
> Sustainable yield estimates are part of SGMA's required basinwide water budget. Section 354.18(b)(7) of the GSP Regulations requires that an estimate of the basin's sustainable yield be provided in the GSP (or in the coordination agreement for basins with multiple GSPs). A single value of sustainable yield must be calculated basinwide. This sustainable yield estimate can be helpful for estimating the projects and programs needed to achieve sustainability."

The 10-year period from WY 2002 to WY 2011 is used to determine the sustainable yield of the Basin. This period is representative of long-term conditions with a mix of wet (3, 30 percent), dry (1, 10 percent), and normal years (6, 60 percent). This distribution of water-year types is similar to that of the first 20 years of the projected water budget (WY 2021 to WY 2040), which has 30 percent wet, 5 percent very wet, 5 percent dry, 10 percent very dry, and 50 percent normal years. During the WY 2002 to 2011 period there is only one well with MT exceedances (well PET0174 shown on **Figure 3-42**). This number of exceedances does not constitute an undesirable result, as explained in **Section 4** of this GSP. Finally, the change in groundwater storage is a net positive for the sustainable yield period (**Figure 3-43**). The sustainable yield is therefore calculated from the average total groundwater pumpage during this period. The sustainable yield is 8,000 AFY for the Basin (**Figure 3-43**). The sustainable yield is not predicated on implementation of projects and actions.

The sustainable yield is a function of the climate conditions in which it is calculated (Loaiciga 2016). The WY 2002 to WY 2011 period is likely to be similar to those of the projected 20-year implementation period. If future climate conditions are better represented by the hotter and drier conditions simulated in the WY 2050 to WY 2070 period of the projected scenario rather than the wetter WY 2021 to WY 2040 period, then the sustainable yield will need to be reduced, projects and management actions will need to occur, or both, to allow for the Basin to avoid undesirable results. The avoidance of undesirable results is also contingent upon the spatial distribution of pumping exhibited in the sustainable yield period. Changes in the location of pumping may induce greater depletion of surface-waters or increased saltwater intrusion, for example. As described in **Section 7**, the water budget and estimated sustainable yield will continue to be evaluated with new information and alternative climate scenarios during the five-year GSP updates. Additionally, while the initial minimum thresholds for depletion of interconnected surface water are not projected to be exceeded during this time period, these will also be further refined during the five-year GSP update in order to better account for the potential impact of basinwide pumpage on surface-water depletion.

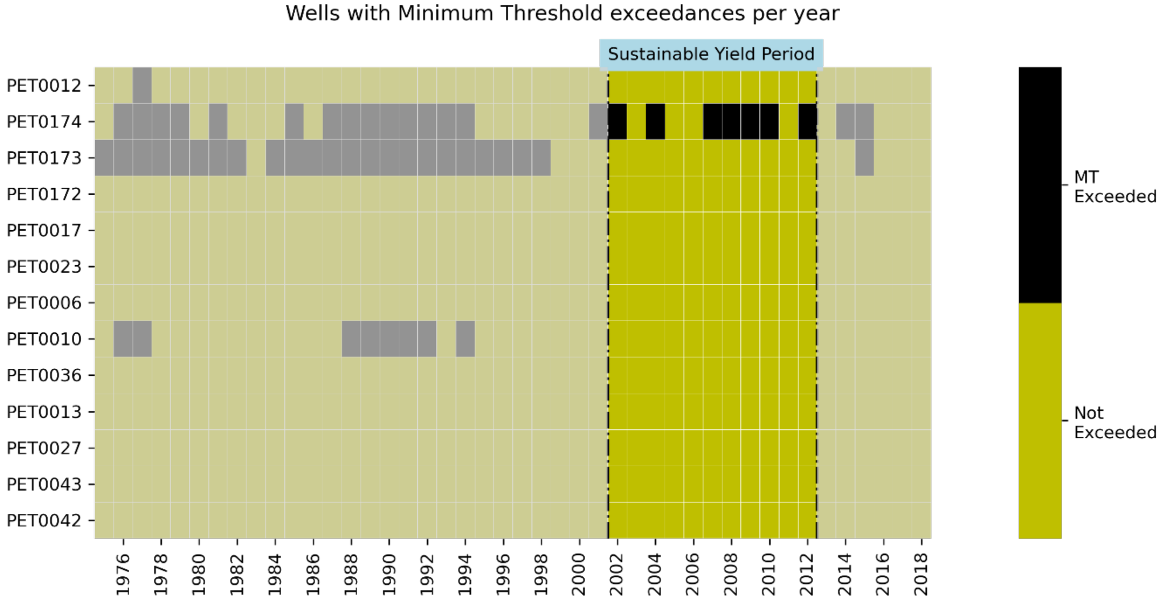


Figure 3-42. Minimum Threshold Exceedances per Year for this Historic Period

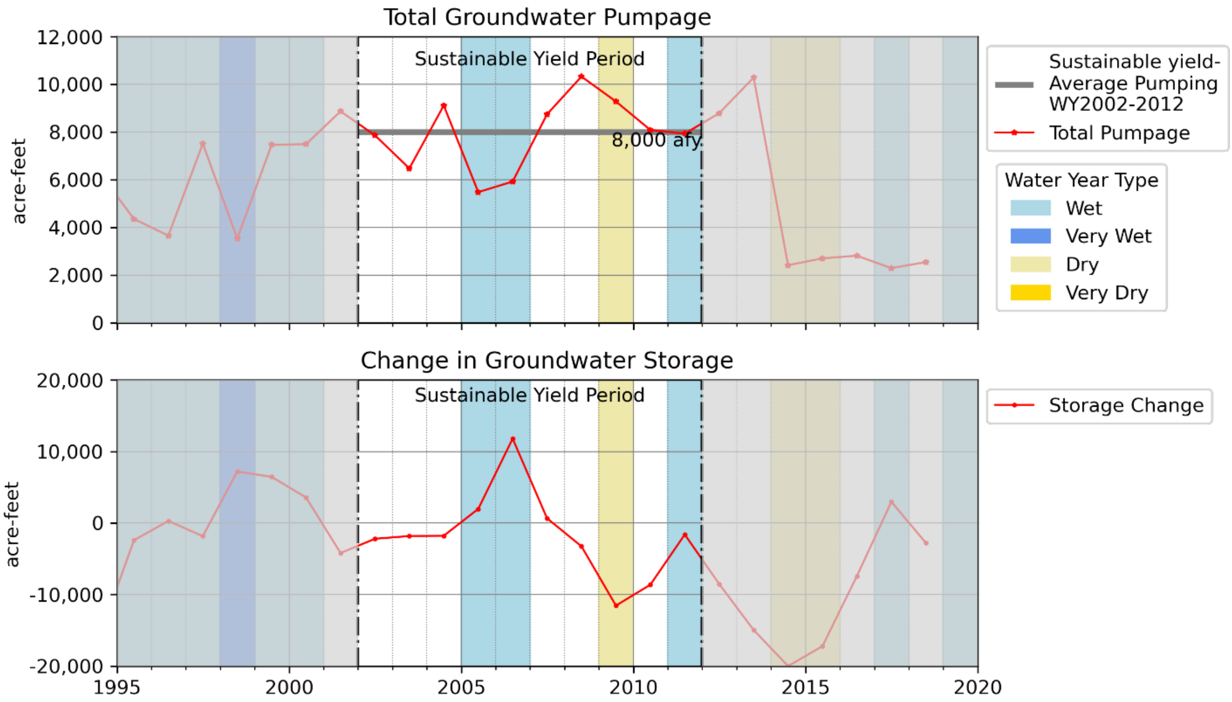


Figure 3-43. Sustainable Yield - Total Groundwater Pumpage and Change in Groundwater Storage

3.5 Management Areas

SGMA provides GSAs with the ability to define one of more management areas within a basin if the GSA determines that the creation of management areas will facilitate implementation of the GSP. Management areas can be used to define different minimum thresholds and be operated to different measurable objectives than the basin at large, provided that undesirable results are defined consistently throughout the basin (23 CCR Section 354.20).

Management areas were not defined for the Basin. Management areas may be considered in the future if the GSA finds that doing so will facilitate implementation of the GSP.

Section 4: Sustainable Management Criteria

Groundwater Sustainability Plan

Petaluma Valley Groundwater Basin

Table of Contents

4 SUSTAINABLE MANAGEMENT CRITERIA 4-1

4.1 Definitions 4-2

4.2 Sustainability Goal 4-3

4.3 General Process for Establishing Sustainable Management Criteria 4-5

4.4 Sustainable Management Criteria Summary 4-5

4.5 Chronic Lowering of Groundwater Levels Sustainable Management Criteria 4-10

4.5.1 Locally Defined Significant and Unreasonable Conditions 4-10

4.5.2 Minimum Thresholds 4-11

4.5.3 Measurable Objectives 4-23

4.5.4 Undesirable Results 4-24

4.6 Reduction in Groundwater Storage Sustainable Management Criteria 4-26

4.6.1 Locally Defined Significant and Unreasonable Conditions 4-26

4.6.2 Minimum Thresholds 4-26

4.6.3 Measurable Objectives 4-28

4.6.4 Undesirable Results 4-28

4.7 Seawater Intrusion Sustainable Management Criteria 4-29

4.7.1 Locally Defined Significant and Unreasonable Conditions 4-30

4.7.2 Minimum Thresholds 4-31

4.7.3 Measurable Objectives 4-36

4.7.4 Undesirable Results 4-36

4.8 Degraded Water Quality Sustainable Management Criteria 4-38

4.8.1 Locally Defined Significant and Unreasonable Conditions 4-38

4.8.2 Minimum Thresholds 4-39

4.8.3 Measurable Objectives 4-48

4.8.4 Undesirable Results 4-48

4.9 Subsidence Sustainable Management Criteria 4-50

4.9.1 Locally Defined Significant and Unreasonable Conditions 4-51
4.9.2 Minimum Thresholds 4-51
4.9.3 Measurable Objectives 4-54
4.9.4 Undesirable Results 4-54
4.10 Depletion of Interconnected Surface Water Sustainable Management Criteria 4-56
4.10.1 Locally Defined Significant and Unreasonable Conditions 4-58
4.10.2 Minimum Thresholds 4-58
4.10.3 Measurable Objectives 4-63
4.10.4 Undesirable Results 4-64
4.10.5 Consideration of Public Trust Resources 4-65

Tables

Table 4-1. Sustainable Management Criteria Summary 4-6
Table 4-2. Summary of Calculations for Minimum Thresholds, Measurable Objectives, and Interim Milestones 4-17
Table 4-3. Petaluma Valley Basin Monitoring Networks 4-40
Table 4-4. Future Monitoring Networks for Project-specific Monitoring 4-41
Table 4-5. Summary of Constituents Monitored at Each Well Network 4-41
Table 4-6. Groundwater Quality Minimum Thresholds Basis 4-42
Table 4-7. Minimum Thresholds for Degradation of Groundwater Quality for the Public Supply Wells Under the Current Monitoring Network 4-42
Table 4-8. Minimum Thresholds and Measurable Objectives for the Depletion of Interconnected Surface Water 4-60

Figures

Figure 4-1. Representative Monitoring Points for Chronic Lowering of Groundwater Levels 4-13
Figure 4-2. Illustration of Calculated 95th Percentile Well Depths and Saturated Thickness Factor 4-14
Figure 4-3. Illustration of Application of Well Impact Depth and Drought Buffer to Minimum Thresholds 4-16
Figure 4-4. Seawater Intrusion Minimum Threshold and Measurable Objective 4-32
Figure 4-5. Baseline Groundwater Quality – Arsenic 2015-2020 4-43
Figure 4-6. Baseline Groundwater Quality – Nitrate 2015-2020 4-44
Figure 4-7. Baseline Groundwater Quality – TDS 2015-2020 4-45

Appendices

Appendix 4-A. Hydrographs of Representative Monitoring Points
Appendix 4-B. Definition of Drought for Sonoma County Groundwater Sustainability Plans

Appendix 4-C. Key Themes and Outcomes from Interconnected Surface Water Practitioners Work Group

Appendix 4-D. Development of Sustainable Management Criteria of Interconnected Surface Water – Petaluma Valley

4 SUSTAINABLE MANAGEMENT CRITERIA

This section identifies the sustainability goal; defines the conditions that constitute sustainable groundwater management; discusses the process by which the GSA will characterize undesirable results; and establishes MTs and MOs for each applicable sustainability indicator.

The MOs, MTs, and undesirable results detailed in this section define the Basin's future desired conditions and inform the selection, prioritization, and planning for projects and management actions to achieve these conditions. Defining these SMC required a significant level of technical analysis using currently available data, the best available scientific knowledge, and substantial input from stakeholders. This section includes a description of how SMC were developed and how they influence all beneficial uses and users. Uncertainty caused by data gaps in the hydrogeologic conceptual model and existing monitoring networks was considered when developing the SMC. Due to this uncertainty, these SMC are considered initial criteria and will be reevaluated and potentially modified in the future as new data become available.

SMC are provided for each of the following sustainability indicators:

- Chronic Lowering of Groundwater Levels
- Reduction in Groundwater Storage
- Seawater Intrusion
- Degraded Water Quality
- Land Subsidence
- Depletion of Interconnected Surface Water (ISW)

Each sustainability indicator subsection follows a consistent format that contains the information required by Section 354.22 et. seq of the GSP Regulations and outlined in the SMC BMP (DWR 2017). The subsection for each sustainability indicator includes a description of:

- How locally defined significant and unreasonable conditions were developed
- How MTs were developed, including:
    - The information and methodology used to develop MTs (Section 354.28 [b][1])
    - The relationship between MTs for other sustainability indicators (Section 354.28 [b][2])
    - Potential effects of MTs on neighboring basins (Section 354.28 [b][3])
    - Potential effects of MTs on beneficial uses and users (Section 354.28 [b][4])
    - Relationship of MTs to relevant federal, state, or local standards (Section 354.28 [b][5])
    - The method for quantitatively measuring MTs (Section 354.28 [b][6])
- How MOs were developed, including:
    - The methodology for setting MOs (Section 354.30)
    - Interim milestones, where applicable (Section 354.30 [a], Section 354.30 [e], Section 354.34 [g][3])
- How undesirable results were developed, including:
    - The criteria for defining undesirable results (Section 354.26 [b][2])
    - Potential causes of undesirable results (Section 354.26 [b][1])

  - Potential effects of these undesirable results on the beneficial users and uses (Section 354.26 [b][3])

4.1 Definitions

The SGMA legislation and GSP Regulations contain terms relevant to the SMC. These terms are defined below using the definitions included in the GSP Regulations (23 CCR Section 351) and, where appropriate, additional explanatory text. This explanatory text is not part of the official definitions of these terms but provides useful clarifications.

- **Interconnected surface water** refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted. ISWs are sections of streams, lakes, or wetlands where the groundwater table is at or near the ground surface or surface water body/stream channel bottom. The interconnection between surface water and groundwater may be seasonal.

- **Interim milestone** refers to a target value representing measurable groundwater conditions, in increments of 5 years. Interim milestones are targets such as groundwater elevations that should be achieved every 5 years to demonstrate progress toward sustainability.

- **Measurable objectives** refer to specific, quantifiable goals for the maintenance or improvement of specified groundwater conditions that have been included in an adopted Plan to achieve the sustainability goal for the basin. MOs are goals that the GSP is designed to achieve, but failure to achieve those objectives shall not be grounds for a finding of inadequacy of the Plan.

- **Minimum threshold** refers to a numeric value for each sustainability indicator used to define undesirable results. MTs are indicators of an unreasonable condition. For example, groundwater levels that maintain operational capacity for water wells may be an MT because groundwater levels dropping below levels that significantly impact well production capacities or dewater wells would be an unreasonable condition.

- **Representative monitoring** refers to a monitoring site within a broader network of sites that typifies one or more conditions within the basin or an area of the basin.

- **Significant and unreasonable conditions** is a phrase used to identify conditions that lead to undesirable results but is not specifically defined in the Definitions section of the GSP Regulations (Section 351). This expression is often confused with, or used interchangeably with, undesirable results. This GSP defines significant and unreasonable conditions as physical conditions to be avoided; an undesirable result is a quantitative assessment based on MTs. Defining significant and unreasonable conditions early in the process of developing SMC for each sustainability indicator helps set the framework by which the quantitative SMC metrics are determined.

- **Sustainability indicator** refers to any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results, as described in Water Code Section 10721(x). The six sustainability indicators relevant to this Basin include chronic lowering of groundwater levels; reduction of groundwater storage; degraded water quality; land subsidence; seawater intrusion; and depletion of ISWs.

- **Uncertainty** refers to a lack of understanding of the basin setting that significantly affects an Agency's ability to develop sustainable management criteria and appropriate projects and management actions in a Plan, or to evaluate the efficacy of Plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed.
- **Undesirable Result** means one or more of the following effects caused by groundwater conditions occurring throughout the basin as described in Water Code Section 10721(x):
    - Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.
    - Significant and unreasonable reduction of groundwater storage.
    - Significant and unreasonable seawater intrusion.
    - Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.
    - Significant and unreasonable land subsidence that substantially interferes with surface land uses.
    - Depletions of ISW that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

    Undesirable Result is not defined in the Definitions section of the GSP Regulations (Section 351). However, the Regulations' description of undesirable result states that it should be a quantitative description of the combination of MT exceedances that cause significant and unreasonable effects in the Basin. Undesirable results should not be confused with significant and unreasonable conditions, as described previously in this section.

4.2 Sustainability Goal

Per Section 354.24 of the GSP Regulations, the sustainability goal for the Basin has three parts:

- A description of the sustainability goal
- A discussion of the measures that will be implemented to ensure the Basin will be operated within sustainable yield
- An explanation of how the sustainability goal is likely to be achieved

Description of sustainability goal:

The goal of this GSP is to adaptively and sustainably manage, protect, and enhance groundwater resources while allowing for reasonable and managed growth through:

- Careful monitoring of groundwater conditions
- Close coordination and collaboration with other entities and regulatory agencies that have a stake or role in groundwater management in the Basin
- A diverse portfolio of projects and management actions that ensure clean and plentiful groundwater for future uses and users in an environmentally sound and equitable manner

Measures to achieve sustainability goal. Projects and actions that the GSA has identified as potential measures to be implemented to ensure sustainability are included in **Sections 6** and **7** of this GSP. These measures include actions proposed to fill data gaps and reduce uncertainty to inform future refinement and possible modification of the initial SMC described herein. While all of the identified measures may not be implemented, some combination of these measures will be implemented to ensure the Basin is operated within its sustainable yield and achieves sustainability. As described in **Section 3**, available data and model projections indicate that current and future groundwater conditions are generally acceptable in the Basin. Therefore, initial measures to achieve sustainability are focused on:

- Implementation and assessment of voluntary conservation and groundwater-use efficiency projects

Additionally, in order to address the inherent uncertainty and further develop potential future projects that may be needed as contingencies or to improve the resiliency of the Basin to future droughts, the following studies and planning will be performed:

- Study and planning of ASR projects
- Study and planning of stormwater capture and recharge projects

Additionally, the following management actions will be implemented within the first 5 years of GSP implementation to supplement the previously described projects:

- Assessment and prioritization of potential policy options, including demand management measures, for future GSA consideration
- Coordination with agricultural groundwater users within the Basin to integrate measures that support sustainable groundwater management with farm plans that are developed at individual farm sites
- Assessment of additional opportunities to expand and/or maximize efficiencies of recycled water supplies

The projects and management actions will be implemented using an adaptive management strategy, which will allow the GSA to react to the progress and outcomes of projects and management actions implemented in the Basin and to make management decisions to redirect efforts in the Basin as necessary to effectively achieve the sustainability goal. **Section 7** of this GSP describes the initial prioritization and sequencing of measures that are considered likely to be implemented in the early stages of GSP implementation.

4.3 General Process for Establishing Sustainable Management Criteria

The SMC presented in this section were developed using a technical analysis of publicly available information; meetings with GSA and member agency staff, Advisory Committee members, the GSA Board, and practitioner work groups; discussions with regulatory agencies; and feedback gathered during public meetings. The general process included:

- Identification of technical data sources in the Basin.
- Discussions with GSA technical staff to develop initial overarching methodologies to developing SMC, and specific approaches for each sustainability indicator.
- Public meeting presentations to the Advisory Committee outlining the approach to developing SMC and discussing initial SMC ideas. The public was provided opportunity to comment during these presentations. The Advisory Committee provided feedback and suggestions for the development of initial SMC.
- Discussions and meetings with staff from other regulatory agencies and local organizations who have shared interests or responsibilities for components of some sustainability indicators, including practitioner work groups convened to inform and support the development of SMC regarding the depletion of ISW.
- Public meeting presentations to the GSA Board on the SMC requirements, a proposed methodology for establishing MTs and MOs, and options for establishing definitions of undesirable results and SMC implications.
- Modifying MTs, MOs, and undesirable results, where appropriate, based on technical analyses, input from GSA and member agency staff, Advisory Committee members, GSA Board members, and the public.

This general process resulted in the SMC presented in this section.

4.4 Sustainable Management Criteria Summary

Table 4-1 provides a succinct summary of the SMC for each of the six sustainability indicators. The rationale and background for developing these criteria are described in detail in the following subsections.

Table 4-1. Sustainable Management Criteria Summary

Sustainability Indicator	Significant and Unreasonable Statement	Minimum Threshold	Measurement	Measurable Objective	Undesirable Result	Interim Milestones
Chronic lowering of groundwater levels	Chronic lowering of groundwater levels that significantly exceed historical levels or cause significant and unreasonable impacts on beneficial users.	Maintain above historical low elevations while accounting for droughts/climate variability and protect at least 95 percent of nearby water supply wells. Metric: Shallower (more protective) of historical low elevations minus 4-year drought OR above the 95th percentile of nearby water supply well depths.	Monthly or monthly-averaged groundwater levels measured at representative monitoring point wells.	**Stable Wells:** Maintain within historical observed ranges. Metric*:* Historical median spring groundwater elevation. **Wells with Declining Trends**: Recover groundwater levels to historical groundwater elevations prior to declining trend. Metric: Historical (generally pre-2010) median groundwater elevation.	25 percent of RMPs exceed MTs for 3 consecutive years.	The MO is based on recent conditions therefore interim milestones are identical to the MO.
Reduction in groundwater storage	Reduction of groundwater storage that causes significant and unreasonable impacts to the long-term sustainable beneficial use of groundwater in the Basin, as caused by: • Long-term reductions in groundwater storage • Pumping exceeding the sustainable yield	Measured using groundwater elevations as a proxy. MT for groundwater storage is identical to the MT for the chronic lowering of groundwater levels.	Annual groundwater storage will be calculated and reported by comparing changes in contoured groundwater elevations. However, monitoring for the chronic lowering of groundwater levels will be used to compare with MT and MOs.	MO for groundwater storage is identical to the MO for the chronic lowering of groundwater levels.	Undesirable result for groundwater storage is identical to the undesirable result for the chronic lowering of groundwater levels.	Interim milestones for groundwater storage are identical to the interim milestones for chronic lowering of groundwater levels.

Sustainability Indicator	Significant and Unreasonable Statement	Minimum Threshold	Measurement	Measurable Objective	Undesirable Result	Interim Milestones
Seawater Intrusion	Seawater intrusion inland of areas of existing brackish groundwater that may affect beneficial uses of groundwater is a significant and unreasonable condition.	The 250 mg/L chloride isocontour located in an area that is protective of beneficial users of groundwater. This MT isocontour is initially located between the currently inferred 250 mg/L isocontour (inferred interface of brackish groundwater) and beneficial users of groundwater (known water wells supplying beneficial users). This MT will need to be reassessed during early stages of GSP implementation once additional monitoring data and information are available, because the initial location is selected from very limited available data.	The chloride isocontour will be developed based on chloride concentrations measured in groundwater samples collected from an RMP network, which will be developed during the early stages of GSP implementation.	The 250 mg/L chloride isocontour at the currently approximate interface of brackish groundwater (that is, current conditions).	When two conditions are met: (1) 3 consecutive years of MT exceedances and (2) the MT exceedance is caused by groundwater pumping.	The MO is set at current conditions; therefore, interim milestones are also identical to current conditions.

Sustainability Indicator	Significant and Unreasonable Statement	Minimum Threshold	Measurement	Measurable Objective	Undesirable Result	Interim Milestones
Degraded water quality	Significant and unreasonable water quality conditions occur if an increase in the concentration of COCs in groundwater leads to adverse impacts on beneficial users or uses of groundwater, due to either: • Direct actions by Petaluma Valley GSP projects or management activities • Undesirable results occurring for other sustainability indicators	The MT is based on 2 additional supply wells exceeding the applicable maximum contaminant levels for (1) arsenic, (2) nitrate, or (3) salts (measured as TDS).	The number of public supply wells with annual average concentrations of arsenic, nitrate, or TDS that exceed maximum contaminant levels in groundwater quality data available through state data sources.	The MO is based on no additional supply wells exceeding the applicable maximum contaminant level for (1) arsenic, (2) nitrate, or (3) salts (measured as TDS).	An undesirable result occurs if, during 2 consecutive years, a single groundwater quality MT is exceeded when computing annual averages at the same well, as a direct result of projects or management actions taken as part of GSP implementation.	The MO is based on current conditions; therefore, interim milestones are identical to current conditions.
Subsidence	Any rate of inelastic subsidence caused by groundwater pumping is a significant and unreasonable condition everywhere in the Basin and regardless of the beneficial uses and users.	0.1 feet per year of total subsidence.	DWR-provided InSAR dataset average annual subsidence for each 100-meter-by-100-meter grid cell.	The MO is identical to the MT (0.1 feet per year of subsidence).	Annual MT of 0.1 feet total subsidence is exceeded over a minimum 50-acre area or cumulative total subsidence of 0.2 foot is exceeded within a 5-year period and MT exceedance is determined to be correlated with: (1) groundwater pumping, (2) an MT exceedance of the chronic lowering of groundwater-level SMC (that is, groundwater levels have fallen below historical lows).	The MO is set at current conditions; therefore, interim milestones are also identical to current conditions.

Sustainability Indicator	**Significant and Unreasonable Statement**	**Minimum Threshold**	**Measurement**	**Measurable Objective**	**Undesirable Result**	**Interim Milestones**
Depletion of ISW	Significant and unreasonable depletion of surface water from interconnected streams occurs when surface water depletion, caused by groundwater pumping within the Basin, exceeds historical depletion or adversely impacts the viability of GDEs or other beneficial users of surface water.	Maintain estimated streamflow depletions below historical maximum amounts. Metric: Shallow groundwater elevations are used as a proxy for stream depletion. The MT is set at 1 foot below the 2020 dry-season average minimum groundwater levels.	Monthly-averaged groundwater levels measured in representative monitoring points (shallow monitoring wells near ISW).	The MO is to maintain groundwater levels within historical observed ranges. Metric: The halfway point between the MT value and the average observed dry-season surface water stage from November 2019 to December 2020.	Undesirable result occurs if MT is exceeded at two wells during dry years or at one well during normal and wet years and are entirely or partially attributable to groundwater pumping under the jurisdiction of the GSA.	To be determined based on scenario modeling results.

Notes:
COC = constituent of concern
RMP = representative monitoring point
TDS = total dissolved solids

4.5 Chronic Lowering of Groundwater Levels Sustainable Management Criteria

The chronic lowering of groundwater levels was the first sustainability indicator addressed in the SMC process described in **Section 4.3**, because it contains the most readily available and robust datasets and is directly related to most of the other indicators. Additionally, SGMA allows for the use of groundwater levels as a proxy for other sustainability indicators if a significant correlation is established between groundwater levels and the other metrics. In this GSP, groundwater levels are used as a proxy for two other sustainability indicators: reduction of groundwater storage and depletion of ISW. This is further described in **Sections 4.6** and **4.10**, respectively.

For the chronic lowering of groundwater-level SMC, the following SGMA definition of an undesirable result assisted in characterizing significant and unreasonable conditions for the Basin and establishing the SMC described below:

- The chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon.
- Overdraft during a period of drought is not sufficient to establish that there is a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.

As described in **Section 3.2.2**, the majority of wells with available historical data exhibit generally stable groundwater-level trends with typical seasonal variations (that is, higher groundwater levels in the spring and lower groundwater levels in the fall). Observed groundwater-level elevations predominantly remain above sea level except for some wells in the southern portion of the Basin near the Baylands and the tidally influenced reach of the Petaluma River. Several wells near the upper reaches of Lynch Creek near the northeastern boundary of the Basin and along the northern boundary of the Basin exhibit decreasing groundwater-level trends over the period of record.

Taking these conditions and stakeholder input into account, the following overall approach guided development of the SMC for the chronic lowering of groundwater levels:

1. For areas with stable trends, maintain groundwater levels within or near historical conditions while accounting for future droughts and climate variability.
2. For areas with declining trends, protect beneficial users that could be impacted by the declining groundwater levels and stabilize and reverse the declining trends.

4.5.1 Locally Defined Significant and Unreasonable Conditions

Locally defined significant and unreasonable conditions were determined based on public meetings and discussions with GSA staff, Advisory Committee members, and the GSA Board.

Significant and unreasonable chronic lowering of groundwater levels in the Basin was defined as follows:

Chronic lowering of groundwater levels that significantly exceed historical levels or cause significant and unreasonable impacts on beneficial users, such as the following:

- Declining groundwater levels that limit the ability of domestic, municipal, or agricultural well owners to access groundwater for beneficial uses (for example, groundwater levels falling below pumping depths of water supply wells), causing significant and unreasonable economic burden on those who rely on basin groundwater
- Groundwater levels falling near basin boundaries that indicate impacts on or from neighboring basins
- Falling groundwater levels that cause impacts on groundwater-dependent vegetation

4.5.2 Minimum Thresholds

Section 354.28 (c)(1) of the GSP Regulations states that "The minimum threshold for chronic lowering of groundwater levels shall be the groundwater elevation indicating a depletion of supply at a given location that may lead to undesirable results." The GSP Regulations further specify that MTs for the chronic lowering of groundwater levels are to be supported by information on the rate of groundwater elevation decline based on historical trends, WY type, projected water use in the basin, and potential effects on other sustainability indicators.

The process for developing the MTs for the chronic lowering of groundwater levels involved the development of numerous alternatives for stakeholder consideration that took into account (1) the GSP Regulations cited in previous subsections; (2) the approach described in the first part of this subsection for considering differing patterns of historical groundwater-level trends; and (3) the significant and unreasonable statement provided in **Section 4.5.1**. The alternatives were developed on behalf of the GSA by technical staff and subconsultants based on an evaluation of historical groundwater elevations over the available period of record (including consideration of average water levels over various time periods, long-term trends, response to the recent drought, and the like), well construction data, and input from stakeholders. The following subsections provide details on the development of MTs.

4.5.2.1 Information and Methodology Used to Establish Chronic Lowering of Groundwater Levels Minimum Thresholds

The information used for establishing the MTs for the chronic lowering of groundwater levels sustainability indicator included:

- Historical groundwater elevation data
- Depths and locations of existing wells

- Maps of current and historical groundwater elevation data
- Input from member agency staff, Advisory Committee members, GSA Board members, and the public regarding significant and unreasonable conditions and desired current and future groundwater elevations communicated during public meetings
- Results of modeling of future groundwater-level conditions

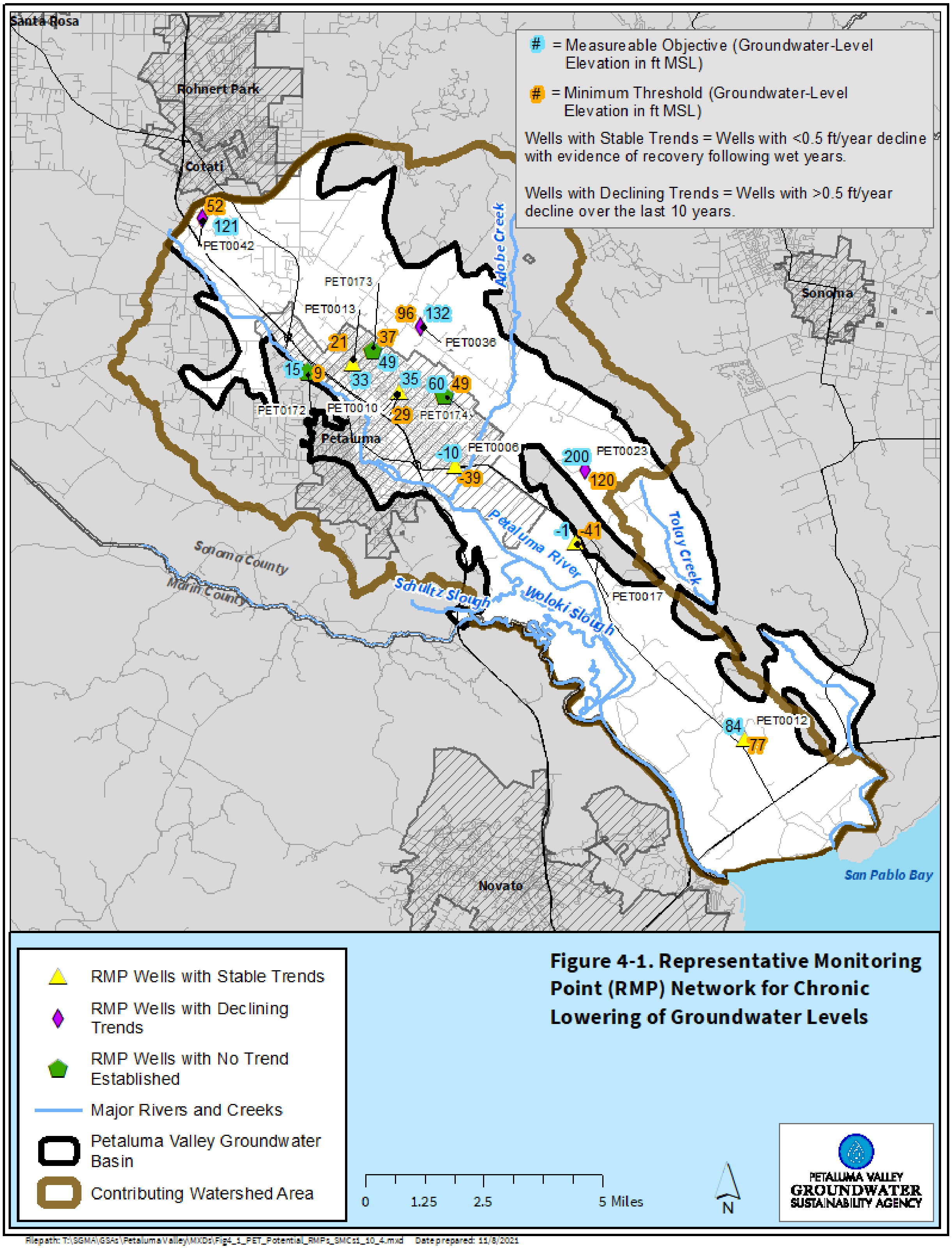
As described in the previous subsections and in **Section 3.2.2**, different patterns of historical groundwater-level trends are observed within the Basin with areas exhibiting long-term stable groundwater-level trends and areas with historical declining trends that have exhibit recovered or recovering groundwater levels. To account for the distinct patterns of historical groundwater-level trends observed within the Basin, different methodologies for calculating MTs were applied to the following two categories of RMPs based on observed patterns in historical and recent groundwater-level trends:

- RMPs with relatively stable long-term groundwater levels defined as less than 0.5 foot per year of decline with evidence of recovery following wet years
- RMPs exhibiting groundwater-level declines (greater than 0.5 foot per year of decline with limited recovery in wet years)

These two different patterns were distinguished based on trend lines calculated by linear regression of observed groundwater levels at each RMP (or from a similarly constructed nearby monitoring well where historical records are limited). **Figure 4-1** shows the locations of the RMPs, and which RMPs are associated with each pattern. The calculated trends are included with the hydrographs in **Appendix 4-A**.

The MTs were set at each RMP based on the three following primary factors:

1. Review of groundwater-level data and hydrographs to identify the lowest historical groundwater elevation at each RMP after removing any measurements flagged as “questionable measurements” or otherwise anomalous measurements from the datasets.
2. Calculation of “well impact depths” in the vicinity of each RMP to identify depths at which the lowering of groundwater levels may impact well users, including domestic, agricultural, public supply, and industrial wells.
3. Calculation of a “drought factor or buffer” to account for reasonably foreseeable future droughts at each RMP with recent groundwater levels that are not below or approaching the above calculated well impact depth.



Filepath: T:\SGMA\GSAs\PetalumaValley\MXDs\Fig4_1_PET_Potential_RMPs_SMCs1_10_4.mxd Date prepared: 11/8/2021

Figure 4-1. Representative Monitoring Points for Chronic Lowering of Groundwater Levels

Calculation of Well Impact Depths

The methodology for incorporating the potential impact on existing well users involved the statistical evaluation of known completion information for water supply wells located within the vicinity of each potential RMP. These statistics were calculated by drawing polygons for each potential RMP area and querying Sonoma Water's Water Well Database (sourced from DWR's Online System for Well Completion Reports, Permit Sonoma, and the USGS). Generally, the Basin boundary and midpoints between potential RMPs were used to draw the vicinity areas. In some cases, physical features that appear to have a direct influence on groundwater movement were used as boundaries of the vicinity areas. For each vicinity area polygon, the total number of supply wells, the shallowest supply well total depth, the 95th percentile shallowest supply well total depth, and the average supply well depth were calculated (these statistics, along with maps showing the vicinity area polygons, are provided in **Appendix 5-B**). For each RMP, the analysis included all types of supply wells contained within the datasets (domestic wells, irrigation wells, public supply wells, and industrial wells). To ensure that the analysis accounts for drawdown due to a reasonable level of production from existing wells, the calculated well impact depths incorporate "saturated thickness factors" of 10 feet, which are added to the 95th percentile shallowest supply well depths.

Figure 4-2 provides a conceptual illustration of this methodology. The figure shows a series of wells, with the well on the farthest right representing the 95th percentile shallowest well depth, and showing how the saturated thickness factor would be applied.

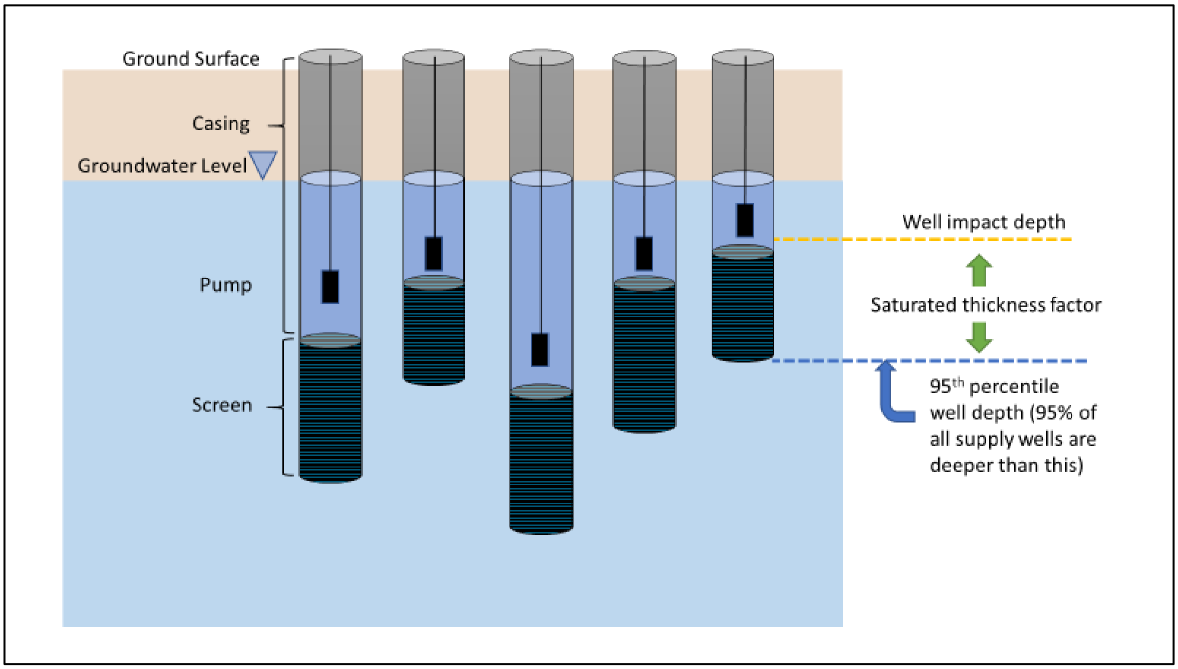


Figure 4-2. Illustration of Calculated 95th Percentile Well Depths and Saturated Thickness Factor

Factoring for Future Drought Conditions

A factor to account for reasonably foreseeable future droughts was calculated for each RMP using the following methodology:

- For wells with 10 or more years of historical data, the largest consecutive 4-year decline during historical dry periods was used
- For wells with fewer than 10 years of historical data, the future simulated largest consecutive 4-year decline was used

As the degree of groundwater-level responses to yearly climate conditions varies based on localized hydrogeologic condition, calculating a factor specific to each RMP incorporates observed groundwater-level responses specific to each RMP vicinity area into the MTs. The declines associated with these drought factors are consistent with levels of observed declines within the Subbasin during historical droughts, which then recovered during subsequent normal and/or wet water years. The calculated drought factors range from 3 to 20 feet.

The historical lows minus the drought factor were applied as the MT to RMPs where this level is above the well impact depth (**Figure 4-3** [Case 1]). For RMPs where the well impact depth is shallower than the historical low minus the drought buffer, the well impact depth was applied as the MT (**Figure 4-3** [Case 2]). **Table 4-2** provides a summary of these metrics and presents the final criteria used for calculating the MT at each RMP. As indicated in **Table 4-2**, MTs for 3 of the 11 RMPs represent the calculated well impact depths (that is, Case 2 [**Figure 4-3]**). At these three locations the well impact depth is shallower than the historical low with the drought factor and is considered more protective of beneficial users. At the eight remaining RMPs the MTs based on the historical lows minus the drought factor were determined to be above (that is, protective of) the calculated well impact depths (that is, Case 1 [**Figure 4-3]**).

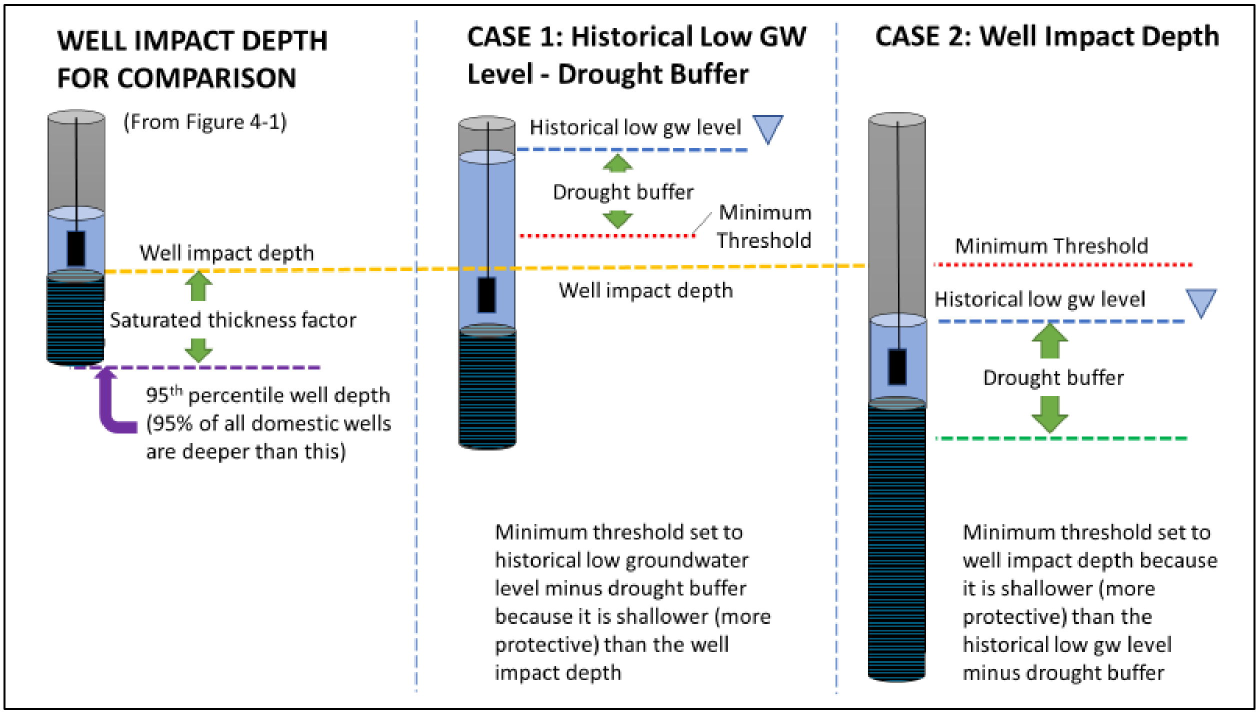


Figure 4-3. Illustration of Application of Well Impact Depth and Drought Buffer to Minimum Thresholds

Table 4-2. Summary of Calculations for Minimum Thresholds, Measurable Objectives, and Interim Milestones

Stable Wells							**MT**	**MO**	**Interim Milestones**
Well ID	**Observed Historical Low (ft msl)**	**Year of Observed Historical Low**	**Calculated Drought Factor (ft)**	**Drought Factor Years**	**Historic Low minus Drought Factor (ft msl)[a]**	**Well Impact Depths (ft msl)[a] 95th**	**Shallower of Historical Low minus 4-year Drought or well impact depth**	**Historical Spring Median (entire)**	**Same as MO**
Pet0006	-27.8	2020	-19.0	Projected	-47	**-39**	-39	-10	-10
Pet0010	31.5	2015	-3.0	2012-2015	**29**	-11	29	35	35
Pet0012	80.5	2014	-3.5	Projected	**77**	3	77	84	84
Pet0013	24.4	2019	-3.0	Projected	**21**	-38	21	33	33
Pet0017	-58.1	1990	-20.0	2011-2014	-78	**-41**	-41	-1	-1
Pet0172	13.0	2019	-4	Projected	**9**	-19	9	15	15
Pet0173	45.1	2019	-8	Projected	**37**	-19	37	49	49
Pet0174	58.6	2020	-10	Projected	**49**	7	49	60	60
Declining Wells							**MT**	**MO**	
Well ID	**Observed Historical Low**	**Year of Observed Historical Low**	**Calculated Drought Factor**	**Drought Factor Years**	**Historic Low minus Drought Factor**	**Well Impact Depths (ft msl)[a] 95th**	**Shallower of Historical Low or well impact depth**	**Historical Spring Median (pre-2010)**	**5-, 10-, and 15-Year Milestones (2027/2032/ 2037)**
Pet0023	139.8	2020	-20	Projected	**120**	7	120	200	165/177/189
Pet0036	111.6	2020	-15.5	1989-1993	**96**	52	96	132	118/123/128
Pet0042	52.2	2018	-14	Projected	38	**52**	52	121	70/87/104

[a] Bold values indicate criteria used for final MT value.

Adaptive Management to Address Data Gaps and Improve/Refine Sustainable Management Criteria

There is appreciable uncertainty regarding the SMC developed for the chronic lowering of groundwater levels sustainability indicator. Specific planned data collection activities that will reduce uncertainty and inform future adjustments or refinements to the chronic lowering of groundwater-level SMC are described in **Section 7** and include:

- Refine information on the depths of nearby water wells from the well log database and information obtained through future well registration program implementation
- Improve mapping and correlation of well depth data with stratigraphic data
- Assess and develop plans to fill data gaps in monitoring networks through targeted additional dedicated monitoring wells and suitable volunteered private wells based on:
  - hydrogeologic properties and geologic features
  - areas of boundary inflows and outflows
  - distribution of pumping
  - location of sensitive beneficial users, such as shallow domestic well users or GDEs)

4.5.2.2 Relationship between Individual Minimum Thresholds and Relationship to Other Sustainability Indicators

Section 354.28 of the GSP Regulations requires that the description of all MTs include a discussion of the relationship between the MTs for each sustainability indicator. In the SMC Best Management Practices document (DWR 2017), DWR clarified that the GSP must describe the relationship between each sustainability indicator's MT by describing why or how a water level MT set at a particular RMP is similar to or different to water level thresholds in a nearby RMP. Additionally, the GSP must describe the relationship between the selected MTs and MTs for other sustainability indicators.

Groundwater elevation MTs are derived from examination of the historical record reflected in hydrographs at each individual RMP and depths of nearby water wells, including domestic well users. Therefore, the MTs are unique at every well, but when combined represent reasonable and achievable groundwater conditions and flowpaths.

An assessment of how other sustainability indicators could be influenced by the chronic lowering of groundwater levels MT indicates the following:

- **Reduction in groundwater storage**. Changes in groundwater elevations are directly correlated to changes in the amount of groundwater in storage and groundwater levels are used as a proxy for the reduction in groundwater storage sustainability indicator. The groundwater elevation MTs are set to establish a minimum elevation that will not lead to undesirable conditions, and that is acceptable to the stakeholders in the area. Therefore, if the groundwater elevation MTs are met (that is, groundwater levels remain stable and above historical lows), they will not result in long-term significant or unreasonable changes in groundwater storage.

- **Seawater intrusion**. A significant and unreasonable condition for seawater intrusion is seawater intrusion inland of areas of existing brackish groundwater that may affect beneficial uses of groundwater. While the available data do not indicate increasing trends in salinity indicators in wells located near the Baylands, lower groundwater elevations, particularly in areas near the margins of the Baylands, could cause seawater to advance inland. For areas with declining groundwater levels, MTs are set near or at recent groundwater elevations with the goal of halting chronic groundwater-level declines. Therefore, the groundwater elevation MTs are intended to not exacerbate, and may help control, the rate of seawater intrusion.

- **Degraded water quality**. A significant and unreasonable condition for degraded water quality would occur if an increase in the concentration of COCs in groundwater leads to adverse impacts on beneficial users or uses of groundwater, due to direct actions by Petaluma Valley GSP projects or management activities or undesirable results occurring for other sustainability indicators. The chronic lowering of groundwater levels could potentially impact water quality by inducing poor-quality water into areas not previously impacted by water quality degradation. However, because MTs are set to avoid significant declines of groundwater levels below historically observed levels, this is not expected to occur.

- **Subsidence**. A significant and unreasonable condition for subsidence is the occurrence of inelastic subsidence caused by groundwater pumping. While continued decline of groundwater levels due to groundwater pumping within the Basin could trigger inelastic subsidence in areas with clay-rich aquifer materials, because MTs are set to avoid significant declines of groundwater levels below historically observed levels, this is not expected to occur.

- **Depletion of ISW**. MTs for the chronic lowering of groundwater levels do not promote additional pumping and aim to maintain groundwater elevations near historical levels in the vicinity of ISW. Therefore, the chronic lowering of groundwater elevations MTs is not anticipated to result in a significant or unreasonable depletion of ISW.

4.5.2.3 Effect of Minimum Thresholds on Neighboring Basins and Subbasins

The Petaluma Valley Basin has two neighboring subbasins that are categorized as medium priority and are also subject to SGMA: the Santa Rosa Plain Subbasin to the north and the Sonoma Valley Subbasin to the east. The Petaluma Valley Basin is also adjacent to the very low-priority Wilson Grove Formation Highlands Basin to the northwest and Novato Valley Basin to the southwest, both of which are not subject to SGMA.

The boundary between the Petaluma Valley Basin and Santa Rosa Plain Subbasin coincides with a surface watershed divide between the Petaluma River watershed and the Laguna de Santa Rosa watershed. The boundary is also the approximate location of a groundwater flow divide;

however, no known structural or geologic features restrict flow between the two areas and groundwater-level changes on one side of the boundary have the potential to influence groundwater levels on the other side. During the historical groundwater-level declines that occurred in the southern portions of the Santa Rosa Plain Subbasin through the early 2000s, no impacts on wells located within the adjacent areas of the Petaluma Valley Basin are known to have occurred. Similarly, no known impacts on wells located within the Santa Rosa Plain Subbasin have occurred related to the limited groundwater-level declines occurring within wells located in the Petaluma Valley Basin near the shared boundary. Because the MTs for the chronic lowering of groundwater aim to maintain groundwater levels above historical lows within the Petaluma Valley Basin, the potential for any negative effects to occur within the Santa Rosa Plain Subbasin related to the MTs for the chronic lowering of groundwater levels is limited.

Groundwater flow between the Petaluma Valley Basin and the Sonoma Valley Subbasin occurs only in the southeastern margins of the Basin in the Baylands area where very little groundwater use occurs due to the natural presence of brackish water. The shared boundary between the Petaluma Valley Basin and the Novato Valley Basin to the southwest is also an area of limited groundwater use within the Baylands area. There are also no GSP projects or management actions planned for these areas of the Basin that might change hydraulic gradients near these shared boundaries. Therefore, the MTs for chronic lowering of groundwater, which aim to maintain groundwater levels near current levels, are unlikely to affect groundwater conditions along these two boundaries.

The boundary between the Petaluma Valley Basin and the Wilson Grove Formation Highlands Basin generally follows the contact between the Quaternary alluvial deposits and the Wilson Grove Formation, with the exception of the City of Petaluma, where the boundary follows the jurisdictional boundary of the City and extends into a portion of the Wilson Grove Formation. Available groundwater-level data along the boundary and information from the simulated water budget indicate that the basins are connected, with groundwater from the Wilson Grove Formation Highlands Basin representing an important source of inflow to the Petaluma Valley Basin. Therefore, groundwater-level changes on one side of the boundary have the potential to influence groundwater levels on the other side. Because the MTs for the chronic lowering of groundwater levels aim to maintain groundwater levels above historical lows within the Petaluma Valley Basin, the potential for any negative effects to occur within the Wilson Grove Formation Highlands Basin related to the MTs for the chronic lowering of groundwater levels is limited.

While not required to be evaluated by SGMA, the potential effect of the chronic lowering of groundwater-level MTs are also very unlikely to influence groundwater levels in other adjoining areas that are not classified as groundwater basins or subbasins by DWR. Groundwater use in these upland areas that flank the eastern and western boundaries of the Basin primarily occurs within the Sonoma Volcanics upgradient of the Basin.

The Petaluma Valley GSA coordinated closely with both the Sonoma Valley and Santa Rosa Plain GSAs; they both set MTs to ensure that they do not prevent each other from achieving sustainability. All three GSAs followed a similar approach and methodology for setting and monitoring MTs. The potential for impacts to occur along all of the above-described boundaries will be evaluated as part of the GSA's routine monitoring and reporting program, which includes both RMP wells and other wells monitored for groundwater levels in the Basin and contributing watershed areas. Additionally, the Petaluma Valley GSA will continue to closely coordinate with neighboring GSAs and the County for areas that are not under a GSA's jurisdiction should any future issues arise.

4.5.2.4 Effect on Beneficial Uses and Users

MTs for the chronic lowering of groundwater levels are set at the more protective of historical low conditions with allowances for future droughts and the depths at which existing water supply wells could be impacted by the lowering of groundwater levels. The MTs are generally advantageous to beneficial users and land uses in the Basin as described in the following paragraphs.

Agricultural land uses and users. The chronic lowering of groundwater-level MTs protects existing agricultural users' ability to meet typical demands by maintaining groundwater levels near current conditions. However, the chronic lowering of groundwater-level MTs places a practical limit on the acceptable lowering of groundwater levels in the Basin, thus conceptually restricting future levels of agriculture in the Basin beyond what is projected in the 50-year baseline scenario without projects to supplement water supplies, or management actions to limit future pumping increases. The potential for this to occur will be addressed through consideration of implementing the projects and management actions discussed in **Section 6**.

Urban land uses and users. The chronic lowering of groundwater-level MTs protects existing municipal and industrial groundwater users' ability to meet typical demands by maintaining groundwater levels near current conditions. However, the chronic lowering of groundwater-level MTs does place a practical limit on the acceptable lowering of groundwater levels in the Basin, thus conceptually restricting future levels of municipal pumping in the Basin beyond what is projected in the 50-year baseline scenario without projects to supplement water supplies, or management actions to limit future pumping increases. The potential for this to occur will be addressed through consideration of projects and management actions discussed in **Section 6**.

Domestic land uses and users. The chronic lowering of groundwater-level MTs are established to protect as many rural residential domestic wells as possible. Therefore, the MTs will likely have an overall beneficial effect on existing domestic land uses by protecting the ability to pump from domestic wells within the Basin.

Ecological land uses and users. Maintaining groundwater near or above historical levels will maintain the connected nature of groundwater and surface water in the Basin. This will protect GDE habitat and generally benefit environmental land uses and users

4.5.2.5 Relation to State, Federal, or Local Standards

No federal, state, or local standards exist that are specific to the chronic lowering of groundwater levels.

4.5.2.6 Method for Quantitative Measurement of Minimum Thresholds

Depth to groundwater will be directly measured at the RMPs identified in **Section 5.3.1** for comparison to MTs. The RMP network includes 11 existing wells. Additionally, between two to four new multi-level monitoring wells, which will monitor the principal aquifer system, are planned to be constructed by the GSA in 2022. It is anticipated that these wells will be incorporated into the RMP network following their construction and the development of SMC for each. The groundwater-level data will be collected in accordance with the monitoring protocols outlined in **Section 5.3.1** and converted to groundwater elevation by subtracting the measured depth to water from the reference point elevation used to take the depth to water measurement.

Available groundwater-level data, including historical data used for the calculation of the MTs and MOs, contain a variety of measurement frequencies ranging from hourly to semiannually. Groundwater-level measurement frequency for the 11 existing wells in the RMP monitoring networks includes the following:

- Two measured more than once per day
- Four measured monthly
- Six measured semiannually

As indicated in **Section 5.3.1**, the goals for groundwater-level measurement frequency will be: (1) measure groundwater levels at least monthly for all RMPs during GSP implementation, and (2) use pressure transducers where feasible to provide a higher level of quality control, so that potential short-term or residual pumping influences can be identified and flagged. Consistent with the monitoring protocols, only static groundwater levels will be compared to MTs.

For reporting seasonal highs and lows for future comparison with MTs, all measurements collected at a higher frequency than monthly will be reported as monthly averages to better align with the measurement frequency within historical datasets used to calculate the MTs. During GSP implementation, individual groundwater-level measurements collected manually and by data loggers will be reviewed for quality control and analyzed for MT exceedances during compilation of GSP annual and 5-year update reports.

GSA staff has identified data gaps in some areas of the Basin in the monitoring networks discussion (**Section 5**). The GSP includes a plan to expand the monitoring network as described in the implementation discussion (**Section 7**).

4.5.3 Measurable Objectives

MOs for the chronic lowering of groundwater levels represent target groundwater elevations for 2042, considering realistic project implementation and allowing for operational flexibility over a range of climate and hydrologic variability.

4.5.3.1 Method for Setting Measurable Objectives

Similar to the approach and methodology used for setting MTs, MOs are reflective of the distinct patterns of historical groundwater-level trends observed within the Basin.

For RMPs exhibiting relatively stable long-term groundwater-level trends, the MO is calculated as the historical median spring groundwater elevation, because the aim of the MO is to maintain groundwater levels within historical ranges for these areas.

For RMPs exhibiting historical or recent declining trends, the MO is calculated as the median of spring groundwater elevations that occurred prior to the onset of declining trends, because the aim of the MO is stabilize and reverse the declining trends in these areas.

MOs for each RMP are listed in **Table 4-2**.

4.5.3.2 Interim Milestones

For RMPs exhibiting relatively stable long-term groundwater-level trends, the MO is essentially set at recent conditions (that is, the aim of the MO for these wells is to maintain groundwater levels within historical and recent ranges); therefore, interim milestones are essentially equivalent to the MO throughout the GSP implementation period.

Interim milestones for wells exhibiting historical or recent historical or recent declining trends were generally selected to define a smooth linear increase in groundwater levels between the observed groundwater elevation at the RMP in 2020, and the MO as presented in **Table 4-2**. For the initial 5-year interim milestone in 2027, the interim milestones are set at current spring groundwater levels to allow time to implement the projects and management actions described in **Section 6**. Interim milestones at 5-year intervals for the 2022 through 2042 time period established at each RMP are included in **Table 4-2**. Interim milestones may be adjusted at any time during the SGMA timeline. It is expected that they will be reconsidered at 5-year intervals when the GSP is revised and updated. The monitoring of basin conditions during the initial 5-year period will provide useful indicators on whether the interim milestones are close to being met. Failure to meet interim milestones is not in and of itself an indication of undesired conditions but is meant to provide information for determining whether the 20-year goals are on track to being achieved. Alternative projects and management actions may be considered or pursued if the interim milestones are not being met.

4.5.4 Undesirable Results

4.5.4.1 Criteria for Defining Undesirable Results

The chronic lowering of groundwater levels undesirable result is a quantitative combination of groundwater elevation MT exceedances. For the Basin, the specific groundwater condition that constitutes an undesirable result is:

Groundwater levels in 25 percent of the RMPs exceed their minimum thresholds for three consecutive fall measurements.

Consistent with DWR guidance, if MT exceedances are caused by emergency operational issues or droughts that extend for longer than the 4-year drought factor incorporated into the MTs (as described in **Section 4.5.2.1**), it is not considered an undesirable result unless the groundwater levels do not rebound to above the MTs during future normal and wet years following long-term droughts.[1] The methodology for the determination of future drought years is provided in **Appendix 4-B**.

Exceedances of MTs at a single well will require investigation to determine if any actions should be considered to avoid potential future onset of undesirable results, as described in **Section 4.5.4.2**.

The 3 consecutive years of MT exceedances was selected by the GSA Board to (1) balance protection of beneficial users with costs related to response actions, and (2) limit the potential for shorter-duration MT exceedances that may not be chronic in nature to trigger undesirable results.

4.5.4.2 Potential Causes of Undesirable Results

The potential causes of undesirable results for chronic lowering of groundwater-level results include:

- Increased groundwater pumping in the Basin leading to chronic groundwater-level declines
- A significant reduction in natural recharge as a result of climate change, reduced groundwater and surface water interaction, or other land surface processes

If the location and volumes of groundwater pumping change as a result of unforeseen rural residential, agricultural, and urban growth that depend on groundwater as a water supply without supplemental supplies, these increased demands might lower groundwater to

---

[1] The SMC BMP (DWR 2017) provides information on how droughts may affect the groundwater-level SMC: "Undesirable results are one or more of the following effects: Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods."

undesirable levels. Reduction in recharge or changes in rainfall patterns could also lead to more prolonged periods of lowered groundwater levels than have occurred historically.

As described in **Section 6**, projects and actions are being considered for implementation and/or contingency plans to augment recharge and reduce groundwater pumping to mitigate the potential for these conditions to occur.

Additionally, to respond to these potential conditions prior to the onset of an undesirable result, the following actions would be implemented if an MT is exceeded at a single RMP that does not trigger an undesirable result:

- Review the available data from the full monitoring network (that is, non-RMP monitoring wells) to assess the potential scale of areas exhibiting declines
- Assess whether the exceedance is climate-related
- Review any known or potential changes in groundwater pumping patterns (for example, new wells brought online, changes in land/water use, and the like), as needed
- Consider whether additional RMPs are needed
- Share information with nearby well owners, as appropriate
- Consider planning or implementing projects/actions, as appropriate (for example, begin with lower cost and/or voluntary projects/actions)

The approach is a proactive means for avoiding the exceedance of undesirable results when warning signs are available. Not all actions would be implemented for each individual exceedance of an MT. The tasks described above would generally be performed sequentially based on the potential severity of the occurrence.

4.5.4.3 Effects on Beneficial Users and Land Use

The potential effects of undesirable results of the chronic lowering of groundwater levels on beneficial users and land use could be the inability of a significant number of private, agricultural, and M&I production wells from supplying groundwater to meet their water demands. The beneficial users that could be impacted by undesirable results from chronic lowering of groundwater levels include domestic well users, irrigation well users, and public water supply well users (inclusive of DACs that obtain water from these user categories). Lowered groundwater levels reduce the saturated thickness of aquifer from which wells can pump, which could lead to increased pumping costs, reduced pumping capacity, or the need to drill new deeper wells. This would effectively increase the cost of using groundwater as a water source for all users. Avoiding undesirable results for the chronic lowering of groundwater levels will limit the potential for these conditions to occur in the future.

4.6 Reduction in Groundwater Storage Sustainable Management Criteria

The reduction in groundwater storage SMC will be evaluated using groundwater levels as a proxy based on well-established hydrogeologic principles that the volume of groundwater in storage is directly proportional to groundwater elevations (Alley et al. 1999). The groundwater elevation MTs and MOs are established to maintain adequate groundwater supplies for all beneficial uses and users. Therefore, preventing groundwater elevations from dropping below MTs, by definition, maintains an adequate amount of water in storage. Maintaining groundwater elevations within the operational range between MTs and MOs is equivalent to no long-term change in storage.

4.6.1 Locally Defined Significant and Unreasonable Conditions

Locally defined significant and unreasonable conditions were determined based on public meetings and discussions with GSA staff, Advisory Committee members, and the GSA Board. A significant and unreasonable reduction in groundwater storage in the Basin is defined as:

Reduction of groundwater storage that causes significant and unreasonable impacts on the long-term sustainable beneficial use of groundwater in the basin, as caused by:

- Long-term reductions in groundwater storage
- Pumping exceeding the sustainable yield

4.6.2 Minimum Thresholds

Section 354.28(c)(2) of the GSP Regulations states that “The minimum threshold for reduction of groundwater storage shall be a total volume of groundwater that can be withdrawn from the basin without causing conditions that may lead to undesirable results. Minimum thresholds for reduction of groundwater storage shall be supported by the sustainable yield of the basin, calculated based on historical trends, water year type, and projected water use in the basin.”

This GSP will monitor changes in the groundwater levels at the RMPs as a proxy for the change in groundwater storage metric. As allowed in Section 354.36(b)(1) of the GSP Regulations, groundwater elevation data at the RMPs will be reported annually as a proxy to track changes in the amount of groundwater in storage.

Based on well-established hydrogeologic principles, stable groundwater elevations maintained above the MTs will indicate that groundwater storage is not being depleted (Alley et al. 1999). Therefore, using groundwater elevations as a proxy, the MT for groundwater storage will be met if the MTs for the chronic lowering of groundwater levels are not exceeded.

4.6.2.1 Information and Methodology Used to Establish Groundwater Storage Minimum Thresholds

Similar to the chronic lowering of groundwater levels SMC, the information used for establishing the MTs for the groundwater storage sustainability indicator included:

- Historical groundwater elevation data
- Depths and locations of existing wells
- Maps of current and historical groundwater elevation data
- Input from stakeholders regarding significant and unreasonable conditions and desired current and future groundwater elevations communicated during public meetings
- Results of modeling of future groundwater-level conditions

4.6.2.2 Relationship between Individual Minimum Thresholds and Relationship to Other Sustainability Indicators

The MTs for the reduction in groundwater storage are the same as those used for the chronic lowering of groundwater levels. Because groundwater elevations will be used as a proxy for estimating changes in groundwater storage, the reduction in groundwater storage sustainability indicator cannot cause undesirable results for the chronic lowering of groundwater levels sustainability indicator.

The relationship between the groundwater storage sustainability indicator and other sustainability indicators is the same as the relationship between the chronic lowering of groundwater levels and other sustainability indicators, as described in **Section 4.5.2.2**.

4.6.2.3 Effect of Minimum Thresholds on Neighboring Basins and Subbasins

The Petaluma Valley Basin has two neighboring subbasins that are categorized as medium priority and are also subject to SGMA: the Santa Rosa Plain Subbasin to the north and the Sonoma Valley Subbasin to the east. The Petaluma Valley Basin is also adjacent to the very low-priority Wilson Grove Formation Highlands Basin to the northwest and Novato Valley Basin to the southwest, both of which are not subject to SGMA.

The potential effect of the groundwater storage MT on neighboring basins, subbasins, and other adjoining areas is the same as the relationship described for the chronic lowering of groundwater levels in **Section 4.5.2.3**.

4.6.2.4 Effect on Beneficial Uses and Users

The MT for a reduction in groundwater storage will maintain stable average groundwater elevations and encourages minimal long-term net change in groundwater elevations and storage.

The potential effects of the groundwater storage MT on beneficial uses and users are the same as the potential effects described for the chronic lowering of groundwater levels in **Section 4.5.2.4**.

4.6.2.5 Relation to State, Federal, or Local Standards

No federal, state, or local standards exist that are specific to groundwater storage.

4.6.2.6 Method for Quantitative Measurement of Minimum Thresholds

Storage MTs will be measured by collecting groundwater-level measurements at the RMP sites in the monitoring network, as described in **Sections 4.5.2.6** and **5.3.1**. These data will be used to monitor groundwater elevations and compare with MTs.

Annual groundwater storage will also be calculated and reported by comparing changes in contoured groundwater elevations to assess changes in groundwater storage.

4.6.3 Measurable Objectives

The change in a storage sustainability indicator was defined using groundwater levels as a proxy for the change in storage MO. The same MTs and MOs are used as are defined in the chronic lowering of groundwater-level indicator to protect against a significant and unreasonable reduction in groundwater storage.

Additionally, even though groundwater levels are being used as a proxy in lieu of using the total volume of groundwater pumped, the achievement of MOs for the chronic lowering of groundwater levels will require that groundwater levels either increase or are maintained at their current levels. Therefore, the MOs will necessitate pumping within the sustainable yield calculated for the Basin in order to have no long-term change in storage once sustainability is reached.

4.6.3.1 Method for Setting Measurable Objectives

The methods for setting the MO for groundwater storage incorporates the same methods for setting the MO for the chronic lowering of groundwater levels described in **Section 4.5.3.1**.

4.6.3.2 Interim Milestones

Interim milestones for groundwater storage are the same as those established for the chronic lowering of groundwater levels. Achieving the chronic lowering of groundwater levels interim milestones will prevent long-term reductions in groundwater in storage.

4.6.4 Undesirable Results

4.6.4.1 Criteria for Defining Undesirable Results

Groundwater in storage will be evaluated with the same MTs and MOs as the chronic lowering of groundwater levels sustainability criteria.

For the purposes of this GSP, the definition of undesirable conditions for the reduction of groundwater storage is the same as the following definition of the chronic lowering of groundwater levels:

Groundwater levels in 25 percent of the RMPs exceed their minimum thresholds for three consecutive fall measurements.

4.6.4.2 Potential Causes of Undesirable Results

The potential causes of undesirable results for the reduction of groundwater storage are the same as those identified for the chronic lowering of groundwater levels in **Section 4.5.4.2**:

- Increased groundwater pumping in the Basin leading to chronic groundwater-level declines
- A significant reduction in natural recharge as a result of climate change or other processes

4.6.4.3 Effects on Beneficial Users and Land Use

The potential effects of undesirable results of groundwater storage on beneficial users and land use are the same as those identified for the chronic lowering of groundwater levels, as described in **Section 4.5.4.3**, which could include the inability of a significant number of private, agricultural, industrial, and M&I production wells from supplying groundwater to meet their water demands. Lowered groundwater levels reduce the thickness of saturated aquifer from which wells can pump, which could lead to increased pumping costs or the need to drill new deeper wells. This would effectively increase the cost of using groundwater as a water source for all users. Avoiding undesirable results for the chronic lowering of groundwater levels will limit the potential for these conditions to occur in the future.

4.7 Seawater Intrusion Sustainable Management Criteria

There are several factors to be considered when developing SMC for seawater intrusion, including the occurrence of significant and unreasonable conditions, the GSA’s ability to determine where and when seawater intrusion is occurring, and its relationship to groundwater pumping.

As indicated in **Section 3.2.4.5** of the **Basin Setting** section, available data, although limited, do not indicate that seawater intrusion has been occurring and impacting beneficial users of groundwater. However, seawater intrusion has the potential to occur within the Basin due to observed declining groundwater levels, which have dropped below sea level in areas of the southern part of the Basin. Significant data gaps have been identified in the southern portions of the Basin that prevent adequate mapping and characterizing the distribution of salinity in groundwater, as identified in **Section 3.1.8**. In particular, groundwater quality data and well construction data are limited in this area and comprehensive monitoring infrastructure is lacking. The GSA has prioritized addressing these data gaps, as further described in **Section 7, Implementation Plan**, of this GSP.

Because of the significant data gaps, an adaptive approach for refining the initial SMC for seawater intrusion will be completed during GSP implementation. Additional characterization described in **Section 7** will provide a more robust understanding of not only current conditions, but also potential future impacts from climate change (that is, sea level rise) and land-use practices in the Baylands area of the Basin.

4.7.1 Locally Defined Significant and Unreasonable Conditions

Information relevant to the identification of significant and unreasonable conditions and development of SMC is summarized in the following paragraphs.

Naturally occurring brackish groundwater currently exists in the Baylands area. Freshwater and saltwater zones within coastal aquifers are separated by a transition zone (sometimes referred to as the zone of dispersion) where there is mixing of freshwater and saltwater. The transition zone is characterized most commonly by measurements of chloride concentrations in groundwater ranging from about 250 to 19,000 mg/L. As described in **Section 3.2.4.5** of the **Basin Setting**, it is understood that the natural brackish groundwater in the Baylands area represents this transition zone of the Basin between the saline waters of San Pablo Bay and fresh groundwater from the more inland areas of the Basin north of the Baylands area.

The limited number of existing groundwater users in the Baylands do not appear to be negatively impacted by the brackish groundwater. As indicated on **Figure 2-5** of **Section 2, Plan Area**, the majority of agricultural crops in the Baylands area are either not irrigated or use recycled water for irrigation. Existing beneficial uses of groundwater in this area are limited to very few agricultural and residential supply wells, which have been pumping groundwater influenced by brackish water for decades, indicating that beneficial users have not been negatively impacted by the natural brackish groundwater in this area. Therefore, current conditions are not considered a significant and unreasonable condition.

Sea level rise impacts may occur in the future. According to communications with DWR SGMA staff during GSP development, the GSA is not required to address future impacts from sea level rise because the impacts from sea level rise are not a result of GSA activities or groundwater pumping,. It is expected that monitoring and assessment of sea level rise impacts, including the use of numerical modeling, will be ongoing throughout the implementation of the GSP.

Land-use changes affect the Baylands area. Historical changes in land use in the Baylands area of the Basin have affected the distribution of saline and fresh surface water, which, in turn, affect the distribution and occurrence of salinity in the underlying groundwater. GSA staff have had initial discussions with Sonoma Land Trust staff who are leading ongoing planning activities associated with wetlands restoration that could affect the occurrence and distribution of saline groundwater in the future. Although the GSA has no authority over such activities, the GSA will continue to coordinate with parties involved in the restoration activities and work with those parties to assess potential impacts of these projects on seawater intrusion that may affect beneficial uses of groundwater in the Basin.

Locally defined significant and unreasonable conditions were determined based on the above information and discussions at public meetings, and discussions with GSA staff, Advisory Committee members, and the GSA Board.

Significant and unreasonable conditions are defined as:

- Seawater intrusion inland of areas of existing brackish groundwater that may affect beneficial uses of groundwater.

Examples of potential adverse impacts related to seawater intrusion are described in **Sections 4.7.2.4** and **4.7.4.3**.

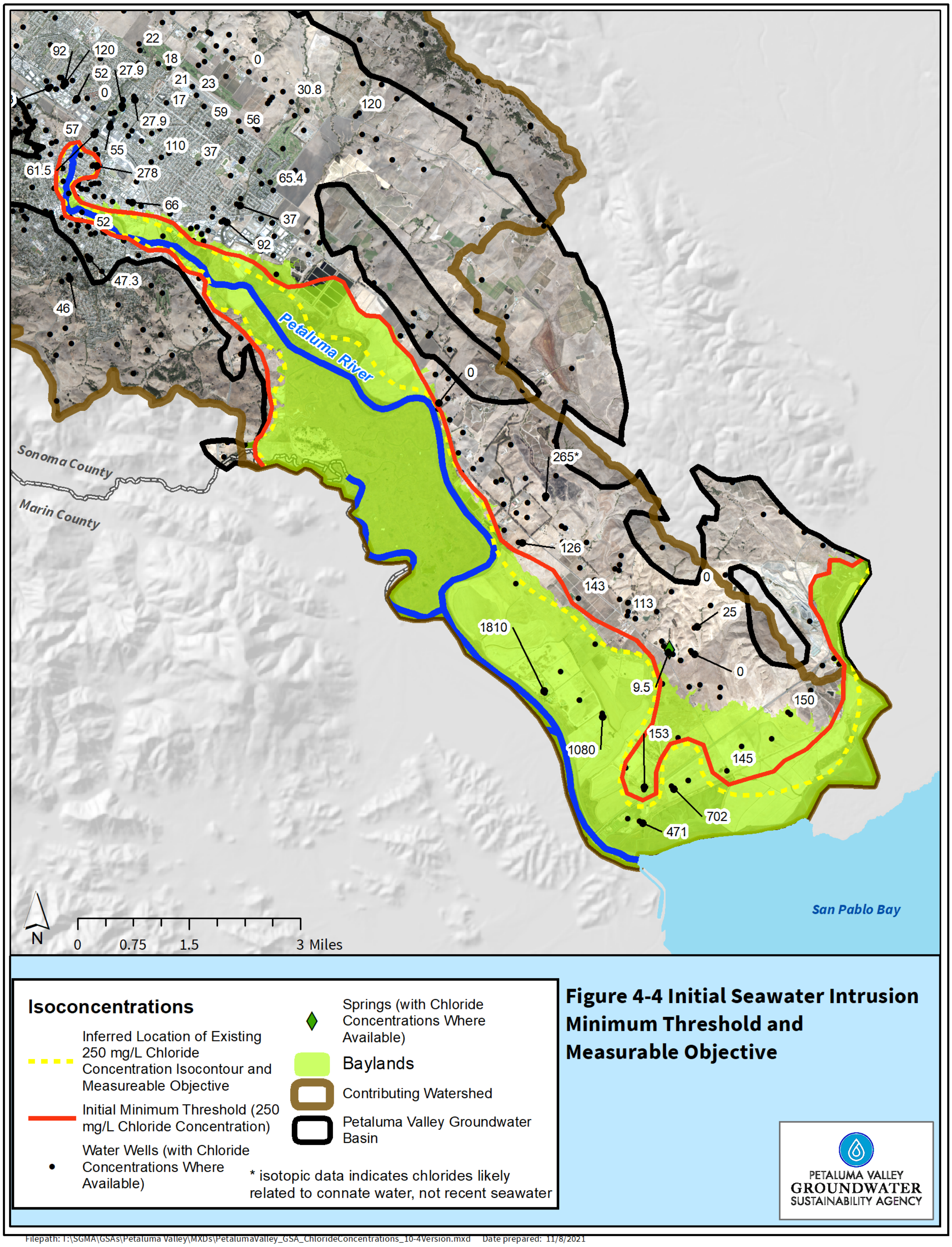
4.7.2 Minimum Thresholds

Section 354.28(c)(3) of the GSP Regulations states that "The minimum threshold for seawater intrusion shall be defined by a chloride concentration isocontour for each principal aquifer where seawater intrusion may lead to undesirable results." The GSP Regulations require the following information to support the descriptions of the seawater intrusion MT and MO:

- Section 354.28(c)(3)(A): Maps and cross-sections of the chloride concentration isocontour that defines the MT and MO.
- Section 354.28(c)(3)(B): A description of how the seawater intrusion MT considers the effects of current and projected sea levels.

The seawater intrusion MT is defined as follows:

The minimum threshold for seawater intrusion is the 250 mg/L chloride isocontour located in an area that is protective of beneficial users of groundwater, as shown on **Figure 4-4**.



Filepath: I:\SGMA\GSAs\Petaluma Valley\MXDs\PetalumaValley_GSA_ChlorideConcentrations_10-4Version.mxd Date prepared: 11/8/2021

Figure 4-4. Seawater Intrusion Minimum Threshold and Measurable Objective

4.7.2.1 Information and Methodology Used to Establish Seawater Intrusion Minimum Thresholds and Measurable Objectives

The MT was defined in the aquifers as the 250 mg/L chloride concentration isocontour to protect beneficial use of groundwater outside the Baylands area, because native chloride concentrations in the inland portions of the Basin are generally below 100 mg/L. This 250 mg/L concentration is the secondary drinking water maximum contaminant level (SMCL) for chloride and is also less than the chloride concentration that can be tolerated by grapes (262 mg/L) without showing adverse effects (University of California Cooperative Extension 2006). Hay cultivars also grown in this area are known to be tolerant of much higher chloride concentrations.

The Baylands area of the Basin near San Pablo Bay has very few wells used for groundwater supply because of the naturally occurring brackish conditions. Consequently, minimal water quality monitoring has been conducted in this area in the past. Because there are significant monitoring well data gaps, the GSA lacks the data needed at this point to adequately map the current 250 mg/L chloride concentration isocontour and to confidently establish the most appropriate location for the MT. The following adaptive methodology uses existing data and provides management flexibility while data are collected during GSP implementation. This approach is anticipated to result in future updates and refinements of the seawater intrusion SMC:

1. The current 250 mg/L chloride isocontour is interpolated from existing groundwater monitoring data, which have been collected through several groundwater monitoring programs and span multiple years. It is understood that these data are not derived from RMPs, or collected contemporaneously; however, the data represents the best currently available information. The estimated baseline 250 mg/L chloride isocontour developed from these data is shown on **Figure 4-4** as the yellow isocontour.

2. The MT isocontour is initially set between (inland) of the baseline 250 mg/L chloride isocontour and areas with known existing water wells serving beneficial users, as shown on **Figure 4-4**. It is anticipated that the MT isocontour will be updated and refined in future GSP updates once additional data are available.

4.7.2.2 Relationship between Individual Minimum Thresholds and Relationship to Other Sustainability Indicators

Assessment of how other sustainability indicators could be influenced by the seawater intrusion MT indicates the following:

- **Chronic lowering of groundwater levels.** Nothing in the seawater intrusion MTs would promote additional pumping that could impact groundwater elevations. Therefore, the seawater intrusion MTs will not result in an exceedance of the chronic lowering of groundwater levels MT.

- **Change in groundwater storage.** Nothing in the seawater intrusion MTs promotes pumping in excess of the sustainable yield. Therefore, the seawater intrusion MTs will not result in an exceedance of the groundwater storage MT.

- **Degraded water quality.** Because chloride is considered a constituent of concern for degraded water quality and the seawater intrusion MTs are designed to protect beneficial users from seawater intrusion (using chloride as an indicator), the seawater intrusion MTs may have a beneficial impact on groundwater quality by preventing increases in chloride concentrations in supply wells.

- **Subsidence.** Nothing in the seawater intrusion MTs promotes additional pumping that could cause subsidence. Therefore, the seawater intrusion MTs will not result in an exceedance of the subsidence MT.

- **Depletion of ISW.** Nothing in the seawater intrusion MTs promotes additional pumping or lower groundwater elevations adjacent to ISW. Therefore, the groundwater quality MTs will not result in a significant or unreasonable depletion of ISW.

4.7.2.3 Effect of Minimum Thresholds on Neighboring Basins and Subbasins

The Petaluma Valley Basin has two neighboring subbasins that are categorized as medium priority and are also subject to SGMA: the Santa Rosa Plain Subbasin to the north and the Sonoma Valley Subbasin to the east. The Petaluma Valley Basin is also adjacent to the very low-priority Wilson Grove Formation Highlands Basin to the northwest and Novato Valley Basin to the southwest, both of which are not subject to SGMA. Because the Santa Rosa Plain Subbasin and Wilson Grove Formation Highlands Basin are not located near the coast, it is not anticipated that they would be affected by the seawater intrusion MTs in the Petaluma Basin.

Because the seawater intrusion MT is designed to prevent additional seawater intrusion related to groundwater pumping, it is unlikely that the MT for the Petaluma Valley Basin will prevent the neighboring Sonoma Valley GSA from achieving and maintaining sustainability. Similarly, it is unlikely that the MT for seawater intrusion will negatively impact the Novato Valley Basin for the same reasons. The Petaluma Valley GSA coordinated closely with the Sonoma Valley GSA to set MTs to ensure that they do not prevent each other from achieving sustainability. Both the Petaluma Valley and Sonoma Valley GSAs followed a similar approach and methodology for setting and monitoring MTs.

4.7.2.4 Effect on Beneficial Uses and Users

The MT is the secondary drinking water standard, which is inherently protective of drinking water as a beneficial use. The MT is also less than the concentration of chloride thought to impact grapes and hay crops, which are the primary crops currently grown in this area. It is recognized that there are groundwater users within the brackish groundwater areas of the Basin with wells that exhibit elevated chloride concentrations (**Figure 4-4**). There are several vineyards in this area that use recycled water for irrigation purposes for that reason.

The potential effects of the seawater intrusion MT on other beneficial uses and users in the Basin are as follows:

- **Agricultural land uses and users**. The seawater intrusion MTs generally provide positive benefits to the Basin’s agricultural water users. Preventing seawater intrusion ensures that a supply of usable groundwater will exist for beneficial agricultural use.
- **Urban land uses and users.** The seawater intrusion MTs generally provide positive benefits to the Basin’s urban water users. Preventing additional seawater intrusion will help ensure an adequate supply of groundwater for urban supplies.
- **Domestic land uses and users**. The seawater intrusion MTs generally provide positive benefits to the Basin’s domestic water users. Preventing additional seawater intrusion will help ensure an adequate supply of groundwater for domestic supplies.
- **Ecological land uses and users**. Although the seawater intrusion MTs do not directly benefit ecological uses, it can be inferred that the seawater intrusion MTs provide generally positive benefits to the Basin’s ecological water uses. Preventing additional seawater intrusion will help prevent unwanted high salinity levels from the coast from impacting ecological groundwater uses. Additionally, coordination between the GSA and entities involved in restoration activities within the Baylands area will help better identify and avoid potential effects on ecological water uses in this area.

4.7.2.5 Relation to State, Federal, or Local Standards

While no federal, state, or local standards exist that are specific to seawater intrusion, the MT is set at the recommended SMCL for chloride established by the SWRCB DDW and is therefore consistent with existing available standards for drinking water.

4.7.2.6 Method for Quantitative Measurement of Minimum Thresholds

As previously noted, and further described in **Section 5**, **Proposed Monitoring Plan**, the monitoring network for seawater intrusion represents a significant data gap that will need to be developed during the early stages of GSP implementation. Monitoring for seawater intrusion just north and along the perimeter of the San Pablo Baylands area will be conducted using a combination of existing water supply wells and additional proposed new dedicated monitoring wells constructed during implementation of the GSP, depending upon well access, construction, and funding availability. Until an adequate monitoring network is developed for seawater intrusion, chloride concentrations measured in groundwater samples from public supply wells within or near the margins of the Baylands area will be used to provide an indication of potential inland incursion of the chloride isocontour. The future monitoring network will be designed to more accurately map the location of the 250 mg/L chloride isocontour.

Future refinement of the SMC will be considered, as additional information is developed to better characterize and monitor the distribution of chloride in the aquifer.

4.7.3 Measurable Objectives

The MO for seawater intrusion is defined as the 250 mg/L chloride isocontour at the currently inferred interface of brackish groundwater (**Figure 4-4)**. The goal of the MO is to protect beneficial users by maintaining this interface at its current location and avoiding any future inland incursion of seawater.

4.7.3.1 Method for Setting Measurable Objectives

The MO isocontour was set at the best estimate of current conditions and will be refined with future monitoring data. The goal is to not move the brackish groundwater interface further inland, because it might then start to impact beneficial users of groundwater.

4.7.3.2 Interim Milestones

The MOs for seawater intrusion are set at current conditions; therefore, the expected interim milestones are identical to current conditions.

4.7.4 Undesirable Results

4.7.4.1 Criteria for Defining Undesirable Results

The seawater intrusion undesirable result is a quantitative combination of chloride concentrations MT exceedances.

Undesirable results for seawater intrusion occur in the Basin when two conditions are met:

1. Three consecutive years of MT exceedances (the MT exceedances occur when the monitoring data indicate that the current extent of groundwater with 250 mg/L of chloride is inland relative to the MT isocontour)

2. The MT exceedance is determined to be caused by groundwater pumping

The 3 consecutive years of MT exceedances was selected by the GSA Board to account for the (1) significant uncertainty associated with the mapping of the chloride isocontour due to current data limitations; and (2) potential future short-term (for example, drought-related or seasonal) incursions of the chloride isocontour that have historically occurred along the margins of the Baylands (Kunkel and Upson 1960).

To ensure that undesirable results are tied to conditions that the GSA can feasibly manage (that is, groundwater levels and groundwater pumping), a correlation methodology will be used to determine if seawater intrusion-related undesirable results have occurred as a result of groundwater-level declines due to groundwater pumping. This methodology will be implemented in conjunction with the GSP monitoring plan that includes regular evaluation of ongoing groundwater quality, including chloride monitoring, and groundwater elevation measurements and trend analysis.

Exceedance of a seawater intrusion MT will trigger implementation of the following methodology to determine if the seawater intrusion is related to groundwater pumping and, therefore, an undesirable result may be occurring that requires action:

- Review of related chloride and TDS groundwater quality data, including WY average and standard deviations, and multi-year averages and standard deviations
- Review of groundwater elevation measurements and trends in RMP and other nearby wells being monitored, including an assessment as to whether groundwater levels have declined below historical lows or sea level
- Evaluation of time series plots of groundwater levels relative to sea level, chloride, and TDS data from nearby monitoring wells
- Evaluation of known or estimated groundwater pumping patterns near potential seawater intrusion
- Numerical modeling to evaluate these reviews and evaluations, as necessary
- Compilation of pertinent data and assessment of any data gaps

Not all actions would be implemented for each individual exceedance of an MT. The tasks described in this section would generally be performed sequentially based on the potential severity of the occurrence. These data will be evaluated to determine whether the cause of seawater intrusion is declining groundwater levels due to groundwater pumping, if this constitutes an undesirable result, and proposed actions needed to halt additional seawater intrusion in the future. Other methods may also be considered based on the specific occurrence and available data and technical tools at the time. Should future MT exceedances occur, the results of the correlation methodology review and evaluation of data and monitoring will be provided with annual reports submitted to DWR. Additionally, any seawater intrusion is of great concern to the GSA and would likely trigger additional studies and potential monitoring efforts to better assess and understand the hydrogeologic framework and causes to prevent further movement inland of chloride in groundwater.

4.7.4.2 Potential Causes of Undesirable Results

Conditions that may lead to an undesirable result include groundwater-level declines along the northern margins of the tidal marshlands and the tidal reaches of the Petaluma River. Groundwater-level declines in these areas could trigger the inducement of brackish water into fresher groundwater aquifers and may impact water quality for beneficial use. Such groundwater-level declines could be caused by ongoing or additional future pumping from supply wells near the margins of the Baylands area.

Other conditions, such as sea level rise or land-use changes (including planned restoration activities), could cause future MT exceedances; however, these are not conditions that the GSA has the ability or authority to control and would not be considered an undesirable result. The methodology described above will help determine whether the causes of potential future MT exceedances constitute an undesirable result. The GSA has initiated discussions and is committed to future close coordination with organizations leading the planned restoration activities to limit the potential for future undesirable results and to appropriately monitor effects of future restoration activities.

4.7.4.3 Effects on Beneficial Users and Land Use

The primary detrimental effect on beneficial users and land uses from seawater intrusion is that the groundwater supply will become saltier and thus impact the use of groundwater for domestic/public supply and agricultural purposes. Seawater intrusion renders non-brackish groundwater essentially unusable for many beneficial users and land uses without expensive mitigation or treatment. Once seawater intrudes into aquifers, reversing and mitigating seawater intrusion can require significant resources and time to address and would significantly increase the cost of water for all users.

4.8 Degraded Water Quality Sustainable Management Criteria

Unlike most other sustainability indicators, degraded water quality is the subject of robust federal, state, and local regulatory regimes carried out by a number of different entities and is not regulated by SGMA. The GSA is not responsible for enforcing existing water quality standards or collecting data to support existing water quality programs, nor is the GSA responsible for natural changes in groundwater quality or groundwater degradation caused by others. However, potential groundwater quality degradation needs to be considered during GSP development to ensure that activities associated with implementing the GSP, such as GSP projects and actions, do not degrade current water quality conditions.

One of the primary challenges in implementing the degraded water quality SMC will be to assess in the future whether any degradation to groundwater quality is due to GSA actions.

4.8.1 Locally Defined Significant and Unreasonable Conditions

Locally defined significant and unreasonable conditions were determined based on public meetings and discussions with GSA staff, Advisory Committee members, and the GSA Board.

Significant and unreasonable water quality conditions occur if an increase in the concentration of constituents of concern in groundwater leads to adverse impacts on beneficial users or uses of groundwater, due to either:

1. Direct actions by Petaluma Valley GSP projects or management activities
2. Undesirable results occurring for other sustainability indicators

Examples of potential adverse impacts are described in **Sections 4.8.2.7** and **4.8.4.3**.

As noted in Section 354.28 (c)(4) of the GSP Regulations, MTs are based on a degradation of water quality, not an improvement of water quality (CCR, 2016). Therefore, this GSP is designed to avoid taking any action that may inadvertently move groundwater constituents that have already been identified in the Basin in such a way that the constituents have a significant and unreasonable impact that would not otherwise occur. COCs were identified based on three criteria:

1. They have an established level of concern such as an MCL or SMCL, or a level that reduces crop production

2. They have been found in the Basin at levels above the level of concern and are routinely analyzed and reported through existing regulatory monitoring programs

3. The occurrence of the COC is extensive throughout the Basin

Based on the review of groundwater quality in **Section 3.2.5**, three COCs were identified that may affect groundwater supply in the Basin. The COCs include:

- Arsenic
- Nitrate
- Salinity (measured as TDS)

There are other point source contaminants found sporadically in the Basin, but these are not regional in extent, are monitored through various other regulatory programs, and consequently SMC are not established in the GSP. New or additional water quality constituents may be identified as potential COCs applicable to the GSP implementation activities through routine consultation and information sharing with other regulatory agencies. The GSA would then consider adding potential COCs and assigning SMC during the 5-year GSP updates.

Future GSP implementation projects or actions that require their own site-specific monitoring network would take into consideration any localized COCs and regulatory requirements.

4.8.2 Minimum Thresholds

The GSP Regulations allow three options for setting degraded water quality MTs. Section 354.28(c)(2) of the GSP Regulations states that “The minimum threshold shall be based on the number of supply wells, a volume of water, or a location of an isocontour that exceeds concentrations of constituents determined by the Agency to be of concern for the basin.” In this Basin, MTs are based on a number of supply wells that exceed concentrations of constituents determined to be of concern for the Basin.

The currently available supply wells for monitoring COCs that have an MCL or SMCL are public supply wells. Should domestic wells or agricultural irrigation wells be incorporated into future monitoring programs established by the GSA or other entities, they could also be included in COC monitoring during future GSP updates.

4.8.2.1 Existing Water Quality Monitoring Programs and Networks

The SMC is based on a number of supply wells, and the GSA identified sets of supply wells that are currently monitored (or are proposed to be monitored in the future) for various groundwater constituents and supply uses such as drinking water and irrigation water. Because these supply wells are monitored under different programs and may have different required sampling schedules (even under the same program), no one set of constituents will be sampled in all wells.

The goal is to use existing monitoring programs for supply well water quality assessment and not create new water quality monitoring networks that the GSA would be responsible for sampling. Initially, it is anticipated that RMPs will come from public supply wells that are already monitored. The only additional sampling the GSA would perform is on a project as-needed basis to specifically identify potential impacts on supply wells due to the development of a project related to GSP implementation.

The only existing regional monitoring program identified in this Basin is public drinking water supply wells, regulated by the SWRCB DDW. Public drinking water supply wells are included in the water quality monitoring network because they are routinely sampled to meet CCR Title 22 water quality reporting requirements as regulated by the SWRCB DDW. Title 22 analyses include arsenic, nitrate, and TDS, which are the Basin COCs. This dataset can be obtained from the SWRCB through the GAMA online portal.

Existing and future water quality monitoring programs may be used to help collect data during GSP implementation and establish consistency with other programs. Additional information on each of the existing monitoring programs is provided in **Table 4-3**. **Table 4-4** provides information on future monitoring networks to be used specifically for monitoring projects and management actions for GSP implementation.

Table 4-3. Petaluma Valley Basin Monitoring Networks

Monitoring Network	Responsible Party	Type of Wells	Constituents Sampled	Sampling Frequency	Purpose of Network
DDW Public Supply Wells	Cities and small water systems	Public supply	Subset of Title 22 constituents	Varies	Protect drinking water beneficials users

Table 4-4. Future Monitoring Networks for Project-specific Monitoring

Future As-needed Monitoring Network	Responsible Party	Type of Wells	Constituents Sampled	Sampling Frequency	Purpose of Network
Future Project Implementation Monitoring Network	GSA	To be determined (public and private wells)	COCs identified as part of the GSP and constituents as required by the project permitting	To be determined	Identify water quality impacts related to site-specific project and action implementation

Each of these well networks are monitored for different purposes and overseen by different entities; therefore, sampling frequency and analytical suites vary. Water quality MTs for each well are selected based on which constituents are analyzed in water samples per existing programs, summarized in **Table 4-5**.

Table 4-5. Summary of Constituents Monitored at Each Well Network

Constituent	Public Supply	SNMP
Arsenic	✓	
Nitrate	✓	✓
TDS	✓	✓

4.8.2.2 Level of Concern for each Constituent of Concern

Each COC has an associated level of concern for each category of beneficial user. For the drinking water supply well category, the level of concern is represented by the MCL or SMCL, as applicable.

The San Francisco Bay Regional Water Quality Control Board (RWQCB) Basin Plan (Basin Plan) designates municipal and agricultural water quality management objectives for the Petaluma Valley. The municipal designation aims to maintain water quality for public supplies below the California MCL and SMCL drinking water standards (RWQCB 2019). The agricultural designation aims to maintain water quality for irrigation below specific thresholds that may be harmful to certain crops (RWQCB 2019).

The bases for establishing MTs for each COC in the Basin are summarized in **Table 4-6**. This table does not identify the total number of supply wells that may exceed the level of concern, but rather identifies how many additional wells will be allowed to exceed the level of concern. Wells that already exceed this level are not counted against the MTs.

Table 4-6. Groundwater Quality Minimum Thresholds Basis

Constituent of Concern	Minimum Threshold Based on Number of Wells
Arsenic	Two additional supply wells exceed the arsenic MCL of 0.010 mg/L.
Nitrate	Two additional supply wells exceed the nitrate measured as nitrogen MCL of 10 mg/L.
TDS	Two additional supply wells exceed the TDS recommended SMCL of 500 mg/L.

4.8.2.3 Development of Minimum Thresholds at Supply Wells

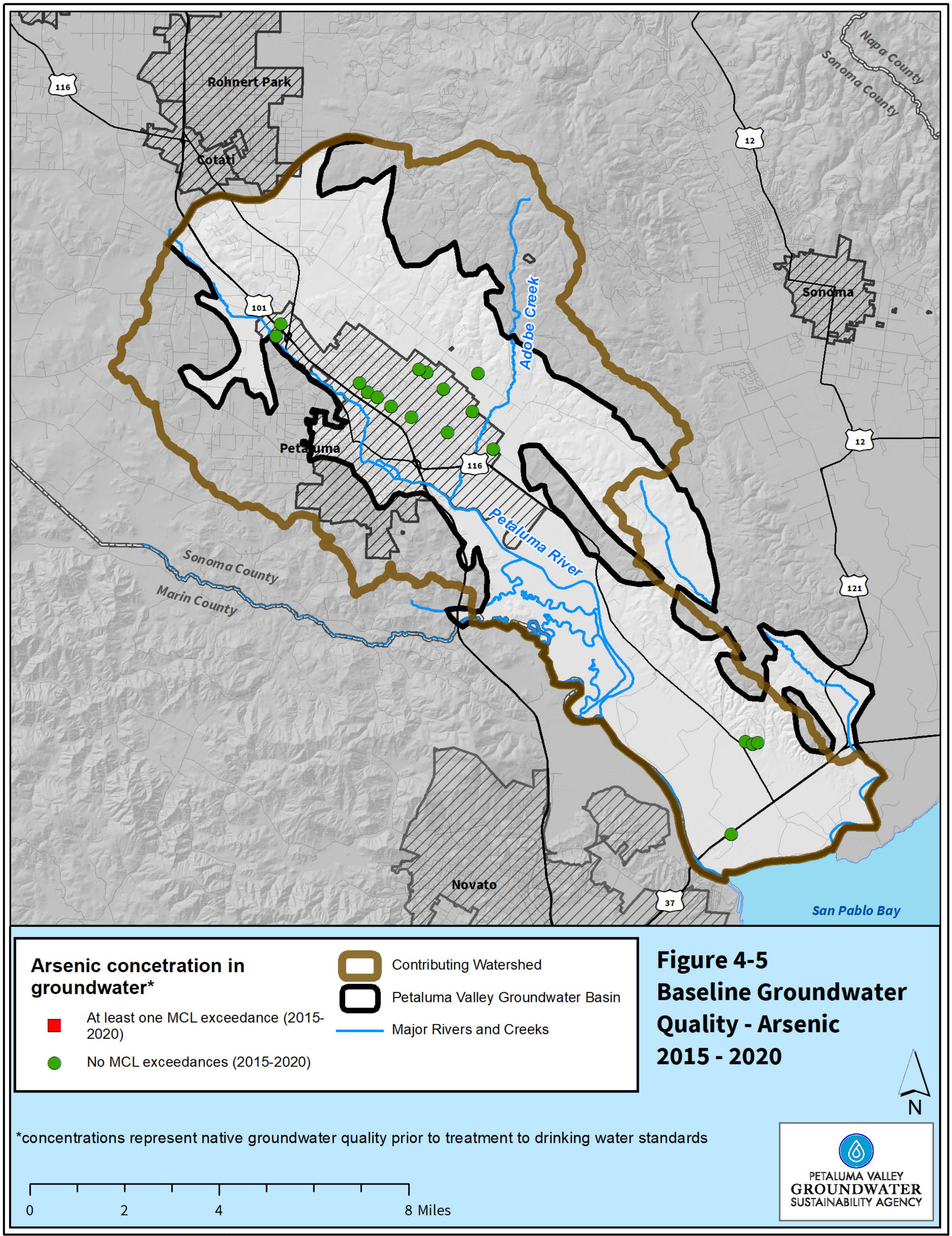
The MTs for degraded water quality for the supply wells are based on the number of additional exceedances of any MCL or SMCL in existing supply wells shown in **Table 4-6**. Establishing the MT as the number of additional exceedances accounts for wells with previous exceedances, assuming these exceedances will likely continue into the future. The GSA Board selected two as the number of additional supply wells with exceedances to represent the MT. The MT for the number of allowed exceedances is therefore equal to the baseline number of exceedances (calculated as the number of public supply wells with any MCL or SMCL exceedance between 2015 and 2020) plus two additional supply wells with an exceedance. Based on the number of supply wells in the existing water quality monitoring network, the number of existing exceedances since 2015 for each constituent is tabulated in **Table 4-7** and the distribution of exceedances is shown on **Figures 4-5** through **4-7**, along with all of the other supply wells included in the initial RMP network.

MT exceedances are based on existing wells only. According to the GSP Regulations, the MTs are based on the same number of supply wells to have exceedances, not necessarily the same wells. The well networks will be reassessed every 5 years to identify any new supply wells that could be added to the monitoring networks. The MT will be increased by one for each new supply well added to the monitoring network with an initial measured concentration exceeding the MCL or SMCL. Additionally, if the MCL or SMCL changes for a GSP-identified COC, the MT should be examined and updated as appropriate.

If new exceedances of MTs are observed that are not due to GSP implementation, those new levels may be used to modify the MT accordingly to better reflect Basin conditions regardless of the GSP implementation actions.

Table 4-7. Minimum Thresholds for Degradation of Groundwater Quality for the Public Supply Wells Under the Current Monitoring Network

Constituent of Concern	Regulatory Exceedance Standard	Standard Units	Number of Sampled Wells in Monitoring Network (2015-2020)	Total Number of Exceedances (2015-2020)	Number of Wells Exceeding Regulatory Standard (2015-2020)	Minimum Threshold
Arsenic	10	µg/L	18	0	0	2
Nitrate	10	mg/L	30	0	0	2
Total Dissolved Solids	500	mg/L	13	1	1	3



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig4_2-4_PET_WQ_MCL_Master.mxd Date prepared: 11/8/2021

Figure 4-5. Baseline Groundwater Quality – Arsenic 2015-2020

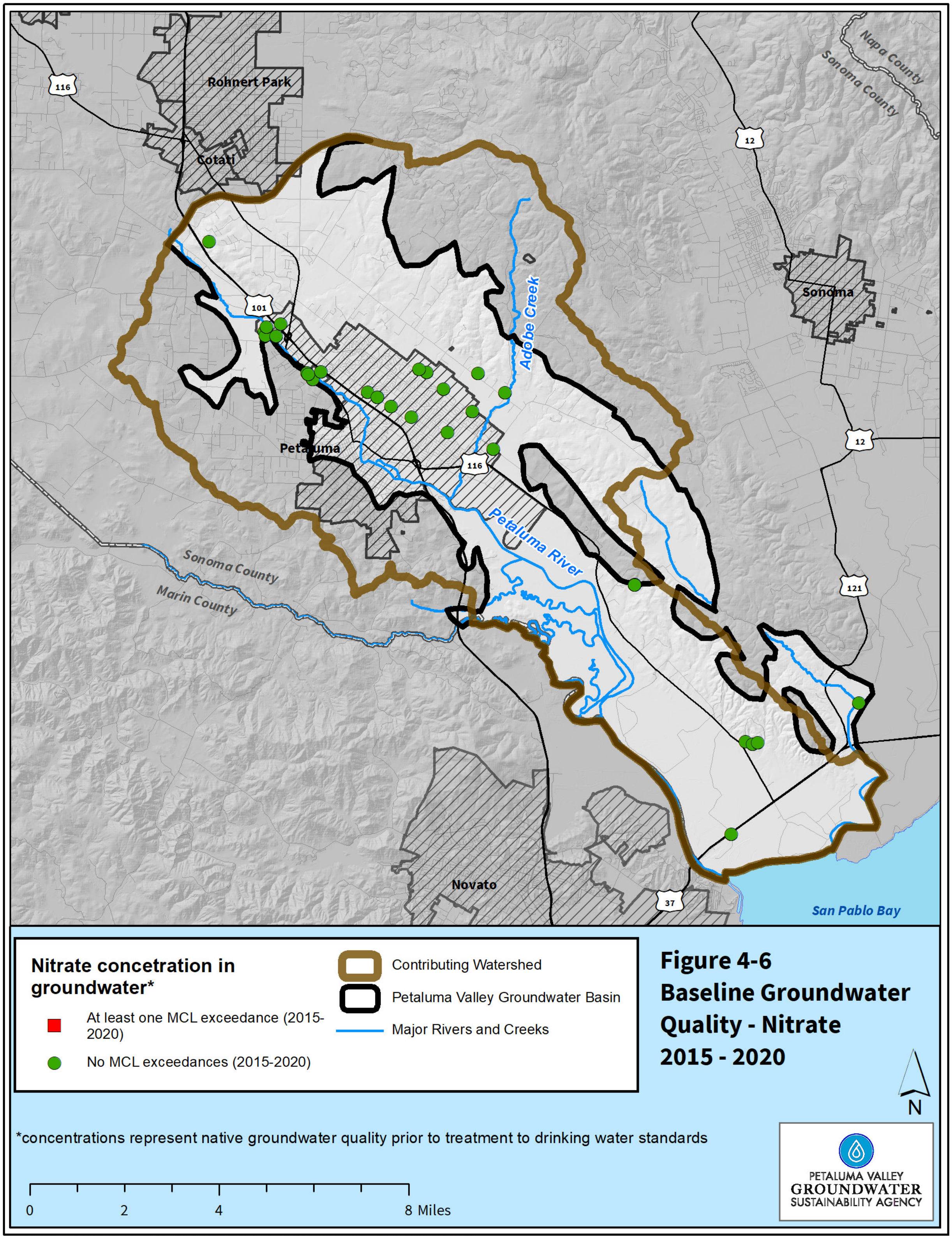
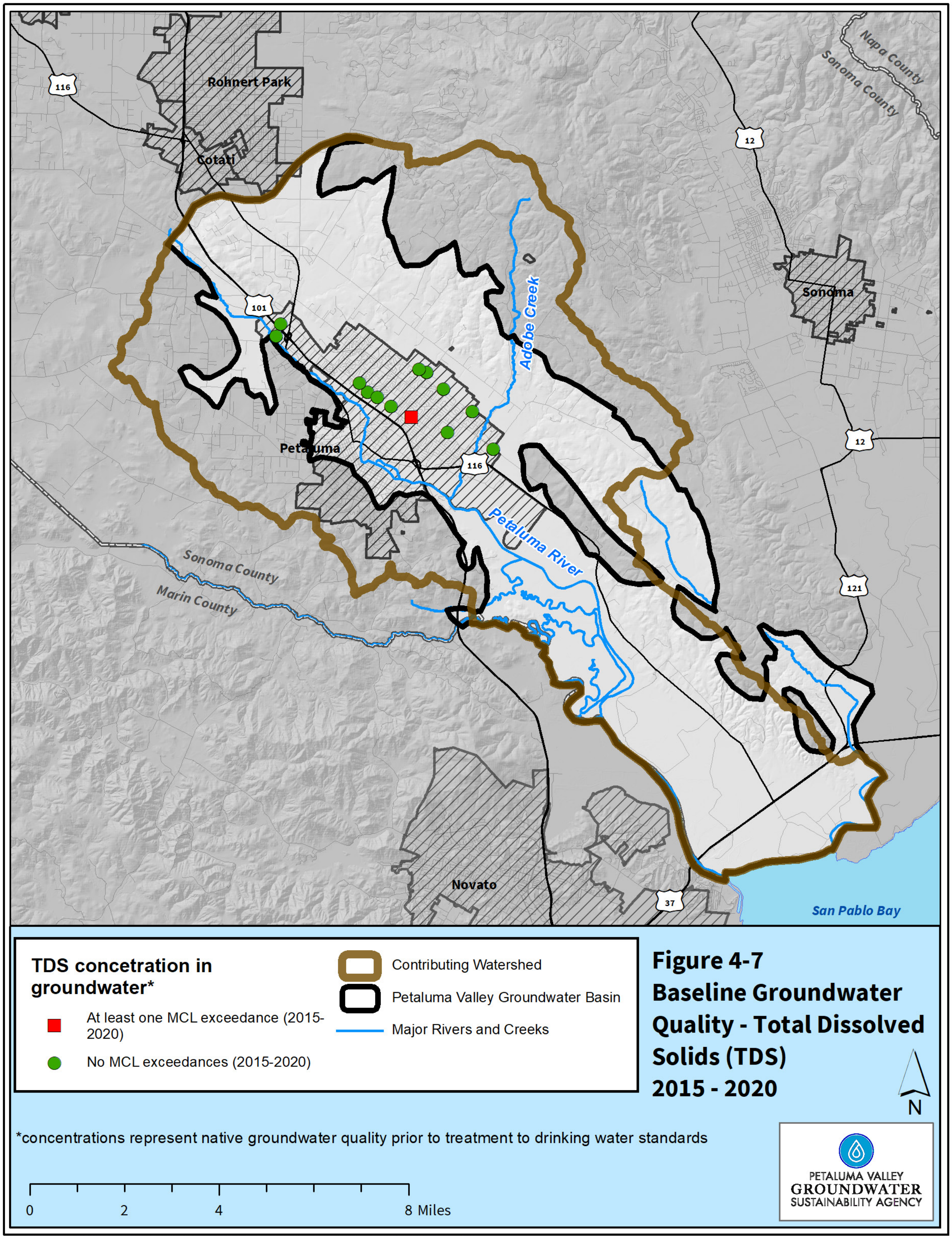


Figure 4-6. Baseline Groundwater Quality – Nitrate 2015-2020



Filepath: T:\SGMA\GSAs\Petaluma Valley\MXDs\Fig4_2-4_PET_WQ_MCL_Master.mxd Date prepared: 11/8/2021

Figure 4-7. Baseline Groundwater Quality – TDS 2015-2020

4.8.2.4 Information and Methodology Used to Establish Water Quality Minimum Thresholds and Measurable Objectives

The exceedances shown in **Table 4-7** were based on a review of recent datasets. The information used for establishing the degradation of groundwater quality MTs includes:

- Historical groundwater quality data from public supply wells in the Basin
- Federal and state drinking water quality standards
- Feedback from GSA staff members and Advisory Committee members.

The historical groundwater quality data used to establish groundwater quality MTs are presented in **Section 3.2.5**. Based on the reviews of historical and current groundwater quality data and federal and state drinking water standards, these standards are appropriate for defining groundwater quality MTs.

4.8.2.5 Relationship between Individual Minimum Thresholds and Relationship to Other Sustainability Indicators

Because SGMA does not require projects or actions to improve groundwater quality, there will be no direct actions under the GSP associated with the groundwater quality MTs. Therefore, there are no actions that directly influence other sustainability indicators. However, preventing the migration of poor groundwater quality may limit activities needed to achieve the MTs for other sustainability indicators.

- **Chronic lowering of groundwater levels.** Groundwater quality MTs could influence groundwater elevation MTs by limiting the source of water that can be used for recharge to raise groundwater elevations. Water used for recharge cannot result in exceedances of any of the groundwater quality MTs. In addition, a change in groundwater elevations may cause a change in groundwater flow direction, which in turn could cause poor water quality to migrate into areas of good water quality.

- **Change in groundwater storage.** Nothing in the groundwater quality MTs promotes pumping in excess of the sustainable yield. Therefore, the groundwater quality MTs will not result in an exceedance of the groundwater storage MT.

- **Seawater intrusion.** Nothing in the groundwater quality MTs promotes additional pumping that could cause seawater intrusion. Therefore, the groundwater quality MTs will not result in an exceedance of the seawater intrusion MT. Avoiding the water quality MTs for TDS, which is a measure of salinity, would also benefit the seawater intrusion MT.

- **Subsidence.** Nothing in the groundwater quality MTs promotes additional pumping that could cause subsidence. Therefore, the groundwater quality MTs will not result in an exceedance of the subsidence MT.

- **Depletion of ISW.** Nothing in the groundwater quality MTs promotes additional pumping or lower groundwater elevations adjacent to ISW. Therefore, the groundwater quality MTs will not result in a significant or unreasonable depletion of ISW.

4.8.2.6 Effect of Minimum Thresholds on Neighboring Basins and Subbasins

The anticipated effect of the degraded water quality MTs on each of the neighboring subbasins is addressed below.

The Petaluma Valley Basin has two neighboring subbasins that are categorized as medium priority and are also subject to SGMA: the Santa Rosa Plain Subbasin to the north and the Sonoma Valley Subbasin to the east. The Petaluma Valley Basin is also adjacent to the very low-priority Wilson Grove Formation Highlands Basin to the northwest and Novato Valley Basin to the southwest, both of which are not subject to SGMA.

Because the MTs in the Petaluma Valley Basin are to prevent the migration of poor-quality water, it is likely that the MTs will not prevent the Sonoma Valley and Santa Rosa Plain GSAs from achieving and maintaining sustainability. The MTs are also not likely to negatively impact the Wilson Grove Formation Highlands Basin or the Novato Valley Basin. The Sonoma Valley GSA coordinated closely with the neighboring Sonoma Valley and Santa Rosa Plain GSAs to set MTs to ensure that the subbasins do not prevent each other from achieving sustainability.

4.8.2.7 Effect on Beneficial Uses and Users

Agricultural land uses and users. The degradation of groundwater quality MTs is designed to avoid negative effects to groundwater quality associated with implementation of the GSP. Avoiding the degradation of groundwater quality for the identified COCs, including salts that can impact agricultural irrigation, helps maintain groundwater quality, providing positive benefits to the Basin’s agricultural water users.

Urban land uses and users. The degradation of groundwater quality MTs is designed to avoid negative effects on groundwater quality associated with implementation of the GSP. Avoiding the degradation of groundwater quality from the identified COCs helps maintain municipal drinking water quality, providing positive benefits to the Basin’s urban water users.

Domestic land uses and users. The degradation of groundwater quality MTs is designed to avoid negative effects on groundwater quality associated with implementation of the GSP. Avoiding degradation of groundwater quality from the identified COCs helps maintain drinking water quality providing benefits for domestic well users.

Ecological land uses and users. Although the groundwater quality MTs are not designed to directly benefit ecological uses, it can be inferred that the degradation of groundwater quality MTs provide generally positive benefits to the Basin’s ecological water uses by helping maintain groundwater quality.

4.8.2.8 Relation to State, Federal, or Local Standards

The degradation of groundwater quality MTs specifically incorporate state and federal standards for drinking water.

4.8.2.9 Method for Quantitative Measurement of Minimum Thresholds

Degradation of groundwater quality MTs will be measured directly using an analysis of samples collected from public drinking water supply wells reported through SWRCB DDW. An average concentration of water quality samples will be used for wells that are sampled more than once a year. If any other routine monitoring of supply wells is initiated in the Basin at a later date, these wells will be considered for inclusion in the water quality monitoring network. The data review will focus on exceedances of MTs, or MCLs and SMCLs for the COCs identified for this GSP. However, if during review of the water quality data, additional constituents appear to frequently exceed MCLs and SMCLs, MTs and MOs will be considered for these additional constituents during GSP 5-year updates.

4.8.3 Measurable Objectives

The MOs for the degradation of groundwater quality represent target groundwater quality distributions in the Basin. SGMA does not mandate the improvement of groundwater quality. Therefore, the GSA has set the MO for each COC to the number of existing supply wells that exceeded the MCL or SMCL from 2015 to 2020 as shown in **Table 4-7**. In other words, the MO is to have no additional supply wells exceeding the applicable MCL or SMCL for any of the COCs.

4.8.3.1 Method for Setting Measurable Objectives

As described above, MOs are established using a similar method to the MTs detailed in **Section 4.8.2**, except the target number of additional MCL or SMCL exceedances is zero.

4.8.3.2 Interim Milestones

The MOs for the degradation of groundwater quality are set at current conditions; there is no anticipated degradation of groundwater quality during GSP implementation that results from the implementation of projects and actions as described in **Section 6, Projects and Management Actions**. Therefore, the expected interim milestones are identical to current conditions.

4.8.4 Undesirable Results

4.8.4.1 Criteria for Defining Undesirable Results

By regulation, the degradation of groundwater quality undesirable result is a quantitative combination of groundwater quality MT exceedances. Some groundwater quality changes are expected to occur independent of SGMA activities; because these changes are not related to SGMA activities they do not constitute an undesirable result. Therefore, the degradation of groundwater quality undesirable result is:

An undesirable result occurs if, during 2 consecutive years, a single groundwater quality MT is exceeded when computing annual averages at the same well, as a direct result of projects or management actions taken as part of GSP implementation.

4.8.4.2 Potential Causes of Undesirable Results

Conditions that may lead to an undesirable result include the following:

- If the location and rates of groundwater pumping change as a result of projects implemented under the GSP, these changes could alter hydraulic gradients and associated flow directions, and cause movement of one of the COCs toward a supply well at concentrations that exceed relevant standards.
- The active recharge of imported water or captured runoff could modify groundwater gradients or alter local geochemical conditions and move one of the COCs toward a supply well in concentrations that exceed relevant limits.
- Recharging the Basin with water that exceeds an MCL, SMCL, or level that reduces crop production may lead to an undesirable result.
- The exceedance of an undesirable results for another sustainability indicator may lead to an undesirable result for degraded water quality.

Prior to determining whether an undesirable result has occurred based on MT exceedances, an investigation of the cause for the exceedance(s) will be conducted by the GSA. Such investigation would likely include the following steps, as needed:

1. Is a project or action by the GSA located in the vicinity and can be reasonably linked to the exceedance?
2. Are undesirable results occurring for any other sustainability indicators that could impact water quality?

If the answer to either 1) or 2), above is yes, then the following additional steps would be taken:

- Evaluate monitoring data from any projects and actions in the vicinity of the exceedance and correlate with the data from the well that had an exceedance
- Review any other available groundwater quality data in the vicinity of the exceedance
- Review, in detail, available laboratory analytical data and laboratory quality assurance/quality control measures
- Resample wells with the exceedances if it is established that the GSA projects or actions may be the cause of the exceedance

For any projects and actions implemented under the GSP, additional groundwater quality monitoring in the vicinity of the project or actions sites may be implemented to determine the possibility of causing undesirable results. Any needed mitigation measures to avoid the negative conditions will be included.

4.8.4.3 Effects on Beneficial Users and Land Use

The undesirable result for the degradation of groundwater quality is adverse impacts on beneficial uses and users in the Basin from groundwater degradation due to actions directly resulting from GSP implementation. Adverse impacts include diminished supply due to water quality impacts that cause non-compliance with drinking water standards or undue costs for mitigating impacts through wellhead treatment or well replacement. Beneficial users that could be impacted by undesirable results from groundwater quality degradation include domestic well users, irrigation well users, and public water supply well users (inclusive of DACs that obtain water from these user categories). If water quality degradation due to GSP implementation activities is avoided, there will be no impact on the use of groundwater and there will be no negative effect on the beneficial users and uses of groundwater. If projects and actions are shown to cause the degradation of localized groundwater quality, however, the GSA will develop mitigation actions.

This undesirable result applies only to groundwater quality changes directly caused by projects or management actions implemented as part of this GSP. This undesirable result does not apply to groundwater quality changes that occur due to other causes.

4.9 Subsidence Sustainable Management Criteria

Land surface subsidence is the change in land surface elevation caused by an increase in effective stress due to groundwater overdraft, tectonics, or other natural processes such as hydrologic isostatic loading. Land surface subsidence may be elastic or inelastic. Elastic subsidence is recoverable as groundwater conditions change. Inelastic subsidence is unrecoverable and is primarily due to the irreversible compaction of clay-rich sediments. Per the GSP Regulations, the GSAs are responsible only for managing inelastic land subsidence caused by lowered groundwater elevations. They are not responsible for managing elastic subsidence or subsidence conditions caused by something other than groundwater pumping, such as tectonic activity.

Available land surface subsidence datasets for the Basin do not indicate the occurrence of inelastic subsidence due to groundwater pumping. Subsidence measurements have been collected in the Basin at one discrete location since 2004 and by satellite in most of the Basin since 2015. The available datasets are summarized in the **Basin Setting** section of this GSP (**Section 3.2.4**). Total subsidence measured by GPS survey at the discrete location was 0.5 inch (or 0.042 foot) since 2004. Total land subsidence measured by satellite InSAR was less than 0.25 inch (or 0.021 foot) since 2015. Together, the subsidence datasets indicated that there is a very slight downward land subsidence trend throughout the Basin and wider region. This trend was apparent in areas of the Basin and beyond, both with and without groundwater pumping.

It is not known if the noted subsidence was elastic or inelastic; however, since the subsidence was found to be regionally consistent, it is not likely attributed to groundwater pumping and more likely due to natural causes such as tectonics or hydrostatic loading. Consequently, it appears that no significant inelastic subsidence has occurred within the Basin due to groundwater pumping.

4.9.1 Locally Defined Significant and Unreasonable Conditions

As described earlier in this section and in **Section 3.2.3**, available Basin-wide datasets (while limited to recent time periods) do not indicate the occurrence of inelastic land surface subsidence due to groundwater pumping. There have been no problems reported by Basin stakeholders related to historical inelastic subsidence (for example, damage to infrastructure or modified drainage patterns). However, the risk of future inelastic land surface subsidence and consolidation of the clay-rich portions of the Basin's aquifer system exists if there are chronic declines of groundwater levels.

Locally defined significant and unreasonable conditions were determined based on public meetings and discussions with GSA staff, Advisory Committee members, and the GSA Board. Significant and unreasonable land subsidence in the Basin was defined as follows:

Any rate of future inelastic subsidence caused by groundwater pumping is a significant and unreasonable condition, everywhere in the Basin and regardless of the beneficial uses and users.

4.9.2 Minimum Thresholds

Section 354.28(c)(5) of the GSP Regulations states that "The minimum threshold for land subsidence shall be the rate and extent of subsidence that substantially interferes with surface land uses and may lead to undesirable results." As such, the defined metric from the GSP Regulations for measuring total subsidence includes the rate of change in land surface elevation. This can be measured with extensometers, continuous GPS stations, leveling surveys, or by satellite with InSAR. It is difficult to assess a priori whether subsidence interferes with surface land uses to address the second portion of the GSP regulation; therefore, the GSA has selected a single protective MT for subsidence for the entire Basin. While zero inelastic subsidence due to pumping is the desire to avoid significant and unreasonable conditions, there is an inherent 0.1-foot potential error in the InSAR technology. The following MT was developed for the Basin to account for this potential measurement error of the data collection method:

The MT for subsidence in the Basin is 0.1 foot per year of total subsidence (elastic and inelastic) measured by InSAR for each of the 100 square meter, or approximately 2.5 acre, grids or pixels in the Basin.

4.9.2.1 Information and Methodology Used to Establish Subsidence Minimum Thresholds and Measurable Objectives

The subsidence MT and MO allow for no measurable additional inelastic subsidence in the Basin due to groundwater pumping. The MT allowance of 0.1 foot per year of subsidence was developed based on the inherent measurement error of InSAR technology described in the previous paragraph.

The InSAR pixels serve as the RMPs. The reported total subsidence value is an average of many individual measurements within each InSAR pixel. InSAR is the method used for establishing MTs and MOs given the spatial coverage, accuracy, and availability at no cost to the GSA (state-funded program for SGMA). Disadvantages of InSAR are that it measures total subsidence rather than inelastic subsidence and the available data record extends only to 2015.

4.9.2.2 Relationship between Individual Minimum Thresholds and Relationship to Other Sustainability Indicators

Subsidence MTs have little or no impact on other MTs, as described below.

- **Chronic lowering of groundwater levels.** Nothing in the subsidence MT promotes additional pumping that could cause chronic lowering of groundwater levels. Therefore, the subsidence MT will not result in an exceedance of the groundwater storage MT.

- **Change in groundwater storage.** Nothing in the subsidence MT promotes pumping in excess of the sustainable yield. Therefore, the subsidence MT will not result in an exceedance of the groundwater storage MT.

- **Degraded water quality.** Nothing in the subsidence MT promotes additional pumping that could cause degradation of groundwater quality. Therefore, the subsidence MT will not result in an exceedance of the groundwater quality MT.

- **Depletion of ISW.** Nothing in the subsidence MT promotes additional pumping or lower groundwater elevations adjacent to ISW. Therefore, the subsidence MT will not result in a significant or unreasonable depletion of ISW.

4.9.2.3 Effect of Minimum Thresholds on Neighboring Basins and Subbasins

The anticipated effect of the subsidence MT on each of the neighboring subbasins is addressed below.

The Petaluma Valley Basin has two neighboring subbasins that are categorized as medium priority and are also subject to SGMA: the Santa Rosa Plain Subbasin to the north and the Sonoma Valley Subbasin to the east. The Petaluma Valley Basin is also adjacent to the very low-priority Wilson Grove Formation Highlands Basin to the northwest and Novato Valley Basin to the southwest, both of which are not subject to SGMA.

Because the subsidence MT in the Petaluma Valley Basin is intended to prevent any measurable inelastic subsidence due to groundwater pumping, it is likely that the MTs will not prevent the Sonoma Valley and Santa Rosa Plain GSAs from achieving and maintaining sustainability. The MTs are also not likely to negatively impact the Wilson Grove Formation Highlands Basin or the Novato Valley Basin. The Petaluma Valley GSA coordinated closely with the neighboring GSAs to set MTs to ensure that they do not prevent each other from achieving sustainability.

4.9.2.4 Effect on Beneficial Uses and Users

Agricultural land uses and users. The subsidence MT is designed to avoid negative effects on infrastructure associated with implementation of the GSP. Avoiding land subsidence helps protect wells and water conveyance infrastructure that are critical to the Basin's agricultural water users.

Urban land uses and users. The subsidence MT is designed to avoid negative effects on infrastructure associated with implementation of the GSP. Avoiding land subsidence helps protect buildings, roads, utilities, wells, and other infrastructure. This provides positive benefits to the Basin's urban water users.

Domestic land uses and users. The subsidence MT is designed to avoid negative effects on infrastructure associated with implementation of the GSP. Avoiding land subsidence helps protect buildings, roads, utilities, wells, and other infrastructure. This provides positive benefits to the Basin's domestic water users.

Ecological land uses and users. The subsidence MT is not designed to directly benefit ecological uses. Preventing future subsidence in the Basin will not harm or benefit ecological water users.

4.9.2.5 Relation to State, Federal, or Local Standards

There are no federal, state, or local regulations related to land subsidence.

4.9.2.6 Method for Quantitative Measurement of Minimum Thresholds

There are two existing subsidence monitoring networks in the Basin, InSAR and one continuous GPS monitoring location. The continuous GPS data are temporally extensive, but spatially limited. Therefore, the GSA intends to utilize the InSAR method for assessment of subsidence SMC. Statewide subsidence data are currently estimated every month by satellite using InSAR methodology. DWR maintains a database of InSAR data and makes it publicly available for use in GSPs.

Quantitative measurements for InSAR data are provided on a monthly timestep by DWR. The DWR database and online map provide an average total subsidence value of many individual measurements within a single 100 square meter, or approximately 2.5 acres pixel. The average for each pixel will be used for the subsidence MT. DWR has stated that, on a statewide level, for the total vertical displacement measurements between June 2015 and June 2019, the errors are as follows:

1. The error between InSAR data and continuous GPS data is 16 millimeters (0.052 foot) with a 95 percent confidence level (DWR 2021b).
2. The measurement accuracy when converting from the raw InSAR data to the maps provided by DWR is 0.048 foot with a 95 percent confidence level.

For the purposes of this GSP, the cumulative error for InSAR data is considered the sum of errors 1 and 2, for a combined total error of 0.1 foot.

The InSAR data provided by DWR reflect both elastic and inelastic subsidence. While it is difficult to compensate for elastic subsidence, a visual inspection of monthly changes in ground elevations suggests that elastic subsidence is largely seasonal. Due to the seasonal elastic fluctuations, annual subsidence will be calculated by comparing InSAR datasets at the same time each year to reduce the effect of any seasonal elastic fluctuations of elevation on observed data.

4.9.3 Measurable Objectives

The MO is the aspirational goal to achieve optimal protection of groundwater conditions. The recommended MO is the same as the MT given that no subsidence related to groundwater pumping is the significant and unreasonable condition. In other words, there is not a more stringent condition for land subsidence than the MT. Similar to the MT, the subsidence MO allows for 0.1 foot of measurement error per year.

4.9.3.1 Method for Setting Measurable Objectives

As described above, MOs are set to be identical to the MTs and therefore follow the same method as detailed in **Section 4.9.2**.

4.9.3.2 Interim Milestones

The MOs for subsidence are set at current conditions and there is no anticipated additional subsidence during GSP implementation that results from groundwater pumping; therefore, the expected interim milestones are identical to current conditions, MTs, and MOs.

4.9.4 Undesirable Results

By regulation, the subsidence undesirable result is a quantitative combination of subsidence MT exceedances. For the Basin, any inelastic subsidence as a direct result of groundwater pumping is considered unacceptable. Because the GSP Regulations allow for elastic and inelastic subsidence due to natural conditions such as plate tectonics and hydrostatic loading, any subsidence resulting from these phenomena are not included in the definition of undesirable results.