

DRAFT Basin Setting Section

Groundwater Sustainability Plan for Petaluma Valley Groundwater Basin

Notes to Reader:

Section 3.2 represents new text for this version of the Draft Basin Setting section and begins on page 15.

****Information and figures referenced herein as (USGS, 2019 unpublished draft) are preliminary and subject to revision. The information has not received final approval by the U.S. Geological Survey (USGS) and is provided on the condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information.****

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3.0 Basin Setting

This section provides information about the physical setting, characteristics and current conditions of the Petaluma Valley Groundwater Basin (Basin), including the identification of data gaps and levels of uncertainty. The information included within this section represents the current understanding of the Basin based on available data and information and serves as the basis for defining and assessing sustainable management criteria and projects and management actions. The Basin Setting section contains four primary subsections:

- Hydrogeologic Conceptual Model (Section 3.1);
- Current and Historical Groundwater Conditions (Section 3.2);
- Water Budget (Section 3.3);
- Management Areas (Section 3.4)

The Basin Setting draws upon previously published studies and reports including the following primary data sources that document the conditions of the Petaluma Valley Basin and contributing watershed areas:

- Cardwell, G.T., 1958, Geology and ground water in the Santa Rosa and Petaluma Valley areas Sonoma County: U.S. Geological Survey Water-Supply Paper 1427, 273 p.
- City of Petaluma, 2016, 2015 Urban Water Management Plan, accessed February 16, 2017, at <http://cityofpetaluma.net/wrcd/pdf/temp/2015UWMPFinal.pdf>.
- Herbst, C.M., 1982, Evaluation of ground water resources, Sonoma County, volume 3: Petaluma Valley, California Department of Water Resources, Bulletin 118-4, 94 p.
- Kulongoski, J.T., Belitz, Kenneth, Landon, M.K., and Farrar, C.D., 2010, Status and understanding of groundwater quality in the North San Francisco Bay groundwater basins, 2004: California GAMA Priority Basin Project: U.S. Geological Survey Scientific Investigations Report 2010-5089, 88 p.
- Space Holder - 2019 USGS unpublished draft report on Petaluma Valley (USGS, 2019, unpublished draft)

For additional details, the reader should refer to these documents and studies.

3.1 Hydrogeologic Conceptual Model

This subsection describes the hydrogeologic conceptual model (HCM) which characterizes the physical components of the surface water and groundwater systems in the basin. As defined in the GSP Regulations, the HCM should provide the following:

- An understanding of the general physical characteristics related to regional hydrology, geology, geologic structure, water quality, principal aquifers, and principal aquitards of the basin setting;

- The context to develop water budgets, mathematical (analytical or numerical) models, and monitoring networks, and
- A tool for stakeholder outreach and communication.

As such, the subsection includes a description of the topography, geography, surface water features, soil characteristics, geologic setting and formations, principal aquifers and aquitards, role of faults, groundwater recharge and discharge area, and data gaps and uncertainties. This information is integrated into the water budget and numerical model described in Section 3.3 (Water Budget) and monitoring networks described in Section 5.0 (Monitoring Program). Additionally, figures and diagrams developed for the HCM are incorporated into community and stakeholder outreach materials.

3.1.1 Topography and Geography

The Basin is located in the North Coast Ranges geomorphic province of California. The North Coast Ranges are characterized by predominantly northwest trending mountains and valleys formed in response to regional tectonic stresses that produced northwest-trending faults related to the San Andreas Fault system. The Basin is immediately northwest of San Pablo Bay and encompasses the majority of Petaluma Valley, bounded by the Santa Rosa Plain Subbasin to the north, the San Pablo Bay to the south, the Sonoma Mountains to the east, and the low lying hills of the Mendocino Range to the west, as shown on Figure 3-1.

Most of the upper portions of the Basin is between sea level and an elevation of 50 ft, while the lower portions primarily consist of tidal marshlands located at or slightly below sea level (USGS, 2019 unpublished draft). The Sonoma Mountains separate the Basin from the Sonoma Valley to the east and vary from moderate to steep relief, sloping gently from a few hundred feet in the south to greater than 2,000 feet in the northeast areas of the contributing watershed, reaching a maximum elevation of 2,295 feet. The remaining uplands surrounding the Basin have modest changes in elevation and are made up of mostly low, rounded hills that generally range from 200 to 300 feet in elevation. The Basin is separated from the Santa Rosa Plain Subbasin to the north by a modest topographic watershed divide about 2 mi northwest of Penngrove (USGS, 2019 unpublished draft).

3.1.2 Surface Water and Drainage Features

The Basin and contributing watershed area is drained by the Petaluma River and its tributaries, which discharge into the tidal marshlands on the north end of San Pablo Bay, as shown on Figure 3-1. The Petaluma River flows at a relatively flat gradient dropping some 260 feet over just approximately 8 miles before reaching the tidal marshlands. The upper reach of the Petaluma River, north of the confluence with Lynch Creek, is ephemeral while the lower reach of the river is tidally influenced, and can flood during periods of high flow (USGS, 2019 unpublished draft).

The headwaters of the tributaries of Petaluma River are located along the southwest slopes of Sonoma Mountain (Lichau Creek, Lynch Creek, and Adobe Creek), the southern slopes of Meacham Hill (Petaluma River), and the eastern slopes of Wiggins Hill (Wiggins Hill Creek) and Burdell Mountain (San Antonio Creek and Black John Slough). Flow in the tributary channels is seasonal; when there are drier-than-normal winters, the main tributary channels will often go dry during the summer (USGS, 2019 unpublished draft). Based on the location of Adobe Creek in comparison to the upper limit of the tidally influenced reach of the Petaluma River, the lower reach of Adobe Creek may also be tidally influenced.

The Petaluma Valley also includes Tolay Creek which is part of the Sonoma Creek watershed, but is included in the study area because it overlies part of the Petaluma Valley groundwater Basin.

3.1.3 Soil Characteristics

Soil types and characteristics in the Basin have been mapped by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), which developed a spatial database of soils for the entire United States (the Soil Survey Geographic Database or SSURGO) (USDA NRCS, 2007). The SSURGO database defines 17 different soil textures (excluding variable and unknown textures) present in the study area (USDA, 1997), which are shown on Figure 3-2a. Soil properties were analyzed based on their hydrologic soil groups to classify the soils into three categories of silty clay, silt, and sandy loam.

The SSURGO database also assigns saturated hydraulic conductivity values to soil groups, which are shown on Figure 3-2b. Saturated hydraulic conductivity is a measurement of the representative or average water transmitting properties of soils and is a good indicator of the soil's infiltration potential. As indicated on Figure 3-2b, the loams and clayey loam soils that predominate the floor of the Basin exhibit relatively low hydraulic conductivities (slow to moderate), on the order of 0.1 to 1 feet per day. Coarser-grained soils present in and around the Basin, which exhibit higher hydraulic conductivity values (moderate rapid) on the order of 1 to 12 feet per day are predominately in the northwest areas of the Basin and within the contributing watershed areas outside of the Basin, including areas of the Wilson Grove Formation northwest of the Basin and the foothills of the Sonoma Mountains northeast of the Basin. At locations where subsurface storage space is available and the underlying geologic formations have sufficient permeability, these more permeable soils (moderate rapid to rapid) could be favorable for surface water recharge.

3.1.4 Regional Geologic Setting and Geologic Units

Petaluma Valley is located within a region of geologic complexity caused by long periods of active tectonic deformation, volcanic activity and sea level changes. Geologic formations within the Basin are grouped into two broad categories (Mesozoic Era basement rocks and younger Cenozoic Era volcanic and sedimentary units) based on the age, degree of consolidation and amount of deformation (such as folding, faulting and fracturing). The Basin is underlain at varying depths by Mesozoic Era (more than 66 million years old) basement rocks consisting of metamorphic, igneous and metasedimentary rocks of the Jurassic/Cretaceous-aged Franciscan Complex overlain or tectonically imbricated by rock of the Great Valley Sequence (Wagner and Gutierrez, 2010; Wagner and others, 2011). A mixture of younger (Tertiary and Quaternary-aged) volcanic and sedimentary rocks and unconsolidated sediments of the Cenozoic Era (less than 66 million years old) overlies these basement rocks. Figure 3-3a presents a geologic map of the Basin and contributing watershed areas showing the surficial distribution of these geologic units, with a stratigraphic column for the units shown on Figure 3-4. Franciscan basement rocks dominate the subsurface on the southwest side of the basin, capped locally by Tolay Volcanics and a relatively uniform thickness of Wilson Grove Formation in the northwestern part of the Basin. The inferred subsurface distribution of the geologic units is displayed on the hydrogeologic cross-section and a three-dimensional geologic framework model developed by the USGS shown on Figures 3-5 and 3-6. Additionally, Figure 3-3b displays the inferred distribution of the primary geologic units within the Basin beneath the Quaternary alluvial materials. Basin depth dramatically increases to the north and east where the basin is filled by a thick sequence of Petaluma Formation and Sonoma Volcanics. Along the basin axis and the trace of the Petaluma River, locally thick accumulations of the Quaternary mixed unit

are present. Near San Pablo Bay at the southeast end of the study area, this unit is capped by a relatively thin veneer of Bay Muds (USGS, 2019 unpublished draft).

3.1.4.1 Geologic Structure

In Petaluma Valley, these geologic formations have undergone several episodes of folding and faulting by several significant strike-slip faults that are part of the San Andreas right lateral strike-slip transform plate boundary system, including the Rodgers Creek, the Burdell Mountain, and the Petaluma Valley faults (USGS, 2019 unpublished draft) (Figure 3-3). These are northwest-trending, generally vertical right-lateral strike slip faults that locally also demonstrate components of either shortening or extension accompanying fault dip-slip movement. The Rodgers Creek and Burdell Mountain faults are mapped at the surface as wide, steeply dipping zones with multiple fault strands, rather than single fault planes. The Petaluma Valley fault, a northwest-trending fault running along the valley axis, is buried beneath alluvium and sharply juxtaposes rocks interpreted as Wilson Grove and Petaluma Formations against one another (USGS, 2019 unpublished draft). The Meacham Hill and Tolay faults (Figure 3-3) are northeast- or southwest-directed reverse thrusts that bound structural highs (areas of shallow basement rocks). In the northwest part of the Basin, several northwest-trending reverse faults of relatively small displacement occur, including the Bloomfield fault and the Cinnabar School fault. These are high-angle fault planes that generally dip to the east (USGS, 2019 unpublished draft).

3.1.4.2 Mesozoic Era Basement Rocks

Mesozoic Era basement rocks are characterized by a variety of consolidated and deformed rock types, including shale, graywacke, mélangé with blocks of chert and greenstone, and thinly interbedded shale and sandstone. As shown in Figure 3-4, basement rocks are widely exposed in the uplands south and west of the Petaluma River and are uplifted along the Tolay fault in the southeastern part of the Basin, where they form “islands” within the Basin. These rocks generally yield very little water, as their porosity is primarily attributed to fractures which are commonly limited in extent and water transmitting capacity. The depth to the Mesozoic basement rocks is shallowest in the west and southwest parts of the Basin where bedrock is as shallow as 100 feet beneath surface outcrops of the Wilson Grove Formation. Basement depth increases rapidly to the east and the northeast, where basement rocks are deeper than 3,000 ft (Figure 3-6).

3.1.4.3 Cenozoic Era Volcanic and Sedimentary Units

Groundwater resources within the Basin are primarily located within the Cenozoic sedimentary units and, to a lesser degree, volcanic units deposited over the Mesozoic basement rocks. Geologic units that are of greatest importance for groundwater resources within Petaluma Valley are described below in general order of decreasing age (older to younger) and include both Tertiary-aged (between 66 to 2.5 million years old) and Quaternary-aged (younger than 2.5 million years old) units.

3.1.4.3.1 Tertiary Volcanic Units

Tolay Volcanics

Overlying the Franciscan basement rocks are local accumulations of the Miocene-aged, predominantly mafic Tolay Volcanics, consisting of lava flows, breccias, tuffs and agglomerates with interbedded stream channel deposits, the oldest known Cenozoic deposits in the Basin (Wagner et al., 2011). Tolay Volcanics are reported to have a highly variable specific yield, and are considered to be a fair to good water producer west of Petaluma (DWR 1982). The lava flows are essentially non-water bearing except where highly fractured by faulting. The Tolay Volcanics are exposed on Burdell Mountain (southwest of

the city of Petaluma), on Meacham Hill (north of the city of Petaluma), and to the east of the Tolay fault (Figure 3-5). Tolay Volcanics are up to 650 ft thick on Burdell Mountain; approximately 160 ft of volcanic rocks are exposed in outcrops to the west of the city of Petaluma.

Sonoma Volcanics

The Sonoma Volcanics of Miocene to Pliocene age (approximately 8 to 2.5 million years old) are a thick and highly variable sequence of volcanic rocks interbedded with volcanoclastic sedimentary deposits (sediments derived from volcanic rocks). The unit consists of thick deposits of volcanic lava flows with some interbedded volcanic ash flows, mud flows, tuffs and volcanoclastic sedimentary deposits of tuffaceous sands and volcanic gravels. The Sonoma Volcanics cover an area of approximately 1,200 square miles in Sonoma and Napa Counties and have been grouped into a western, eastern and northern groups based on their age, with the western group, which is the oldest of the three, present in Petaluma Valley (Sweetkind et al, 2011).

The Sonoma Volcanics are exposed throughout the Sonoma mountains and on both sides of the Rodgers Creek fault on the east side of the Basin and extend beneath the valley floor where they are buried beneath younger geologic units. The Sonoma Volcanics are highly variable in lithology and their subsurface distribution is often difficult to discern from well drillers logs. The Sonoma Volcanics include a thick accumulation of andesitic and basaltic tuffs containing interbedded lavas and volcanoclastic rocks (Wagner and others, 2011). These volcanic rocks interfinger with the Wilson Grove and Petaluma Formations in the Basin (Figure 3-4). The total thickness of Sonoma Volcanics ranges up to at least a few thousand feet; however, volcanic-rock thickness is highly variable.

The Sonoma Volcanics exhibit a large variation in water-bearing properties, with a mixture of fractured lava beds, unwelded tuffs and interbedded volcanoclastic sedimentary deposits generally providing the best aquifer materials. Lava beds have extremely low primary permeability and only fractures or the tops and bottoms of individual flows yield significant water. Unwelded tuffs can yield water similar to high porosity, high permeability alluvial sediments. Because of their heterogeneous nature, the Sonoma Volcanics have a highly variable specific yield.

3.1.4.3.2 Tertiary Sedimentary Units

Tertiary sedimentary units within the Basin were deposited in fault-compartmentalized basins that formed in response to the development of the San Andreas fault system. These sedimentary units are assigned to two formations: the fine-grained marine sandstone of the Wilson Grove Formation, exposed northwest of the Basin, and the fluvial, estuarine, and lacustrine Petaluma Formation, exposed on the northeast and east side of the Basin along the east flank of the Sonoma Mountains (USGS, 2019 unpublished draft) (Figure 3-3).

Wilson Grove Formation

The Miocene to Pliocene Wilson Grove Formation consists of fine- to medium-grained, thick-bedded to massively-bedded, moderate- to well-sorted, uncemented to weakly cemented fossiliferous marine sandstone, and its distribution is shown on Figures 3-4 and 3-6. Two units have been described for the Wilson Grove Formation: an upper oxidized continental unit of brown sandstone, clay and gravel, and a lower reduced, shallow marine unit of blue sandstone with shells. The two units are separated by an erosional surface and sometimes by lava flows of the Sonoma Volcanics (DWR, 1982). The Wilson Grove

Formation is generally 650-950 feet thick based on outcrop exposures and drillers logs northwest of the Basin, and may be as much as 3,000 ft thick in the adjacent Wilson Grove Formation Highlands Basin further to the northwest (Powell and others, 2004). The Wilson Grove Formation interfingers with the Petaluma Formation in the Basin.

Petaluma Formation

The Petaluma Formation is a Miocene- to Pliocene-aged sedimentary unit that was deposited in transitional continental and shallow marine environments, and accounts of the bulk of the Basin fill. Figures 3-3 and 3-6 show its distribution in the Basin. The unit is dominated by deposits of moderately to weakly consolidated, silty to clayey mudstone with local beds and lenses of poorly sorted sandstone and minor beds of nodular limestone and conglomerate. It has been subdivided into an upper, middle and lower member, but is treated as a single unit for the purposes of this GSP. The Petaluma Formation is exposed in fault-bounded blocks along a 1 to 2 mile belt in the northeastern part of the Basin, where the sand and sandstone lenses yield water to wells. Well yields vary with the thickness and extent of sands encountered in the well, but are generally low.

3.1.4.3.3 Quaternary Sedimentary Deposits

Quaternary Mixed Unit

A lithologically heterogeneous unit of alternating thin beds of conglomerate, sand, and mudstone was identified by the USGS beneath the Quaternary alluvial deposits on the basis of well lithologic data (Figure 3-3b); this unit is not mapped at the surface and is lithologically unlike the Wilson Grove and Petaluma Formations (USGS, 2019 unpublished draft). This unit may be broadly correlative with the Pliocene–Pleistocene terrestrial deposits mapped as Huichica Formation and Glen Ellen Formation that are exposed in the nearby Sonoma Valley groundwater subbasin. This unit is referred to as the Quaternary Mixed Unit by the USGS and in this GSP, although the age of these deposits has not been determined and the deposits may be in part Pliocene in age (USGS, 2019 unpublished draft).

Quaternary Alluvial Deposits

Quaternary alluvial deposits cover much of the valley floor and include Holocene (younger than 100,000 years) to modern stream channel and stream terrace deposits (loose alluvial sand, gravel and silt) and surrounding late Pleistocene to Holocene undissected stream terrace deposits, older alluvium and alluvial fan deposits. In general, the alluvial material nearest the valley margins and directly along major stream courses contain the greatest proportions of coarse-grained sediments (Figure 3-3a).

Quaternary alluvial fan deposits form a nearly continuous layer over the northeastern Petaluma Valley (Figure 3-3a). These deposits consist of poorly sorted coarse sand and gravel and moderately sorted fine sand, silt, and silty clay, with gravel content increases near the alluvial fan heads. The alluvial fan deposits contain lenses of very fine sand, which may be derived from the adjacent Wilson Grove Formation. The alluvial fan deposits typically have moderate to high yields, and good water quality.

Quaternary Bay Muds

Quaternary bay mud deposits of Holocene age cover the southern part of the Basin along the Petaluma River (Figure 3-3a). These deposits are primarily composed of organic rich muds and silts with small

amounts of sand. The bay muds were deposited during a higher stand of sea level and, as such, contain entrapped brackish and saline water.

The thickness of the bay muds is uncertain as very few wells exist in this unit, but is estimated to range from 200 feet along the shore of San Pablo Bay to near zero at its margins. Due to the low permeability and poor water quality associated with the bay muds, they are generally not tapped for groundwater supply.

3.1.5 Principal Aquifer System

The GSP Regulations require the identification of principal aquifers and aquitards within groundwater basins. Principal aquifers, which are defined by DWR as “aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems”, have unique and important requirements defined in the GSP Regulations, which require the following for each principal aquifer:

- Characterization of physical properties, structural barriers, water quality conditions, and primary uses
- Groundwater elevation contour maps
- Hydrographs
- Change in storage estimates
- Minimum thresholds and measurable objectives
- Sufficient monitoring network, including groundwater levels and water quality

Based on available data and information, a single principal aquifer system is proposed for the Basin. The principal aquifer system consists of the following aquifer units which have been identified within the Basin and contributing watershed areas and described by the USGS: the Petaluma and Wilson Grove Formations, Sonoma Volcanics, Quaternary mixed unit, and to a lesser degree, the Quaternary alluvial deposits.

While these aquifer units exhibit distinct lithologic and aquifer properties, data limitations regarding the degree of hydraulic connection between the units both laterally and vertically do not allow for the characterization of these units as separate principal aquifer systems. The limitations on available information and data are due, in part, to the high degree of heterogeneity associated with the geologic units, deformation related to folding and faulting of Tertiary-aged units which are difficult to discern in the subsurface, similarities in texture and composition of many of the sedimentary units, and related lack of high quality lithologic descriptions for the subsurface. The appropriateness of the principal aquifer designation within the Basin will continue to be evaluated and considered as more data and information becomes available regarding the lateral and vertical characteristics and hydraulic connections between the different aquifer units is developed during implementation of the GSP.

3.1.5.1 Principal Aquifer System Framework and Properties

The principal aquifer system consists of the following aquifer units, which occur to varying degrees within the Basin: the Petaluma and Wilson Grove Formations, Sonoma Volcanics, Quaternary mixed unit, and to a lesser degree, the Quaternary alluvial deposits. The distribution, subsurface extent, and structural and stratigraphic boundaries between these primary aquifer units are strongly controlled by

displacement along faults within the Basin, most notably the Petaluma Valley and Meacham Hill Fault. As shown in Figures 3-3b and 3-6, west of these two fault zones the primary aquifer units are limited to the Quaternary mixed unit and Wilson Grove Formation and east of the fault zones the Petaluma Formation and Sonoma Volcanics represent the primary aquifer units.

Groundwater flow between aquifers in the Basin is controlled by the areal extent of each aquifer unit, the degree of hydraulic connection to underlying or adjacent aquifers, and permeability of fault zones that separate aquifers. The aquifer system is conceptualized as a set of distinct aquifer units, which are strongly compartmentalized into fault-bounded domains. In Figure 3-3b, the shallow Quaternary alluvial deposits have been removed, exposing the fragmented nature of the underlying aquifer system in the subsurface.

To provide an assessment of aquifer properties, data from 125 wells were compiled by the USGS throughout the basin to determine the range and distribution of well productivity. Drillers' reports provided information on well tests, including discharge rate, water-level drawdown, and the length of test. Productivity was computed as specific capacity, given in terms of gallons per minute per foot [(gal/min)/ft] of drawdown. Coarse-grained, well-sorted sedimentary materials have high values of specific yield and specific capacity because of the large amount of connected pore volume in the material. Conversely, cemented deposits and clay-rich deposits have limited or very small pore spaces, and correspondingly lower values of specific yield and specific capacity (USGS, 2019 unpublished draft).

Quaternary alluvial deposits are considered aquifer units of more limited areal extent along major streams and beneath the alluvial fans primarily on the eastern side of the Basin. Previous work by Herbst (1982) suggests that these alluvial aquifers are vertically continuous and may be hydraulically connected with underlying aquifers in permeable formations, such as to the northwest of Petaluma where alluvial deposits overlie the Wilson Grove Formation. Reported specific-yield values of the Quaternary alluvial deposits ranged from 8 to 17 percent (Herbst, 1982); specific capacity was not computed because of uncertainty identifying wells open only to this unit. Well yields range from 50 to 150 gallons per minute (gpm) (DWR, 2014).

The Quaternary mixed unit is present only along the axis of Petaluma Valley, generally beneath the course of the Petaluma River (Figure 3-3b and 3-6). This aquifer is likely hydraulically connected with both overlying Quaternary alluvial deposits and with the Wilson Grove Formation, which is present only in the northwest part of the Basin. Although previous studies of the Basin did not report aquifer properties for the Quaternary mixed unit, this unit is similar to the Glen Ellen Formation in the Santa Rosa Plain and Sonoma Valley Subbasins; therefore, reported values of specific yield between 3 and 7 percent may be applicable (Herbst and others, 1982).

The Wilson Grove Formation forms a single, continuous aquifer unit, due to general lithologic homogeneity and the absence of faults. The sand and sandstones of the Wilson Grove Formation are generally productive aquifers, with reported specific yield of 10 to 20 percent (Herbst, 1982) and a range in specific capacity of 0.05 to 0.5 (gal/min)/ft. The yields of wells in the Wilson Grove Formation range from 100 to 1,500 gpm (DWR, 2014).

The Petaluma Formation has the greatest extent of any of the aquifer units, occupying much of the eastern part of the Basin (Figure 3-3b and 3-6). The Petaluma Formation aquifer unit is composed of discontinuous lenses of sands and gravels, and hydraulic connections with overlying and adjacent

aquifers only exist where these lenses are juxtaposed and interfinger with other aquifers. Wells in the Petaluma Formation produce moderate amounts of water when they intercept the sand and gravel lenses, but well productivity can be low because of the clay-dominated lithology of the Petaluma Formation. Estimated specific yield for the Petaluma Formation from previous studies ranges from 3 to 7 percent (Herbst, 1982) and specific capacity ranges from 0.015 to 7.5 (gal/min)/ft. The specific capacities for the Petaluma Formation are approximately equivalent to transmissivities of 4.0 to 2,005 ft²/d for confined aquifers and 3.7 to 1,504 ft²/d for unconfined aquifers.

Sonoma Volcanics are present only at the northeast edge of the Basin, while Tolay Volcanics occur in relatively isolated regions within the Basin (Figure 3-6). Water production from the Sonoma Volcanics is highly variable and specific yield is estimated to range from 0 to 15 percent (Herbst, 1982) while specific capacity ranges from 0.03 to 0.5 (gal/min)/ft. The specific capacities for the Sonoma Volcanics are approximately equivalent to transmissivities of 8.0 to 133.7 ft²/d for confined aquifers and 6.0 to 100.2 ft²/d for unconfined aquifers.

3.1.5.2 Principal Aquifer System General Water Quality

Section to be completed upon receipt of updated USGS Draft Water Quality Chapter

3.1.5.3 Principal Aquifer System Primary Uses

The principal aquifer system serves a number of different users and uses within the Basin groundwater extractions being from a combination of domestic water supply wells which provide water to rural residential properties in the unincorporated areas of the Basin, agricultural irrigation wells used for crop irrigation, industrial used for businesses and public water supply wells for municipal and smaller public supply systems.

In some areas shallow portions of the principal aquifer system also provides a significant amount of base flow to streams within the Basin which contributes to streamflow and provides benefits to ecosystems in the Basin. Additionally, in some areas where groundwater levels are close to the ground surface, such as near streams and in the tidal marshland areas, the shallow portions of the principal aquifer system provides water for vegetation communities in the Basin.

3.1.5.4 Aquitards

Aquitards composed of clay deposits can locally separate the shallow and deeper portions of the principal aquifer systems and serve to locally confine deeper portions of the principal aquifer system. Regionally continuous aquitards have not been identified within the Basin. Due to the more clay rich lithology of the Petaluma Formation and the Quaternary Mixed Unit, aquitards are more prevalent within these aquifer units and locally vertically separate the principal aquifer system. Wells spanning unconfined and confined layers, however, can provide pathways for groundwater to flow between layers that could affect both the hydraulics and water quality of these areas.

3.1.6 Lateral and Vertical Extent of Basin

The structural setting and distribution of geologic units and primary aquifer units described above influence the Basin extents, which are defined by DWR, as documented in Bulletin 118. In general, the lateral extent of the Basin is defined by the surficial distribution of the Quaternary sedimentary units and the Tertiary Petaluma Formation based on the 1982 Geologic Map of the Santa Rosa Quadrangle (CDMG, 1982). Exceptions to this occur at the northern boundary, where the surface watershed divide between the Petaluma Valley Basin and Santa Rosa Plain Subbasin forms the boundary, and within the

western portions of the City of Petaluma, where a basin boundary modification approved by DWR in 2019 extended the boundary to encompass the jurisdictional areas of the City where the Wilson Grove Formation is present at the surface.

The base of the Basin is defined by a combination of the depth to basement rocks and the approximate depth at which viable water supply aquifers are no longer present. Productive freshwater aquifers within the Basin generally occur at shallower depths with the deeper wells within the Basin extending to approximately 800 feet and no existing known water wells extending deeper than 1,300 feet. At depths exceeding approximately 1,500 feet, aquifers are likely not usable for water supply due to a combination of: (1) lower well yields related to increased consolidation and cementation of aquifer materials at these depths and (2) poor quality water related, in part, to the presence of brackish connate water. The base of the Basin is therefore defined to occur at 1,500 feet except where the depth to basement rocks occurs shallower than 1,500 feet, in which case the top of the basement rocks represents the base of the Basin.

3.1.7 Effects of Faults on Groundwater

Faults can affect water flow and well production, because groundwater movement may be inhibited or preferentially increased across or within faults and fault zones. Faulting can break even very strong rocks, producing fracture zones that tend to increase permeability, and may provide preferential paths for groundwater flow. Conversely, some faults can form groundwater barriers, if the faulting grinds the broken rock into fine-grained fault gouge with low permeability, or where chemical weathering and cementation over time have reduced permeability. The hydraulic characteristics of materials in a fault zone, and the width of the zone, can vary considerably so that a fault may be a barrier along part of its length but elsewhere allow or even enhance groundwater flow across it. Faults also may displace rocks or sediments so that geologic units with very different hydraulic properties are moved next to each other (USGS, 2019 unpublished draft).

The effect of faults on the groundwater flow is difficult to determine in the Basin for two reasons: (1) the lack of aquifer-test data near faults, and (2) northwest-trending faults in the basin run parallel to the predominant direction of groundwater flow along the axis of the valley. Although there are insufficient data to determine the effect of these faults on groundwater levels and flows, previously published work of Cardwell (1958) and Herbst (1982) do not indicate any potential effect of the Burdell Mountain and Rodgers Creek faults. Current work based on groundwater level mapping also suggests that the Bloomfield, Cinnabar School and Petaluma Valley faults do not influence groundwater levels in this area (USGS, 2019 unpublished draft). Previous work of Herbst (1982) suggests that the fault-related juxtaposition of low-permeability rocks (basement or Tolay Volcanics) with more permeable units may influence groundwater levels, rather than the result of any special hydraulic properties of the fault zones themselves. It was not possible to evaluate the potential effect of the Lakeville fault on water levels, due to the lack of water-level data on the east side of the fault (USGS, 2019 unpublished draft).

3.1.8 Natural Groundwater Recharge and Discharge

Sources of groundwater recharge in the Basin are infiltration from precipitation, seepage from the Petaluma River and its tributaries, irrigation return flow, and inflow from San Pablo Bay and the adjacent saltwater marshes. Leakage from water-supply infrastructure is another possible source; however, the city estimates that losses are minimal and are not considered to be important sources (USGS, 2019 unpublished draft). Groundwater discharges as baseflow to streams, spring flow, evapotranspiration

(ET), and groundwater pumpage. Basin groundwater recharge and discharge can also occur as underflows across the Basin boundary.

Groundwater Recharge

Recharge to aquifers in the Basin primarily occurs through streambed recharge along portions of Petaluma River and its tributaries, as well as through direct infiltration of precipitation and along the margins of the valley areas (mountain front recharge). West Yost (2004) concluded potential recharge occurs through infiltration along stream channels where erosion has exposed permeable beds within the Petaluma and Wilson Grove formation. Herbst (1982) estimated that approximately 20 percent of the Basin is capable of contributing to groundwater recharge using criteria based on measured infiltration rates (greater than 0.6 in/hr) and land slopes (less than 15 percent), primarily within and northwest of the city of Petaluma and along the crest of Sonoma Mountain.

Groundwater Discharge

Groundwater discharge occurs in the Basin as stream baseflow (gaining streams), discharge at springs and seeps, discharge at interconnected wetlands. Groundwater also discharges through evapotranspiration from phreatophytes, and groundwater pumping, however these two components of groundwater discharge are described in Section 3.3 (Water Budget).

Natural groundwater discharge to streams, or baseflow, occurs during the wet season along the Petaluma River and its tributaries north of the tidally influenced reach. Groundwater discharges through springs in areas of the Sonoma Mountains where stratigraphic contacts between fractured volcanic rocks and the underlying Franciscan basement forces water to land surface. Most of the groundwater discharge through ET occurs where depth to groundwater is shallow, such as in the tidal marshlands.

3.1.9 Data Gaps and Uncertainty

While the information and data presented in this hydrogeologic conceptual model incorporates the best available information and datasets, it is recognized that all hydrogeologic conceptual models will contain varying degrees of uncertainty that can be improved through additional data collection and analysis. Addressing the following primary identified data gaps would improve and reduce uncertainty of the hydrogeologic conceptual model for the Petaluma Valley Basin and will be considered and prioritized in Section 6 (Projects and Actions) and Section 7 (Implementation Plan).

Aquifer and Aquitard Continuity and Properties and Role of Fault Zones

As described in preceding sections, the geologic complexities of the Basin and limited high quality subsurface lithologic data limits the understanding of the lateral and vertical continuity and properties of aquifers and aquitards in the Basin.

- Filling three-dimensional data gaps in the monitoring network for each primary aquifer in the Basin. Depth-dependent water level and water quality data are needed to improve understanding of the hydrogeology and aquifer system, which could be improved through construction of dedicated nested monitoring wells in key areas.
- Gaining a better understanding of the role of faults within and along the boundaries of the Basin, with a focus on the role of the Meacham Hill, Petaluma Valley, and Cinnabar School

Faults. Potential methods for addressing this data gap could include the performance of aquifer tests and geophysical surveys in the vicinity of these faults.

- Developing better information on basin boundary characteristics, such as the direction and magnitude of fluxes across Basin boundaries, including boundaries between the Basin and adjoining groundwater basins and boundaries between the Basin and the upper contributing watershed areas outside of the Bulletin 118 basins. Potential methods for addressing this data gap could include the construction of dedicated nested monitoring wells and/or performance of aquifer tests and geophysical surveys in the vicinity of the boundaries.
- Improving the understanding of groundwater flowpaths near areas of brackish water in southern Petaluma Valley will support the appropriate setting of Sustainable Management Criteria in this area. Potential methods for addressing this data gap could include the construction of dedicated nested monitoring wells and/or and geophysical surveys in this area.

Recharge and Discharge Areas and Mechanisms and Surface Water/Groundwater Interaction

Improved understanding recharge and discharge mechanisms within the Basin for both the shallow and deep aquifer systems will support the appropriate selection of projects and actions needed for the Basin.

- Gaining an improved understanding of the interconnection of streams to the shallow aquifer system, including seasonal variability and how groundwater pumping can affect streamflow. Additional shallow monitoring wells near stream courses, stream gages and meteorological stations can help advance this understanding.
- Geochemical or tracer studies can help better understand both recharge and discharge mechanisms to both the shallow and deep aquifer systems, as well as surface water/groundwater interaction within the Basin.

3.2 Current and Historical Groundwater Conditions

This subsection describes the current and historical groundwater conditions within the Basin and contributing watershed areas. As described in the GSP Regulations, “Each Plan shall provide a description of current and historical groundwater conditions in the basin, including data from January 1, 2015, to current conditions, based on the best available information that includes the following”:

- Groundwater Elevation Data: Contour maps, hydrographs
- Change in Storage Estimates: Annual and cumulative changes, including groundwater use and water year type
- Seawater Intrusion: Maps and cross sections for each principal aquifer
- Groundwater Quality: Issues that may affect supply and beneficial uses, map of contaminant sites and plumes
- Land Subsidence: Extent and annual rate
- Interconnected Surface Water: Timing of depletions, map of groundwater dependent ecosystems

In order to assess and evaluate the above-listed conditions for the Basin and contributing watershed areas, this subsection includes a description of the following conditions based on available information and data:

- Climate conditions and trends;
- Groundwater elevation data and trends;
- *Estimates of storage changes;*
- Groundwater quality data and trends, including an assessment of seawater intrusion;
- Land surface subsidence data and trends;
- *Surface water conditions and trends; and*
- *Assessment of interconnected surface water and groundwater dependent ecosystems.*

3.2.1 Climatic Conditions and Trends

Regional climate patterns in the Northern California region encompassing the basin and contributing watershed are characterized by Mediterranean conditions. Distributions of temperature and rainfall display high spatial and temporal variability due to the combination of coastal and inland weather systems. The intersection of these variable weather patterns with the rugged topography of the Coast Ranges results in a variety of microclimates.

The Mediterranean climate in the Basin and contributing watershed influences water demands by separating the year into wet and dry seasons. During the dry season outdoor irrigation demands, particularly for agriculture, are not met by precipitation. Approximately 95 percent of the annual precipitation normally falls during the wet season (October to April), with a large percentage of the rainfall typically occurring during three or four major winter storms. The occurrence of precipitation is affected by atmospheric rivers, which concentrate rainfall and runoff along narrow bands in the atmosphere. Nearly 50% of precipitation in the Sonoma County area is due to atmospheric rivers (Dettinger, et al, 2011). The quantity of rainfall over the contributing watershed increases with

elevation, with the greatest precipitation over the highest ridges, reaching nearly 50 inches per year in the Mayacamas and Sonoma Mountains (**Figure 3-9a**).

Mean annual precipitation in the basin has been assessed using both observed data from Climate Station Petaluma (USC00046826), which is located in Petaluma at an elevation of 25 ft (NGVD 29), as well as yearly averages calculated using the PRISM model for the Basin and contributing watershed area. The station has moved locations throughout its operations, and has been located and named: PETALUMA, PETALUMA AIRPORT, PETALUMA AP, PETALUMA FIRE STA 2, PETALUMA FIRE STN 2, PETALUMA FIRE STN 3. The Petaluma station has operated from 1893 to present, with periods of negligible data coverage until 1913, generally good coverage from 1913 to 1937 (85% of days with reported data), and from 1938 to present consistent coverage (97% of days reported). Records for this station are stored on the U.S. Historical Climatology Network until the year 2019. The yearly averaged precipitation measured from this station from 1893 through water year 2018 is 24.3 inches, compared with 24.5 inches, as calculated by the PRISM model, as shown on **Figure 3-9b**. This calculation is based on the annual Water Year standard nomenclature, which begins on October 1 and ends the following calendar year on September 30.

For the Water Budget in Section 3.3, water years must be characterized as wet, dry and normal years. To determine wet and dry periods, the 5-year running average was calculated from the precipitation record. Years with 5-year averages greater than 110% of the record average are considered wet, and years with 5-year averages less than 90% of the record average are considered dry. To perform this analysis alternate sources of precipitation data were obtained because in the Petaluma precipitation record there exists erroneous data and missing periods of record. These alternate sources include records from nearby meteorological stations with long-term records and monthly historical simulated data from PRISM. The daily data for the Petaluma station and the PRISM data were aggregated by water year (**Figure 3-9b**). Nearby stations in Bodega Bay, Santa Rosa and Sonoma are included to verify that historical PRISM output compare reasonably when Santa Rosa station data are absent. There are 17 wet years in the period from 1950 to 2018, and 19 dry years in the same period (**Table 3-1**). The 1960's is the decade with the most dry years (six), whereas the 1980's, 1990's and 2000's have 5 or more wet years. In the same period, from 1950 to 2018, two years in the 1970's (1977 and 1976) had the first and second lowest yearly precipitation; 1983, 1998 and 1995 had the highest yearly precipitation in the same period, with totals about 4.5 times as great as the lowest years. All years in the 2000's are classified as normal or wet, indicating that the effects of the drier 2010's were likely buffered by the wet previous decade. The intensity of the dry period from WY 2012 to WY 2016 has been regularly exceeded in the last 100 years. The 5-year moving average precipitation value reached in WY 2016 is higher than the values reached for 44 years within the period from 1893 to 2018, indicating that the conditions from WY 2012 to 2016 are not uncommon and occur about 35% of the time.

Climate change impacts over the historical period from 1913 to 2018 are assessed in **Figure 3-9c** for the Basin. The temperature records were obtained from the Global Historical Climatology Network Monthly (GHCNM) for the station 42500046826 which corresponds to the station described above. Similar to the PRISM precipitation record, the GHCNM incorporates numerous quality assessments and bias corrections from the observed temperature records (Lawrimore et al, 2011). The trend of the monthly GHCNM air temperature is an increase of 1.97 degrees Fahrenheit per century over the record.

3.2.2 Groundwater Elevations and Trends

This section describes current and historical groundwater elevation conditions and trends based on the Draft USGS Report (USGS, 2019 unpublished draft) and available data from the monitoring programs described in Section 2.4. Data presented and evaluated as part of this section includes:

- Groundwater-level contour maps (**Figures 3-10a-c**); and
- Long-term groundwater-level hydrographs (**Figures 3-11, 3-12a-e, and Appendix A**)

Groundwater-Level Contour Maps

Preliminary groundwater level elevation contour maps from the Draft USGS Report for Spring 1951, Fall 1980, and Spring 2015 are shown in **Figures 3-10a, 3-10b, and 3-10c**, respectively, and indicate the following

- Spring 2015 groundwater-level elevations ranged from approximately 465 feet mean sea level (msl) near the eastern edge of the basin to -13 feet msl in the southern central portion of the basin near the confluence of Adobe Creek and the Petaluma River.
- Flow patterns have remained relatively similar in the basin since 1951, with groundwater moving from the higher elevations in the east and west of the watershed, toward the Petaluma River.
- Groundwater-level elevations are near or below sea-level in the areas adjacent to the Petaluma River from the southern portion of the City of Petaluma to San Pablo Bay. In this area of low water levels, the river may be gaining or losing depending on the tidal cycle and the resultant river stage height in relation to groundwater elevations with the river generally gaining during low tides and losing during high tides (USGS, 2019 unpublished draft).

It is important to note that groundwater elevations measured in nearby wells can be highly variable due to differences in well design (i.e., the depth and length of well screen intervals) and the spatial variations in aquifer materials (which can vary abruptly due to the complex geologic conditions and numerous fault zones present in Petaluma Valley). Therefore, the associated groundwater level contour maps represent generalized groundwater level flow patterns and should not be used to interpret more localized or site-specific conditions.

Groundwater Level Trends

Long-term groundwater-level trends were evaluated using data from 41 wells in the Basin and the contributing watershed area (**Figure 3-11**). In general, long-term trends were evaluated using data collected on a semiannual basis. For some wells, groundwater-level elevation data is 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 the contributing watershed area are provided in **Appendix A**. These hydrographs present the change in groundwater elevation (vertical axis in feet) over time (horizontal axis in years). 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 discernable trends are presented in **Figures 3-12a-e**.

As indicated on the long-term hydrographs, the majority of the observed wells exhibit generally stable groundwater-level trends with typical seasonal variations (i.e. higher groundwater levels in the spring and lower groundwater levels in the fall). Observed groundwater-level elevations predominantly remain above sea level with the exception of some wells in the southern portion of the Basin near San Pablo Bay (**Figure 3-12b**: PET0005, PET0004, PET0008, PET0014) and near the tidally influenced reach of the Petaluma River (**Figure 3-12c**: PET0006, PET0017).

Some wells near or just outside the eastern edge of Basin (**Figure 3-12c**: PET0026, **Figure 3-12d**: PET0033, PET0038, PET0039) exhibit slightly decreasing groundwater-level trends over the period of record. Wells PET0026, PET0033, and PET0039 also exhibit large irregular fluctuations likely due to local groundwater pumping. Near the northern edge of the basin, Well PET0042 and, to a lesser extent Well PET0041 exhibit decreasing groundwater-level trends from about 2005 to present (**Figure 3-12e**). However, Well PET0043, also near the northern edge of the basin, exhibits a stable groundwater-level trend from 2005 to present and a slightly increasing trend for the overall period of record (1990-present, **Figure 3-12e**).

3.2.3 Estimated Changes in Groundwater Storage

This section will be completed following development of the water budget section.

3.2.4 Land Surface Subsidence

Changes in land surface elevation may be caused by tectonic processes, hydrologic isostatic loading, increases in effective stress caused by excessive groundwater pumping, and other processes. In locations where multiple processes impact land surface elevations, it may be difficult to determine the cause of changes. The North Bay region is located in the tectonically active Pacific margin, characterized by numerous active faults and geologically recent volcanic activity. In addition to the effects of tectonics, water stored on earth's surface and subsurface exerts a downward pull on the earth's crust. Increases in stored water increase this downward force, whereas declines in storage release this downward force. This hydrologic isostatic loading is important in California, occurs on 100s to 1000km scales, and explains much of the land surface changes in areas without significant groundwater pumping or tectonic processes (Borsa et al, 2014). In areas of intensive water use, groundwater pumping can cause subsidence by reducing hydrostatic pressure. When water is removed hydrostatic pressure decreases, which in turn increases the weight that the skeletal structure of the aquifer must support (effective stress). Aquifer materials rich in clays may collapse under this weight thus causing a lowering of the ground surface and a potentially unrecoverable loss in aquifer storage.

Existing data related to the potential for land subsidence in the basin is limited to Global Position System (GPS) data collected as part of a plate boundary study and a focused study of the Rodgers Creek fault zone. GPS data is being collected as part of a Plate Boundary Observatory (PBO) network to monitor tectonic Earth movements in North America. The project is led and managed by University Navigation Signal Timing and Ranging Global Positioning System Consortium, a university-governed consortium. PBO's network of 1100 permanent continually-operating GPS stations spans the Pacific/North-American plate boundary in the western United States and Alaska, with additional stations on the stable continental interior. One PBO GPS (Plate Boundary Observatory Global Positioning System) station is

located within the Petaluma Valley basin (**Figure 3-13a**). This station (PET00127; P198) has been actively monitored since 2004 and results are shown in **Figure 3-13b**.

From 2004 to 2019 the GPS station in the basin has shown vertical changes of -0.5 inches (**Figure 3-13b**). From 2015 to 2019 the vertical change for the station is -0.13 inches, with yearly changes of -0.0325 inches per year. The ground height changes observed in the basin correlate with nearby stations and regional stations. The other stations in Bodega Bay, Marin, Napa, and in the Russian River areas exhibit longterm declines in ground height that closely mirror those of the Petaluma station. Given the similarity in the Petaluma ground height change with 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 Petaluma is likely not the cause of the subsidence observed at the PET0127 station.

The spatial variation of ground surface change within the basin is shown in **Figure 3-14**. 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 three year period.

Data collected as a part of a study of the Rodgers Creek fault for evidence of tectonic fault creep revealed evidence of potential land subsidence in the southern portions adjacent Santa Rosa Plain Subbasin (Funning et. al., 2007). The study used Permanent Scattering Interferometric Synthetic Aperture Radar (PS-InSAR) technique from satellite data from 1992-2001 to analyze the area for land surface deformation related to fault movements (**Figure 3-15**). PS-InSAR is an advanced processing technique for satellite radar data, which uses the radar returns from stable targets on the ground to generate a series of surface displacement changes over time, with atmospheric effects mitigated.

While not specifically designed to investigate potential land subsidence due to groundwater pumping, the fault study does not identify any areas in the basin with significant vertical displacements during the timeframe of the study (1992-2001).

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 areas. Localized areas of poor groundwater quality within the Basin and contributing watershed areas 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 (e.g., industrial, agricultural, or urban land uses), including an area of nitrate contamination in the northwestern portions of the Basin and contributing watershed areas.

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, total dissolved solids, arsenic, nitrate, boron 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 thermal, brackish or saline groundwater. The analytical 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 which are required to treat the water to below applicable drinking water standards prior to delivery.

3.2.5.1 General Groundwater Quality Characteristics

This section is currently under development.

3.2.5.2 Naturally Occurring Constituents of Interest

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

Arsenic

Arsenic is a relatively common element which occurs naturally in the environment. Arsenic is considered a carcinogen, and the maximum contaminant level (MCL) for arsenic has been set at 10 micrograms per liter ($\mu\text{g/L}$). Arsenic solubility increases with increasing water temperature, and also tends to desorb from aquifer matrix materials under alkaline conditions (pH greater than 8.0) (USGS 2010). Due to its increased solubility with increased temperature, arsenic is commonly elevated in groundwater that is affected by hydrothermal fluids.

The Draft USGS Report compiles arsenic data collected between 1977 and 2016 from 49 wells, 3 springs, and 2 surface water sampling points within the Basin and contributing watershed areas. The occurrence and distribution of arsenic in groundwater and surface water is displayed on **Figure 3-16**. A discussion of the arsenic data from the Draft USGS Report is as follows:

“Of the 49 samples from wells in the Petaluma Valley Watershed (PVW) study area with arsenic analyses, seven (about 14 percent) had arsenic concentrations greater than or equal to the MCL and eight had moderate concentrations of arsenic (5 to ≤ 10 $\mu\text{g/L}$). The sole sample from a well perforated in the Quaternary alluvium (well W30/PET0056) had an arsenic concentration below the MCL (2.5 $\mu\text{g/L}$). None of the springs had arsenic concentrations above the MCL. One of the two surface-water samples, SW1 had a moderate relative-concentration of arsenic (6.23 $\mu\text{g/L}$). The highest arsenic concentration reported is 20 $\mu\text{g/L}$, which was measured in a sample from well W61, a mixed-depth well perforated in the Petaluma Formation. The median arsenic concentration in samples from wells with arsenic analyses perforated in the Wilson Grove Formation, Quaternary mixed unit, and Petaluma Formation were 7.0, less than detection, and 3.6 $\mu\text{g/L}$ respectively.”

Boron

Boron is a naturally occurring element in rocks and soils, and also may be found in wastewater, fertilizers and pesticides. Boron is a necessary nutrient for human health, but also has been found to be a contaminant to the environment and may cause human health impacts, although it is not considered a carcinogen and not many comprehensive health studies have been completed. A State Notification Level (NL-CA) of 1,000 µg/L has been established for public drinking water supplies. However, boron in irrigation water at concentrations as low as 700 ug/l can be toxic to sensitive plants such as grapes (Farrar et al, 2006).

The Draft USGS Report compiles boron data collected between 1959 and 2016 from 29 wells, 2 springs, and 2 surface water sampling points within the Basin and contributing watershed areas. The occurrence and distribution of boron in groundwater and surface water is displayed on **Figure 3-17**. A discussion of the boron data from the Draft USGS Report is as follows:

“One of the 29 samples from wells in the PVW with boron analyses (about 3 percent) had a boron concentration greater than or equal to the NL-CA. The highest boron concentration (1,800 µg/L) was measured in the sample from well W71/SRP0233, a deep well perforated in the Petaluma Formation (located outside the Basin at the northern edge of the contributing watershed-**Figure 3-17**). The median boron concentration in samples from wells with boron analyses perforated in the Wilson Grove Formation, Quaternary mixed unit, and Petaluma Formation were 16, 200, and 300 µg/L, respectively. Boron concentrations in water sampled from springs were below the NL-CA. Boron concentrations in water sampled from surface-water sites were below the NL-CA; however, the boron concentration in water from site SW1 was 651 µg/L.”

Total Dissolved Solids

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 SMCL of 500 mg/L based on taste and odor thresholds.

The Draft USGS Report compiles TDS data collected between 1959 and 2016 from 56 wells, 3 springs, and 2 surface water sampling points within the Basin and contributing watershed areas. The occurrence and distribution of TDS in groundwater and surface water is displayed on **Figure 3-18**. A discussion of the TDS data from the Draft USGS Report is as follows:

“Eighteen of the 56 wells (about 32 percent) sampled in the PVW with reported TDS values had concentrations greater than or equal to the SMCL of 500 mg/L. The median TDS concentration in samples from wells with TDS analyses in the Wilson Grove Formation, Quaternary mixed unit, and Petaluma Formation were 342, 495, and 416 mg/L respectively. The sole sample from the Quaternary alluvium (W30/PET0056) had a TDS concentration that exceeds the SMCL (1,060 mg/L). None of the samples from springs had a TDS concentration exceeding the SMCL. Both of the surface-water samples had TDS concentrations exceeded the SMCL. In general, the highest groundwater TDS concentrations were reported for wells perforated in the Quaternary alluvium, Quaternary mixed unit and Petaluma Formation with many of the wells adjacent to the Petaluma River (**Figure 3-18**). The highest TDS concentration reported for the groundwater samples was 2,970 mg/L, which was measured in a sample from mixed-depth well W62/PET0075 perforated in the Petaluma Formation. Well W63/PET0005 (unknown well construction) had a similarly high TDS concentration, with a value of 2,920 mg/L. Both

wells W62/PET0075 and W63/PET0005 are in the southern part of the Petaluma Formation, in an area where groundwater is influenced by overlying Bay Mud deposits, the intrusion of high-salinity water from San Pablo Bay, or high-salinity connate water. Other wells in this area (W65/PET0082, W66/PET0083, and W67/PET0084) also had TDS concentrations that exceeded the SMCL. For wells in the northern part of the study area, the median TDS concentration was greatest for wells perforated in the Quaternary mixed unit.”

Chloride

Chlorides are widely distributed in nature as salts of sodium (NaCl), potassium (KCl), and calcium (CaCl₂). Chlorides are leached from various rocks into soil and water by weathering and can also be an indicator for seawater intrusion. Chloride has a secondary maximum contaminant level (SMCL) of 250 mg/L based on taste and odor thresholds.

The Draft USGS Report compiles chloride data collected between 1959 and 2016 from 63 wells, 3 springs, and 2 surface water sampling points within the Basin and contributing watershed areas. The occurrence and distribution of chloride in groundwater and surface water is displayed on **Figure 3-19**. A discussion of the chloride data from the Draft USGS Report is as follows:

“Seven of the 63 samples from wells in the PVW study area with chloride analyses (about 11 percent) had concentrations greater than or equal to the SMCL of 250 mg/L. The median chloride concentration in samples from wells with chloride analyses in the Wilson Grove Formation, Quaternary mixed unit, and Petaluma Formation were 63.0, 92.0, and 59.0 mg/L respectively. The sole sample from the Quaternary alluvium (well W30/PET0056) had a chloride concentration that exceeds the SMCL (278 mg/L). None of the samples from springs had chloride concentrations greater than the SMCL. One of the surface-water samples (SW1), sampled in the tidally-influenced reach of the Petaluma River, had a chloride concentration greater than the SMCL (1,940 mg/L) and represents a mixture of Petaluma River water and San Pablo Bay water that has migrated up river due to tidal fluctuations. Surface-water site SW2 had a chloride concentration of 130 mg/L, similar to groundwater in the area.”

3.2.5.3 Anthropogenic Constituents of Interest

Nitrate

Nitrate 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 nitrate in drinking water are considered to be especially unhealthy for infants and pregnant women (SWRCB, August 2010) and the MCL for nitrate as N is 10 mg/L, which is equivalent to 45 mg/L as dissolved NO₃.

The Draft USGS Report compiles NO₃ data collected between 1959 and 2016 from 60 wells, 3 springs, and 2 surface water sampling points within the Basin and contributing watershed areas. Because the NO₃ data presented in the Draft USGS Report are from varying sources, with different analytical methods

used, the data are reported as dissolved NO₃ or nitrate plus nitrite (NO₃+NO₂) as N. The occurrence and distribution of NO₃ in groundwater and surface water is displayed on **Figure 3-20**. A discussion of the NO₃ data from the Draft USGS Report is as follows:

“Only one of the 60 groundwater samples from wells in the PVW with NO₃ analyses (less than 2 percent) had a NO₃ concentration greater than or equal to the MCL (W5, 10.9 mg/L as N). Unfortunately, construction information is missing for this well; however, the well is in a residential area which suggests that it may be a shallow well. The median NO₃ concentration in samples from wells with NO₃ analyses in the Wilson Grove Formation, Quaternary mixed unit, and Petaluma Formation were below the detection limit, below the detection limit, and 0.2 mg/L as dissolved NO₃, respectively; and below the detection limit as NO₃+NO₂ for all of the hydrogeologic units. None of the springs and surface-water samples had NO₃ concentrations exceeding the MCL. Although almost all of the concentrations were below the MCL, NO₃ was detected throughout much of the basin. NO₃ concentrations in water from wells perforated in the Sonoma Volcanics and Basement rocks, where anthropogenic contributions are expected to be low, were all less than or equal to 2.2 mg/L as N, or less than or equal to 5 mg/L as NO₃.”

Regulated sites

This section is currently under development.

[3.2.5.4 Seawater/Freshwater Interface](#)

This section is currently under development.

[3.2.6 Surface Water and Groundwater Connectivity](#)

This section is currently under development.

[3.2.6.1 Interconnected Surface Water](#)

[3.2.6.2 Groundwater Dependent Ecosystems](#)

[3.3 Water Budget](#)

[3.4 Management Areas](#)