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Section 3: Basin Setting
Groundwater Sustainability Plan for
Santa Rosa Plain Groundwater Subbasin

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3.0 Basin Setting

This section provides information about the physical setting, characteristics and current conditions of the Santa Rosa Plain Subbasin, including the identification of data gaps and levels of uncertainty. The information included within this section represents the current understanding of the Subbasin based on available data and information and serves as the basis for defining and assessing sustainable management criteria, potential 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 Santa Rosa Plain Subbasin and contributing watershed areas:

- Santa Rosa Plain Basin Advisory Panel, 2014, Santa Rosa Plain Watershed Groundwater Management Plan. http://www.scwa.ca.gov/files/docs/projects/srgw/SRP_GMP_12-14.pdf
- Woolfenden, L.R., and Nishikawa, Tracy, eds., (2014), U. S. Geological Survey. Simulation of groundwater and surface-water resources of the Santa Rosa Plain watershed, Sonoma County, California: U.S. Geological Survey Scientific Investigations Report 2014–5052. https://pubs.usgs.gov/sir/2014/5052/
- Nishikawa, Tracy, ed., (2013), Hydrologic and geochemical characterization of the Santa Rosa Plain watershed, Sonoma County, California: U.S. Geological Survey Scientific Investigations Report 2013–5118. https://pubs.usgs.gov/sir/2013/5118/
- Kulongoski, J.T., Belitz, Kenneth, Landon, M.K., and Farrar, Christopher, 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.
- Kadir, T.N. and McGuire, R.A., 1987, Santa Rosa Plain ground water model: California Department of Water Resources Central District, 318 p.
- Herbst, C.M., Jacinto, D.M., and McGuire, R.A., 1982, Evaluation of ground water resources, Sonoma County, volume 2: Santa Rosa Plain: California Department of Water Resources, Bulletin 118-4, 107 p.
- Cardwell (1958). Geology and ground water in the Santa Rosa and Petaluma areas, Sonoma County, California: U.S. Geological Survey Water Supply Paper 1427, 273 p.

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 Santa Rosa Plain Subbasin is located in the North Coast Ranges geomorphic province of California and is one of three coastal alluvial subbasins of the Santa Rosa Valley Groundwater Basin. 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 Subbasin generally occupies a relatively flat northwest trending structural depression between low lying hills of the Mendocino Range to the west and the Sonoma Mountains and Mayacamas Mountains to the east, as shown on **Figure 3-1**.

The Subbasin lies mostly between elevations of about 50 and 150 feet above sea level. The north-northwest trending axis of the valley extends for about 20 miles, from Meacham Hill on the south to near the Russian River on the north; the valley width ranges mostly from 4 to 7 miles. The valley floor consists of a low uneven topography, developed on alluvial flood plains, terraces, and fans eroded by west-flowing intermittent streams (Sowers and others, 1998). Rincon and Bennett valleys occur just east of the Plan Area and occupy an approximately 7-mile long northwest-trending fault-bounded trough, 1 to 2 miles east of, and parallel to the Subbasin. The Sonoma Mountains and a narrow Mayacamas Mountains ridge mostly separate the two valleys, connecting the valleys only through a narrow gap in eastern Santa Rosa (**Figure 3-1**).

The highlands surrounding the Subbasin have modest changes in elevation, with peaks generally lower than 2,500 ft asl, and most ridge lines between 500 and 1,500 ft asl. The

Mendocino Range in this area is made up of mostly low, rounded hills that generally range from 200 to 300 feet in elevation. The Sonoma Mountains rise from near sea level to elevations of 1,000-2,500 feet southeast of Santa Rosa. Along the southeastern Subbasin boundary, the Sonoma Mountains' maximum elevation is 2,452 feet. The Mayacamas Mountains are less steep and elevations mostly vary between 500 and 2,500 feet. The maximum elevation of highland surrounding the Subbasin is 2,730 feet, at the summit of Mt. Hood in the Mayacamas Mountains.

3.1.2 Surface Water and Drainage Features

The Subbasin and contributing watershed area is mostly within the middle Russian River drainage basin and includes three main drainage subbasins based on the National Hydrography Dataset (NHD), that collectively cover an area of 251 square miles. These three main drainage subbasin areas are named for the main streams in each area: Mark West Creek, Santa Rosa Creek, and Laguna de Santa Rosa. The drainage subbasins are shown on **Figure 3-2**, along with other major and minor tributary streams (Simley and Carswell, 2009). The Subbasin also contains numerous natural and man-made surface water bodies, including small lakes, ponds and wetland areas. The following sections describe these drainage subbasins, as well as other significant surface water features.

Mark West Creek

The Mark West Creek drainage subbasin covers 86 square miles in the northern Subbasin and contributing watershed area. Mark West Creek (**Figure 3-2**), has a 29.9 mile-long channel originating at an elevation of 1,922 feet in the Mayacamas Mountains.

The main channel of Mark West Creek is perennial throughout much of its length (Simsley and Carswell, 2009), having summer flows maintained by numerous springs near the headwaters. Most of the main channel is in its natural state and much of the riparian vegetation adjacent to the Mark West Creek channel, as well as the creek bed, is undeveloped and characteristic of natural channel conditions. Some tributaries of Mark West Creek are perennial, but most are either ephemeral or intermittent and become dry during late spring to early fall.

Santa Rosa Creek

The Santa Rosa Creek drainage subbasin is a 77 square mile drainage area in the central and eastern Plan Area (**Figure 3-2**). Santa Rosa Creek is a 22-mile long channel flowing in a westerly direction from drainage divides in the Mayacamas and Sonoma Mountains, to its confluence with the Laguna de Santa Rosa drainage channel. The source of Santa Rosa Creek is at an elevation of 1,940 feet near the summit of Hood Mountain,

Santa Rosa Creek originates in steep terrain of the Mayacamas Mountains, an area of mostly natural vegetative cover. The middle Santa Rosa Creek drainage crosses the City of Santa Rosa and adjacent agricultural lands, whereas the lower Santa Rosa Creek drainage traverses mainly agricultural land. Through the urbanized city landscape, Santa Rosa Creek flows in an engineered channel with concrete or earthen embankments. The upper Santa Rosa Creek and its tributary, Matanzas Creek, are perennial steams that carry diminished flows in late summer and fall. Other Santa Rosa Creek tributaries generally have engineered channels and flows are intermittent (Simley and Carswell, 2009).

Laguna de Santa Rosa, Peripheral Streams and Drainages

The Laguna de Santa Rosa drainage subbasin is an 88 square mile area drained by the Laguna de Santa Rosa channel, upstream of the Santa Rosa Creek tributary, (**Figure 3-2**). The "Laguna de Santa Rosa" also refers to the general area of wetlands, ponds, and vernal pools within the area of the 100-year floodplain surrounding the main Laguna de Santa Rosa channel. The Laguna de Santa Rosa channel and floodplain together form a natural overflow basin connecting Santa Rosa Creek, Mark West Creek, and the smaller creeks in the Subbasin with the Russian River. The Laguna de Santa Rosa channel drains the southern and southwestern areas of the Subbasin and contributing watershed area.

The Laguna de Santa Rosa channel originates at an elevation of 260 feet, west of Cotati and close to the southern boundary of the Subbasin (**Figure 3-2**). Much of the Laguna de Santa Rosa upstream of the Mark West Creek juncture is below an elevation of 50 feet. Santa Rosa Creek, which is not included in the Laguna de Santa Rosa drainage subbasin, is the largest tributary to the Laguna de Santa Rosa. Other important Laguna de Santa Rosa tributaries include Copeland Creek, Crane Creek, Hinebaugh Creek, Five Creek, Colgan Creek, Gossage Creek, Washoe Creek, and Roseland Creek. Copeland Creek and Crane Creek have short perennial reaches (Simley and Carswell, 2009) draining the Sonoma Mountains in the southeastern part of the Subbasin. Copeland Creek is perennial in its upper sections, becomes intermittent as it flows westward across the alluvial fan east of Rohnert Park, and is mostly channelized as it continues flowing westward through the Rohnert Park and Cotati before joining the Laguna de Santa Rosa. Downstream of tributary junctions, the Laguna de Santa Rosa is a very low gradient drainage network defined by straight and engineered channels, canals, and drainage ditches through urbanized and agriculturally developed lands. The Laguna de Santa Rosa main channel is perennial, although summer flows can be quite small.

3.1.3 Soil Characteristics

Soil types and characteristics in the Santa Rosa Plain 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 3-3a**. The majority of the valley floor is characterized by clayey soils and loams with gravelly and cobbly loams and more prevalent along alluvial fans and hilly areas. The southern portions of the Subbasin are characterized by much more clay-rich soils. Gravelly and sandy soils are primarily limited to the low hills in the southwestern portions of the Subbasin and the western portions of the contributing watershed outside the Subbasin and along narrow stream channels within the Subbasin.

The SSURGO database also assigns saturated hydraulic conductivity values to soil groups, which are shown on **Figure 3-3b**. 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 3-3b**, the loams and clayey loam soils that predominate the floor of the Subbasin exhibit relatively low hydraulic conductivities (slow to moderate), on the order of 0.1 to 4 feet per day. Coarser-grained soils present in and around the Subbasin, which exhibit higher hydraulic conductivity values (moderate rapid) on the order of 4 to 12 feet per day are predominately in the hilly areas in the southwest portions of the Subbasin, along the lower portions of Santa Rosa Creek, Mark West Creek and Windsor Creek. The highest saturated hydraulic conductivities (rapid to very rapid) on the order of 12 to 40 feet per day primarily occur within streambed channels. 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

The Santa Rosa Plain 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 Subbasin are grouped into two broad categories (Mesozoic Era basement rocks and younger Cenezoic Era volcanic and sedimentary units) based on the age, degree of consolidation and amount of deformation (such as folding, faulting and fracturing). The Subbasin 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, Coast Range Ophiolite, and Great Valley Sequence. 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 (Nishikawa et al, 2013 and Wagner and Gutierrez, 2017). **Figure 3-4a** presents a geologic map of the Subbasin and contributing watershed areas showing the surficial distribution of these geologic units. The inferred subsurface distribution of the geologic units is displayed on the hydrogeologic cross-sections shown on **Figures 3-5. Note to Reader**: An additional north-south geologic cross-section is in development along with several more detailed hydrogeologic cross sections that will be included in subsequent draft of Section 3.1, along with a written description and discussion of the cross-sections in the following sections.

3.1.4.1 Geologic Structure

The Coast Ranges structure is dominated by the San Andreas right-lateral transform fault system, which includes the San Andreas zone of faults to the west, the Rodgers Creek, the Maacama, and the Bennett Valley fault zones, which are all right lateral strike slip faults. The Rodgers Creek fault zone is approximately 0.6 mile wide and consists of a northern Healdsburg fault segment and a southern Rodgers Creek fault segment, separated by the Santa Rosa Creek floodplain. The Bennett Valley fault zone is a narrow, steeply dipping right lateral fault. On the west side of the Subbasin, the Sebastopol fault is a curved zone of east-side-down normal faults at the break in slope between the west side hills and valley floor. The Sebastopol fault generally coincides with the lowest Subbasin elevations, forming the contact between Quaternary sediments and the underlying Wilson Grove formation. An unnamed fault east of the Sebastopol Fault may be a branch from the Sebastopol, and is important for deep groundwater flow and quality (Nishikawa et al, 2013). All of these faults have sufficient offset to juxtapose different geologic units against one other and serve as the main boundaries for the sedimentary basins beneath the Subbasin.

Analysis of gravity data reveals two steep-sided sedimentary structural troughs beneath the Subbasin: the Windsor structural basin beneath the northern portion of the Subbasin and the Cotati structural basin beneath the southern portions. These two structural troughs are modeled to range up to 10,000 feet deep and separated by northwest to west-northwest trending, northeast dipping Trenton Ridge thrust fault, which forms a bedrock high between the structural basins possibly as shallow as 1,000 feet below ground surface (Langenheim et al, 2006 and 2010; McPhee et al, 2007; Nishikawa et al, 2013).

Available information on the effects of faults on groundwater movement and groundwater quality is described in Section 3.1.6 below.

3.1.4.2 Mesozoic Era Basement Rocks

The Subbasin sits on a bedrock basement of deformed and faulted Mesozoic age rocks of the Franciscan Complex, Great Valley Sequence, and Coast Range ophiolite. The Mesozoic basement rocks are only exposed outside of the Subbasin at the northern boundary and within the east-central portion of the contributing watershed where rocks of the Franciscan Complex and Coast Range Ophiolite occur (Nishikawa et al, 2013).

Mesozoic Era basement rocks generally yield very little water, as their porosity is primarily attributed to fractures which are commonly limited in extent and water transmitting capacity. Wells completed in the basement rocks generally produce relatively small amounts of water suitable for domestic supply. Successful domestic wells commonly produce 5 gpm or less from basement rocks in the hills and mountains within the contributing watershed area. While the basement rocks locally provide a viable, sole source supply for many households, they are not considered a significant water supply source in the Subbasin (Parker Groundwater, 2014).

3.1.4.3 Cenozoic Era Volcanic and Sedimentary Units

Groundwater resources within the Subbasin are primarily located within the Cenozoic volcanic and sedimentary units deposited over the Mesozoic basement rocks. The thick sedimentary layers and some of the volcanic rocks that overlie the Mesozoic bedrock in the Subbasin are capable of storing and yielding large quantities of groundwater. The water-bearing properties of the geologic units vary considerably as a result of changes in rock type within units and inter-fingering between units. This variability determines how much water can be obtained from wells in different parts of the watershed. Geologic units that are of greatest importance for groundwater resources within Santa Rosa Plain (Nishikawa et al, 2013) 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

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 volcaniclastic 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 volcaniclastic 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 (Sweetkind et al, 2011). The western age group occurs within the Santa Rosa Plain and contributing watershed areas and includes the Sonoma Mountain assemblage, which includes rhyolite, rhyodacite breccia interbedded with Petaluma Formation sediments, mafic andesitic and basalt flows, tuffs and volcaniclastic sediments (Wagner et al, 2011).

The Sonoma Volcanics are exposed throughout the Mayacamas and Sonoma mountains and along the margins of the Subbasin 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 in the Sonoma Valley. Additionally, the upper part of the Sonoma Volcanics interfingers with sedimentary units of the Glen Ellen and Petaluma Formations in places further complicating subsurface mapping of volcanic units. The total thickness of the volcanic units is highly variable and has been estimated to be up to 3,000 feet thick near Sonoma Mountain (Farrar et al, 2006).

3.1.4.3.2 Tertiary Sedimentary Units

Petaluma Formation

The Petaluma Formation is a Pliocene-aged (approximately 5 million years old) sedimentary unit that was deposited in transitional continental and shallow marine environments. The unit is dominated by more or less consolidated silt or clay-rich mudstone, with local beds and lenses of poorly-sorted sandstone and minor conglomerate beds and has been subdivided into an upper, middle and lower member. The lower member is up to 750 ft thick and is predominantly dense beds of mudstone that have the lowest hydraulic conductivity within the formation. The formation coarsens in the 3,500-ft thick middle and upper parts, in which beds of poorly sorted sands and gravels result in increased hydraulic conductivity. In general, the beds of coarser materials are thin and not of great lateral extent (Nishikawa et al, 2013).

Wilson Grove Formation

The late Miocene to late Pliocene, sandstone-dominated Wilson Grove Formation is exposed in the low hills west of the Subbasin and is also continuous in the subsurface to the east for some distance, where it interfingers with the Petaluma Formation beneath Quaternary Alluvial Deposits and, in the northern Subbasin, the Glen Ellen Formation. The Wilson Grove Formation is relatively thick (300 ft to greater than 1000 ft thick), and mostly composed of weakly cemented marine-deposited sandstone, with volcanic ash intervals. The predominance of relatively clean sand and the low degree of cementation in the Wilson Grove Formation result in moderate to high permeability.

Glen Ellen Formation

The Glen Ellen Formation is also Pliocene- to Pleistocene-aged (approximately 3 to 3.5 million years old) fluvial sedimentary unit deposited along alluvial fans and adjoining flood plains. The unit consists primarily of clay-rich stratified stream deposits of poorly sorted sand, silt, and gravel. Beds of these sediments vary from coarse- to fine-grained, commonly over distances of a few tens to a few hundreds of feet, both laterally and vertically.

3.1.4.3.3 Quaternary Sedimentary Deposits

Quaternary Alluvial Deposits

Quaternary alluvial deposits cover much of the flat eastern and southern 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. The Quaternary alluvial deposits consists of sedimentary deposits that are widespread throughout the Subbasin and contributing watershed, generally in close proximity to and comprising minor aquifers of limited extent along modern streams and beneath alluvial fans. These deposits are dominated by alluvial fan and floodplain deposits eroded from rock exposed in the flanking hills. The deposits generally consist of mixed poorly- to well-sorted sand, silt, clay, gravel, cobbles and boulders, as interfingering, variably thin or thick beds of limited lateral extent (tens to hundreds of feet). Layers in the older alluvium add up to a thickness of about 400 feet and younger alluvium layers are generally less than 150 feet thick (Nishikawa et al, 2013).

3.1.4.4 Lateral and Vertical Extent of Subbasin

The structural setting and distribution of geologic units described above influence the Subbasin extents, which are defined by DWR, as documented in Bulletin 118 (DWR, 2016). The lateral extent and boundaries of the Subbasin are defined as follows:

- The southern boundary of Subbasin coincides with a surface watershed divide between the Laguna de Santa Rosa drainage subbasin and the Petaluma River Watershed. The boundary is also the approximate location of a groundwater flow divide, however no known structural of geologic features restrict flow between the two areas.
- The contact between the topographically higher Sonoma Volcanics and the Petaluma Formation and overlying Quaternary alluvial deposits defines the eastern boundary of the Subbasin from Lichau Creek to just south of Healdsburg, with the exception of a small segment west of Lake Ralphine where Santa Rosa Creek has eroded away the Sonoma Volcanics and the Rincon Valley Subbasin adjoins the Santa Rosa Plain Subbasin.
- The northwestern boundary of the Subbasin follows the contact between the Glen Ellen Formation and Quaternary alluvial deposits of the Russian River Valley within the Healdsburg Area Subbasin.
- The remaining western boundary follows the contact between the Wilson Grove Formation and either the Quaternary alluvial deposits or the Petaluma Formation, with the exception of the City of Sebastopol, where the boundary follows the jurisdictional boundary of the City and extends into a portion of the Wilson Grove Formation.

The base of the Subbasin is not defined based on a transition in geologic materials, such as the Mesozoic Basement rocks that occur at depths exceeding 10,000 feet in some areas. Rather, the vertical extent of the Subbasin is defined based on the approximate depth at which viable water supply aquifers are no longer present. The productive freshwater aquifers generally occur at shallower depths with the deepest wells within the Subbasin extending to approximately 1,500 feet and no existing known water wells extending deeper than 2,000 feet. At depths exceeding approximately 2,000 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 and geothermally-affected waters.

3.1.5 Principal Aquifer Systems and Aquitards

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 <u>each</u> 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

The Cenozoic volcanic and sedimentary units described above form a heterogeneous and continuous body of saturated materials below the water table, where groundwater occurs in pore spaces of the Quaternary alluvial deposits, Glen Ellen, Wilson Grove, and Petaluma Formations, and the Sonoma Volcanics (Nishikawa et al, 2013). The distribution, subsurface extent, and interfingering of these five primary aquifer units reflect the Subbasin's complex geologic history of tectonic deformation concomitant with volcanic activity and sediment deposition in alluvial, lake and estuarine settings.

In order to characterize the aquifer systems within the Santa Rosa Plain for the purpose of implementing SGMA, two principal aquifer systems have been identified based on available data and information: the shallow and deep aquifer systems. This aquifer system characterization is consistent with grouping used for existing monitoring programs (Parker, 2014 and Woodward Curran, 2018) and supported by findings from the USGS studies within the Subbasin (Nishikawa et al, 2013 and Woolfenden, et al, 2014). As further described below, properties and features considered in grouping the shallow and deep aquifer systems into separate aquifer systems include the degree of surface water connectivity, degree of confinement, and responses to hydraulic stresses such as recharge and pumping. Although the deep and shallow aquifer systems are grouped separately, the boundary between the shallow and deep aquifer systems is not intended to represent a distinct boundary to groundwater flow.

The degree of hydraulic separation between the two is variable throughout the Subbasin with some areas, such as where clay aquitard materials between the two aquifer systems are thinner or absent, exhibiting stronger hydraulic communication. The identification of the boundary between the two aquifer systems is further complicated by the complex stratigraphic relationships and high degree of heterogeneity associated with the aquifer units. The appropriateness of the principal aquifer system designation within the Subbasin will continue to be evaluated and considered as more data and information is developed during implementation of the GSP regarding the lateral and vertical characteristics and hydraulic connections between the different aquifer units.

The shallow aquifer system generally extends from the water table to depths ranging from 150 to 200 feet below the ground surface. The shallow aquifer system is present over the entire lateral extent of the Subbasin and primarily occurs within Quaternary alluvial deposits and Glen Ellen Formation. However, in a few limited areas where these units are absent or thin near the margins of the Subbasin, the shallow aquifer system locally occurs within sedimentary units of the Wilson Grove and Petaluma Formations. The shallow aquifer system is generally present under unconfined or semi-confined conditions with semi-confined conditions generally occurring in areas of the shallow aquifer system that exhibit higher proportions of clay and silt units. In some localized and limited areas very shallow and seasonal perched aquifers are present where infiltrating water can perch on very shallow lenses of clay: these are not considered to be part of the shallow aquifer system, as they are not continuous, not tapped for water supply, and likely do not contribute to the baseflow of streams.

Aquifer units beneath the shallow aquifer system are characterized collectively as the deep aquifer system and occur under confined or semi-confined conditions within the Wilson Grove Formation, Petaluma Formation and Sonoma Volcanics. The deep aquifer is generally present beneath approximately 200 feet bgs (i.e., below the shallow aquifer system) and the thickness of individual permeable aquifer zones within the deep aquifer system is highly variable and can range from several feet to hundreds of feet in thickness. In areas where multiple permeable zones occur within the deep aquifer system, these different zones can sometimes exhibit distinct features (eg, distinct water quality signature or appreciable differences in hydraulic head) and can generally be further subdivided into upper and lower aquifers. However, the continuity of these distinct upper and lower portions is not well constrained nor correlative across the Subbasin due, in part, to the limited number of wells and lithologic information for the deep aquifer system. In areas where data is available, distinctions between the upper and lower portions of the deep aquifer system are discussed in this GSP.

Attributes of the shallow and deep aquifer systems which generally correlate throughout the Subbasin and facilitate distinguishing between the two include the following:

- The shallow aquifer system generally is separated from the underlying deep aquifer system by sequences of clay, which form aquitards that predominantly occur in either the lower portions of the Glen Ellen Formation or upper portions of the Petaluma Formation, as evidenced by noted differences in water quality (Nishikawa et al, 2013) and estimated hydraulic properties, such as vertical hydraulic conductivity (Woolfenden, et al, 2014). Hydraulic conductivity is typically 10 to 100 times lower in the vertical direction compared with the horizontal direction due to anisotropic flow conditions typical of layered sedimentary aquifer systems (Heath, 1983). These anisotropic conditions inhibit groundwater flow vertically and cause increasing confinement of groundwater with increasing depth. The separation caused by clay aquitards in the Subbasin is likely less prevalent along the western boundary, where the sand-rich Wilson Grove Formation dominates the subsurface (Nishikawa et al, 2013).

- The shallow aquifer system is generally present under unconfined to semi-confined conditions, while the deep aquifer system is commonly present under semi-confined or confined conditions (Woolfenden et al, 2014).
- The shallow aquifer system generally exhibits stable long-term groundwater levels, while deeper aquifer system wells have exhibited appreciable periods of declining groundwater levels in certain areas of the Subbasin (Parker, 2014 and Sonoma Water, 2017).
- While seasonal fluctuations in groundwater-levels are observed in both the shallow and deep aquifer systems, rapid increases and decreases in groundwater levels within the deep aquifer system appear to correlate closely with groundwater pumping events whereas responses within the shallow aquifer system appear more muted or delayed (Nishikawa et al, 2013).
- In many areas the shallow aquifer system is locally and seasonally connected to streams and surface waters within the Subbasin, while the deep aquifer system is not physically connected with surface waters of the Subbasin and hydraulic communication between the deep aquifer system and surface waters is expected to exhibit a muted and delayed response.
- Differences in groundwater quality between the shallow and deep aquifer zones are common, as indicated in Section 3.1.5.2, below.

Characteristics of the shallow and deep aquifer systems, including individual aquifer unit materials and properties, general water quality and primary uses based on available data and limitations are further described below.

3.1.5.1 Materials and Properties of Primary Aquifer Systems

Aquifer properties include aquifer storage properties (specific yield for unconfined aquifers and storativity or specific storage for confined aquifers) and aquifer transmission properties (hydraulic conductivity and transmissivity). While these properties can be estimated using lithologic texture descriptions from well drillers logs, they are most accurately determined by conducting aquifer tests consisting of pumping a well at a known and controlled rate for a sufficient period of time (typically several days) and observing the groundwater-level response in the pumped well and neighboring observation wells. Very few aquifer tests have been conducted and reported within the Subbasin, therefore the values for these properties are a source of uncertainty.

Shallow Aquifer System Materials and Properties

Materials and properties of the two geologic units that predominantly comprise the shallow aquifer system are described below.

Quaternary Alluvium

Quaternary alluvial deposits which blanket much of the Subbasin predominantly include alluvial fan deposits, stream channel deposits, older alluvium, and basin deposits (Wagner and Gutierrez, 2017). The generally coarse-grained alluvial fan and stream channel deposits, and their close proximity to modern streams, allow for rapid recharge of precipitation and runoff to the groundwater system and exchanges between groundwater and surface water. The composition of the older alluvium is variable, consisting of a mixture of fine- and coarse-grained sediments. The basin deposits which primarily occur within the southern portions of the Subbasin are finer grained and exhibit low permeability. Groundwater is unconfined in most places within the alluvial deposits, but semi-confined conditions exist in areas with higher proportions of clay or silt (Nishikawa et al, 2013). .

The Quaternary alluvial deposits provide some water to shallow wells and contribute part of the water to deeper wells that also draw from underlying formations. Within the Subbasin and contributing watershed, yields from wells that are completed only in alluvial deposits ranged from 1 to 650 gpm. The highest well yields are in the northern Subbasin near Mark West Creek (Nishikawa et al, 2013). The alluvial deposits are generally poorly sorted and, locally, contain large fractions of clay resulting in a range of specific yields (the amount of water a saturated aquifer will yield by gravity – or what is available to wells) between 8 and 17 percent. Hydraulic conductivity values from the two available aquifer tests range from 2 to about 51 feet per day (ft/d), and storativity values range from about 0.0013 to 0.19. The large range of hydraulic properties is consistent with the lithologic heterogeneity and varying degree of confinement of the alluvial deposits (Nishikawa et al, 2013; Parker Groundwater, 2014).

Glen Ellen Formation

The relatively high content of clay-sized material, degree of compaction, and cementation tend to limit the permeability of the Glen Ellen. Within the Subbasin, the Glen Ellen Formation ranges from tens of feet to several hundred feet thick (Sweetkind, 2010). Where sufficiently thick, the Glen Ellen Formation includes some beds of moderately- to well-sorted, coarse-grained materials that have high permeability and yield appreciable amounts of water to wells. . . Most wells in which the Glen Ellen Formation is the principal water-bearing unit will produce between 15 to 30 gpm. The specific yield and hydraulic conductivity of the Glen Ellen Formation has been estimated to range from 3 to 7 percent and 13-23 ft/day, respectively (Nishikawa et al, 2013; Parker Groundwater, 2014).

Deep Aquifer System Materials and Properties

Materials and properties of the three geologic units that comprise the predominantly deep aquifer system are described below.

Wilson Grove Formation

Within the Subbasin and contributing watershed, most wells screened partially or totally in the Wilson Grove Formation are within the upper stratigraphic horizons, which are coarser grained and more permeable than deep deposits to the west. Domestic wells drilled into the Wilson Grove Formation yield on average about 20 gpm. Large capacity and municipal wells can yield up to 1,000 gpm or more. Wells drawing from the upper part of the Wilson Grove Formation have estimated specific yields in the range of 10 to 20 percent, higher than any of the other rocks or sediments in the Subbasin. Estimates of hydraulic conductivity and storativity from aquifer tests conducted in 11 wells in the western portions of the Subbasin range from 3 to 65 ft/d and 0.00095 to 0.08, respectively.

Petaluma Formation

The productivity of wells drilled in the Petaluma Formation depends mostly on the total thickness of the thin, poorly sorted beds of sand and gravel perforated by the well. In general, the upper member of the Petaluma Formation is the most productive. The Petaluma Formation is considered at least 3,000 ft thick in places within the Subbasin and, even though the formation is dominated by clay, thin, moderately to poorly sorted beds of sands and gravels can be encountered in sufficient quantity by deeper wells that yields greater than 100 gpm are possible.

Domestic wells drilled into the Petaluma Formation yield an average of about 20 gpm and range from 10 to 50 gpm. However, areas of coarser grained materials provide higher yields, for example, in the Rohnert Park area municipal wells drawing predominantly from the Petaluma Formation have produced as much as 500 gpm. Specific yields are typically low in the Petaluma Formation, ranging from 3 to 7 percent. Estimates of transmissivity based on specific capacities of Rohnert Park municipal wells range from 130 to 1,600 ft^2/d.
Due to the large amount of silt- and clay-sized particles, the specific yields of wells completed in the Petaluma Formation are generally low, varying from 3 to 7 percent (Nishikawa et al, 2013; Parker Groundwater, 2014).

Sonoma Volcanics

The Sonoma Volcanics exhibit a large variation in water-bearing properties, with a mixture of fractured lava beds, unwelded tuffs and interbedded volcaniclastic 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. This formation has the highest variability in water-bearing properties in the Santa Rosa Plain.

Water production from wells drilled into thick air-fall pumice units can exceed a few hundred gpm, but wells drilled into unfractured lavas or welded tuffs can produce less than 10 gpm, and dry holes are sometimes encountered. For wells penetrating the Sonoma Volcanics, previous studies suggest a range of well yields between 10 and 50 gpm; however, some of the wells penetrate more than one formation, and the relative contributions are unknown. The specific yield of the Sonoma Volcanics has been reported to be in the range of 0 to 15 percent and transmissivity has been estimated to range from 0.8 to 5,300 ft2/d. (Nishikawa et al, 2013; Parker Groundwater, 2014).

3.1.5.2 General Water Quality Characteristics

Groundwater quality is highly variable throughout the study area and is generally acceptable for beneficial uses, although constituents of potential concern pose challenges on a localized basis within the study area. Specific conductance, chloride, total dissolved solids, nitrate, arsenic are considered water quality constituents of potential concern in the Subbasin and contributing watershed because some samples from wells exceeded state or federal recommended or mandatory regulatory standards for drinking water. In general groundwater within the Subbasin is of mixed cation-bicarbonate type with median dissolved solids concentrations of approximately 350 milligrams per liter. Some distinctions between shallow and deeper aquifer system water quality includes:

- Water samples from wells completed within the shallow aquifer system generally exhibit greater proportions of calcium and magnesium, while deep zone samples exhibit greater proportions of sodium and potassium, which is consistent with increasing mineralization and ion exchange between clays and groundwater with increasing distance and depth from recharge sources (Nishikawa, 2013). typically isotopically heavier in comparison with the deep zone and anthropogenic constituents, such as nitrate and tritium are more commonly found in the shallow aquifer system in comparison to the deep aquifer system.
- As determined by carbon 14 dating or the presence of tritium, the shallow and deep aquifers exhibit different groundwater ages, with the deep well samples all exhibiting water ages of 4,000 years or older and the shallow aquifer generally containing waters recharged within the last 50 years (Nishikawa et al, 2013).

Further data and discussion of groundwater quality conditions and trends are included in Section 3.2.

3.1.5.3 Aquifer System Primary Uses

The shallow aquifer system serves a number of different users and uses with the primary extractions being from domestic water supply wells which provide water to rural residential properties in the unincorporated areas of the Subbasin. In some areas agricultural and public water supply wells are also completed either completely or partially within the shallow aquifer system. The shallow aquifer system is a primary source of recharge to the deep aquifer system and also provides a significant amount of baseflow to many of the streams within the Subbasin which contributes to streamflow and provides benefits to ecosystems in the Subbasin. 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 aquifer system provides water for vegetation communities in the Subbasin.

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

3.1.5.4 Aquitards

Aquitards composed of clay deposits commonly separate the shallow and deep aquifer systems and serve to locally confine the deeper aquifer system to varying degrees causing semi-confined and confined conditions. Clay aquitards are common within some portions of the Quaternary alluvial deposits, such as the basin deposits within the southern portions of the Subbasin, the Glen Ellen Formation, and Petaluma Formation and serve to confine more permeable sand and gravel aquifer zones within the Wilson Grove and Petaluma Formations of the deep aquifer system. Due to the complicated interfingering stratigraphic relations of the Petaluma Formation with the Wilson Grove Formation and Sonoma Volcanics, some wells can pass from one formation into another more than once. The interfingering of the three formations can also place relatively impermeable lavas or clay beds above more permeable sand or gravel beds, producing confined groundwater conditions (Nishikawa et al, 2013). 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 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, which can affect localized groundwater flow regimes.

Faults in the Subbasin and contributing watershed serve as major structural boundaries for geologic formation and groundwater movement. Faults have also played a major role in the geometry of the basin with the formation the Windsor and Cotati structural troughs, separated by the Trenton Ridge Fault. Major faults, which are present along or near the boundaries of the Subbasin include the Rodgers Creek-Healdsburg Fault Zone, along the eastern boundary and the Sebastopol Fault, along the western boundary. The Trenton Ridge Fault and two unnamed faults present in the southern portions of the basin are the main mapped faults located within the interior of the Subbasin, (**Figure 3-4**). The Rogers Creek Fault appears to act as a barrier to groundwater flow and also creates groundwater upflow or mixing along part of its length. The Sebastopol Fault appears to limit the lateral groundwater movement to the east. To the east of the Sebastopol Fault, an unnamed fault is at least a partial barrier to groundwater flow and appears to create upflow or mixing along part of its length (Nishikawa et al, 2013).

The alignments of thermal springs and wells (affected by volcanic heat sources), along and near Subbasin and contributing watershed valley-bounding faults, indicate that some faults enable deep waters to move upward to the surface or into shallow formations. West of the Rogers Creek Fault, and directly downgradient (in the groundwater flow direction), groundwater compositions change from characteristics typical of recent rainfall replenishment to those of hydrothermal or connate water (water included during accumulation of the rock or sediment materials). These changes suggest that the fault orientation and activity may be directing groundwater downward and causing deep mixing of older and more recently replenished waters. The Sebastopol Fault may be acting as a barrier to shallow flow, but does not appear to impede flow at greater depths.

3.1.7 Natural Groundwater Recharge and Discharge

Groundwater Recharge

The principal sources of recharge to groundwater systems within the Subbasin and contributing watershed are direct infiltration of precipitation and infiltration from streams. Minor sources of recharge include infiltration from septic tanks, leaking water-supply pipes, leaking storm drain pipes, irrigation water in excess of crop requirements, and crop frost-protection applications. The shallow aquifer system receives most of this recharge. Recharge that reaches the deeper aquifer zones is more poorly defined and likely comes from a combination of leakage from overlying shallow aquifers and mountain front recharge along the margins of the valley. The amount of groundwater recharge and discharge is estimated a number of ways through direct measurement, approximation incorporating some literature-based variables, and with the use of the groundwater model.

Previous estimates of groundwater recharge in the Santa Rosa Plain have primarily included qualitative assessments. Natural recharge potential mapping of the Subbasin and contributing watershed was conducted that incorporates soil permeability, slope, and shallow geologic unit permeability (0 to 50 ft bgs) (Winzler & Kelly GHD, 2012). The weighting of each parameter – slope (20%), soil (30%), and geology (50%)- is generally based on other similar studies and guidance (Sesser et al., 2011; DWR, 1982; and Muir and Johnson, 1979) and sensitivity analysis. The natural recharge potential map (**Figure 3-6**) ranks the very high to very low relative potential for natural groundwater recharge from rainfall infiltration. The term recharge potential is used because the actual recharge rate also depends on other factors such as the distribution of precipitation, the locations of streams and other surface water bodies, and the connection to deeper aquifers (which were not incorporated into that study). Areas showing a higher recharge potential using this desktop approach are generally located within the flatter areas of the Glen Ellen Formation and the areas underlain by the Wilson Grove Formation. Potential constraints or limitations that are not directly incorporated into the analysis include the presence of shallow or perched groundwater, natural springs, and existing groundwater quality.

Groundwater Discharge

Groundwater discharge occurs in the Subbasin 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 discharges occur where groundwater levels are higher than either the land surface or surface water surface in stream channels. Groundwater discharge appears as stream baseflow (gaining streams) and as the source of Laguna de Santa Rosa wetlands, discharge from springs, evapotranspiration from phreatophytes, and groundwater pumpage.

Based on USGS' National Hydrography Dataset and National Water Information System, there are 28 mapped springs and seeps in the Subbasin and contributing watershed, as shown on **Figure 3-7**. On the west side, groundwater discharges from the Wilson Grove Formation through springs and seeps, and on the east side discharge is from the Sonoma Volcanics and Glen Ellen formation.

3.1.8 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 Sonoma Valley Subbasin 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 Subbasin and limited high quality subsurface lithologic data limits the understanding of the lateral and vertical continuity and properties of aquifers and aquitards in the Subbasin. Developing the following information would improve our understanding of aquifers and aquitards:

- Filling three-dimensional data gaps in the monitoring network for each primary aquifer in the Subbasin. 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 Subbasin, with a focus on the role of the Sebastopol Fault, Trenton Fault and Unnamed Fault. 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 Subbasin boundaries, including boundaries between the Subbasin and adjoining groundwater basins and boundaries between the Subbasin 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.

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

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

- 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.
- Conducting geochemical or tracer studies, which 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 Subbasin.

3.2 Current and Historical Groundwater Conditions

This subsection describes the current and historical groundwater conditions within the Subbasin 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 Subbasin 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 Subbasin 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 broad variety of microclimates.

The Mediterranean climate in the Subbasin 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 93 percent of the annual precipitation normally falls during the wet season (October to May), with a large percentage of the rainfall typically occurring during three or four major winter storms. Precipitation is highly 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 3-8a**).

Mean annual precipitation in the Santa Rosa Plain has been assessed using both observed data from Climate Station Santa Rosa (USC00047965), which is located in downtown Santa Rosa at an elevation of 51 ft (NGVD 29), as well as yearly averages calculated using the PRISM model for the Subbasin and contributing watershed area. The Santa Rosa station has operated from 1903 to present, with periods of missing and incomplete records. Records for this stations are stored on the U.S. Historical Climatology Network Water until the year 2010, and monthly data is stored within the California Data Exchange Center as SRO. The yearly averaged precipitation measured from this station from 1903 through water year 2018 is 29.3 inches, compared with 33.3 inches, as calculated by the PRISM model, as shown on **Figure 3-8b**. 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 Santa Rosa 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 Santa Rosa station and the PRISM data were aggregated by water year (**Figure 3-8c**). Nearby stations in Bodega Bay, Petaluma and Sonoma are included to verify that historical PRISM output compare reasonably when Santa Rosa station data are absent. There are 18 wet years in the period from 1950 to 2018, and 13 dry years in the same period (Table 3-1). The 1990's is the decade with the most dry years, five dry years, whereas the 1970's, 1980's and 1990's have

4 or more wet years. In the same period, two years in the 1970's (1977 and 1976) had the first and second lowest yearly precipitation. 1983, 2017 and 1998 had the highest yearly precipitation in the same period, with totals about 4 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.

Future climate change projections will be described in the Water Budget Section (3.3)

3.2.2 Groundwater Elevations and Trends

Changing patterns of land use, surface water and groundwater use, as well as climate changes, can cause changes in groundwater levels and movement directions. This section describes current and historical groundwater elevation conditions and trends based on available data from the monitoring programs described in Section 2.4. While records for some wells extend back to the 1950s, the majority of available groundwater-level data is from the last ten to fifteen years. Data presented and evaluated as part of this section includes:

- Historical groundwater-level contour maps (**Figure 3-9a-b**)
- Recent groundwater-level contour maps for each principal aquifer (**Figures 3-10a-b**)
- Long-term groundwater-level hydrographs (**Figures 3-11a-e**)
- Groundwater-level trend maps (**Figure 3-12a-b**)
- Short-term groundwater-level hydrographs (**Figures 3-13b-i**)

Groundwater-Level Contour Maps

Historical groundwater-elevation contour maps of groundwater-levels in the Subbasin and contributing watershed (**Figure 3-9a**) show overall groundwater flow directions and trends for selected seasons between 1951 through 2007. The contours presented on these maps, which are provided to present overall patterns, do not distinguish between wells completed in the shallow and deep aquifer systems and are considered composites of both principal aquifer systems. **Figure 3-9a** shows that the dominant direction of groundwater flow in the spring of 1951 was from the east toward the west side in the northern part of the Subbasin, and from the east towards the Laguna Santa Rosa in the southern portion of the basin. The influence of Mark West and Santa Rosa Creeks also appear as upstream deflections in the contours, indicating segments of these watercourses were likely being fed from groundwater discharge (gaining stream condition) at that time.

Groundwater-elevation contours for 1990 (**Figure 3-9a**) show the two most significant changes in groundwater levels included: (1) a decline of groundwater levels in the Rohnert Park-Cotati area with groundwater level declines exceeding 100 feet in this area; and (2) approximately 20 feet of groundwater level decline west of the City of Santa Rosa. The substantial declines in the southern portions of the Subbasin are primarily attributed to increases in municipal groundwater pumping associated with population growth through the 1980s and 1990s.

Groundwater-elevation contours for 2007 (**Figure 3-9a**) show higher water levels in the Rohnert Park-Cotati area and a reduced pumping depression. These changes coincided with a significant pumping reduction at City of Rohnert Park wells (**Figure 3-9b**), primarily due to increased imports of Russian River water provided by the Water Agency, as well as increased conservation and recycled water use. The reduction of the 1990s groundwater depression suggests that reduced pumping in the Rohnert Park-Cotati area allowed groundwater levels to recover to elevations typical of the early 1970s.

More recent groundwater-elevation contour maps prepared for the GMP and for this GSP separate shallow aquifer system and deeper aquifer system wells in order to contour the two principal aquifer systems separately. Groundwater-elevation contour maps for 2015 are provided in **Figures 3-10a and 3-10b** and indicate that groundwater in the Subbasin generally flows westward from recharge areas in the highlands (Sonoma and Mayacamas Mountains) to the east, toward the Laguna De Santa Rosa, the primary discharge area, on the west. From the south end of the valley, groundwater flows northwesterly toward the Laguna De Santa Rosa. Comparison between the shallow and deep aquifer system groundwater-elevation contour maps indicates that groundwater elevations in the deeper zone aquifers are approximately 10 to 40 feet lower than groundwater elevations in the shallow aquifer system in portions of the Santa Rosa Plain. Comparing these recent measurements with the historical contour maps described above suggest two groundwater pumping depressions in the southern and western portions of the Santa Rosa Plain have continued to exhibit recovery of groundwater levels.

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 the Subbasin). 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

Changes in groundwater levels were evaluated for both long-term trends and short-term (e.g., seasonal) trends using data collected from the monitoring program. In general, longer term trends were evaluated using data collected on a monthly to semiannual bases and short-term trends were evaluated using data collected on a more frequent basis (e.g., monthly to hourly or less) using data from wells instrumented with pressure transducers.

Long-Term Trends

Representative hydrographs showing a select number of well hydrographs distributed throughout the Subbasin are provided in **Figures 3-11a through 3-11d** (note: these are in the process of being updated to 2019 with wet and dry cycles added – overall trends remain the same). Additionally, hydrographs for all wells included in the groundwater-level monitoring program are provided in Appendix A. These hydrographs present the change in groundwater elevation (vertical axis in feet) over time (horizontal axis in years).

As indicated on **Figures 3-11a through 3-11d**, nearly all of the hydrographs indicate relatively stable groundwater-level conditions over time with the exception of wells within the southern portions of the Subbasin. As shown on **Figure 3-11a**, a few hydrographs show a decline in groundwater levels for the late 1970's and 1980's, which reached a maximum in the early 1990's followed by recovery in the early 2000's. As described above the historical groundwater declines in this area are primarily associated with increases in municipal groundwater pumping related to population growth through the 1990's coupled with droughts in 1976-77 and 1987-92 and the recovered groundwater levels coincide with the aforementioned reduced pumping in this area since the early 2000's.

Recent Trends

To help assess recent trends from the larger group of hydrographs included in Appendix A, trend lines have been added to the records for a subset these wells. To calculate the trend lines, well elevation measurements were first divided into spring and fall records for each year; the averages of these measurements are then the average spring and fall measurement for each year. Depending upon available data, 5-year or 10-year groundwater elevation trends were calculated using the average spring groundwater elevations. The slope of the trend lines then was computed using the method of ordinary least squares linear regression to estimate the change in groundwater level in feet per year.

These calculated groundwater-level trends display the average groundwater level change per year in feet at selected wells in **Figure 3-12a** for the shallow aquifer system, and in **Figure 3-12b** for the deep aquifer system. One of two time periods was used for each well displayed, 2005 to 2015 or 2010 to 2015, depending upon the groundwater level monitoring data available. The larger colored dots with thicker outline represent the longer 10-year period, and the smaller dots represent a five year time period.

As illustrated on **Figure 3-12a**, most of the shallow zone wells (45 of 64 wells) exhibit relatively table groundwater level trends (change of less than + 0.5 feet per year). Nine of the 45 wells show declining trends of 0.5 to 1.0 feet per year, one well exhibited a declining trend of 1.0 to 2.0 feet per year. Increasing trends of 0.50 to more than 2.75 feet per year are observed in nine wells located mostly along or outside of the western margins of the Subbasin and within the contributing watershed area of the Wilson Grove Formation Highlands Basin.

Figure 3-12b shows that groundwater level trend data are more limited in the deeper-zone wells (a total of 24 wells is included in the trend analysis). Eight of the 24 wells indicate declining trends of 0.5 to more than 2.0 feet per year; eight wells exhibit increasing trends of 0.5 to greater than 2.0 feet per year; and eight wells show relatively stable groundwater level trends.

Short-Term Trends

A number of production and monitoring wells within the Subbasin have been outfitted with pressure transducer dataloggers in order to assess short-term groundwater-level trends. These include monitoring wells in the vicinity of Sonoma Water production wells along the western edge of the Subbasin, a series of shallow monitoring wells along Copeland Creek in the southeastern corner of the Subbasin, City of Santa Rosa production wells (active and inactive), test wells and monitoring wells located throughout and adjacent to the Subbasin, and several inactive City of Rohnert Park production wells. The locations of high-frequency groundwater-level monitoring points are shown on **Figure 3-13a**.

City of Rohnert Park Wells

Four City of Rohnert Park inactive production wells (Wells 17, 24, 26, and 38) are currently monitored via pressure transducer dataloggers. Groundwater-level hydrographs for these wells are presented on **Figure 3-13b**. Prior to 2006, groundwater-level elevations measured in the Rohnert Park wells were significantly lower than they are today. From 2006 to present, groundwater-level elevations have been relatively stable in the Rohnert Park wells, with exception of a decline of approximately 20 feet in Well 24 since approximately 2013. Since 2006, seasonal groundwater-level fluctuations range from approximately 5 to 30 feet and are most pronounced in Wells 17 and 38, and least pronounced in Well 26. Seasonal high groundwater levels are typically observed in March to June and Seasonal low groundwater levels are typically observed in September to November in these wells.

City of Santa Rosa Wells

The City of Santa Rosa maintains a network of high-frequency groundwater-level monitoring points with the frequency of water-level data collection ranging from monthly to once every six hours. This network includes six active or emergency/standby municipal production wells (Farmers Lane No. 1, Farmers Lane No. 2, Farmers Lane No. 3, Leete Well, Carley Well, and Peter Springs Well). All of these wells are over 200 feet deep with the exception of the Peter Springs Well which is 160 feet deep. Farmers Lane No. 1 and Farmers Lane No. 2 are both over 1,000 feet deep. Groundwater-level hydrographs for these wells are presented on **Figure 3-13c**. As shown in **Figure 3-13c**, these wells are all located along the eastern edge of the Subbasin (east of the Rodgers Creek Fault Zone), with the Leete Well located outside of the Subbasin, but within the contributing watershed area. In general, non-pumping groundwater levels are very stable in these wells with artesian conditions present in the Farmers Lane No. 1, Farmers Lane No. 2, and Leete wells. Seasonal groundwater-level fluctuations range from approximately 20 to 30 feet in the Farmers Lane No. 3, Carley, and Peter Springs Wells. Drawdown related to seasonal pumping of Farmers Lane Nos. 1 and 2 are also evident in the hydrographs for those two wells, in addition to the nearby Farmers Lane No. 3.

Groundwater-level hydrographs for five City of Santa Rosa shallow (total depths ranging from 82 to 200 feet) high-frequency groundwater-level monitoring points are shown on **Figure 3-13d**. The Patio, Doyle, and Hoen Wells are all in the vicinity of the Farmers Lane production wells on the eastern edge of the Subbasin. These wells exhibit seasonal groundwater-level fluctuations ranging from approximately 5 to 25 feet, which are most pronounced in the Patio Well and least pronounced in the Doyle Well. The Helman Ave. Well is located in the southern portion of the Subbasin, near the City of Cotati and the Hurlbut Rd. Well is located just outside of the Subbasin, north of the City of Sebastopol. Groundwater-level data from these wells do not exhibit pronounced seasonal fluctuations or responses to precipitation events. Occasional short-term declines, likely associated with local groundwater pumping, followed by subsequent recovery to relatively stable conditions are observed in both wells.

Groundwater-level hydrographs for six City of Santa Rosa deep (between 200 and 500 feet deep) high-frequency groundwater-level monitoring points are shown on **Figure 3-13e**. The Northwest Village and Sharon Park Test Wells are located in northwest Santa Rosa and exhibit similar hydrographs with stable groundwater-level elevations and seasonal fluctuations of approximately 10 feet. The Madrone and Brigadoon Test Wells are located outside of the Subbasin, in eastern Santa Rosa and exhibit similar hydrographs with seasonal groundwater-level fluctuations ranging from approximately 5 to 20 feet. The Galvin test well is located on the eastern edge of the Subbasin, near Bennett Valley and exhibits larger seasonal groundwater-level fluctuations up to approximately 50 feet. The Irwin Dr. Well is located in the central-western portion of the Subbasin, approaching the City of Sebastopol and exhibits seasonal groundwater-level declines, possibly related to local groundwater pumping, of up to 45 feet. The overall groundwater-level elevation trends for all of these wells during their respective observation periods appear to be very stable.

Groundwater-level hydrographs for six City of Santa Rosa deep (greater than 500 feet deep) high-frequency groundwater-level monitoring points are shown on **Figure 3-13f**. The Slater and Martha Way Wells are located on the eastern edge of the Subbasin, in the vicinity of the Farmers Lane and Peter Springs production wells. The hydrographs for these wells are nearly identical and depict seasonal groundwater-level fluctuations of approximately 20 to 25 feet. From east to west, the Freeway, Northwest Community Park, and Place 2 Play Wells are located from the 101 Freeway, progressively closer to the center of the Subbasin. Seasonal groundwater-level fluctuations in these wells range from approximately 5 to 15 feet and are most pronounced in the Freeway and Northwest Community Park Wells and least pronounced in the Place 2 Play wells. The hydrographs for these wells illustrate how seasonal fluctuations in the deep aquifer system are likely less pronounced and happen later (seasonal high groundwater levels are typically observed in April in the Freeway Well and in May in the Place 2 Play Well) towards the center of the Subbasin versus towards the eastern edge. The River Rd. #2 Well is located in the northern-central portion of the Subbasin near Mark West Creek. The groundwater-level hydrograph for this well exhibits seasonal fluctuations ranging from approximately 5 to 10 feet with seasonal high elevations typically observed in April to June and seasonal low elevations typically observed in August to September. The overall groundwater-level elevation trends for all of these wells during their respective observation periods appear to be very stable.

Sonoma Water Monitoring Wells

Sonoma Water conducts a high-frequency groundwater-level monitoring program in dedicated monitoring wells in the vicinity of its Occidental Road, Todd Road, and Sebastopol water supply wells. The groundwater supply wells are located along the Water Agency's aqueduct on the western edge of the Subbasin. Currently, 14 monitoring wells are instrumented with pressure transducer dataloggers (locations shown on **Figure 3-13a**), which record groundwater elevation data at intervals ranging from every 1 to 4 hours. Groundwater-level hydrographs for shallow and deep monitoring wells in the vicinity of the Sonoma Water's supply wells are presented on **Figures 3-13g and 3-13h**, respectively. In general, the data collected as part of the Sonoma Water's groundwater-level monitoring program document:

- normal seasonal fluctuations in groundwater levels on the order of 5 to 15 feet in the shallow wells;
- rapid drawdown and recovery in response to pumping cycles within the deeper monitoring wells perforated across the same horizon as the groundwater supply wells;
- no discernable short-term responses to pumping cycles within shallower monitoring wells;
- an overall trend of lowering of deeper zone groundwater levels between approximately 2000 and 2009 when the groundwater supply wells were operating relatively continuously followed by subsequent recovery of groundwater levels from 2009 to present; and
- general stability of shallow zone groundwater levels, with the exception of shallow zone monitoring wells located near the Occidental Road supply well (OCC-MW-2, OCC-MW-3, and OCC-MW-5) which exhibited declines ranging between 15 to 30 feet between approximately 2000 and 2009 followed by subsequent recovery or stabilization of groundwater levels from 2009 to present.

Copeland Creek Monitoring Wells

Sonoma Water conducts a high-frequency groundwater-level monitoring program in a series of shallow monitoring wells in the vicinity of Copeland Creek, in the southeast corner of the Subbasin (**Figure 3-13i**). Groundwater-level hydrographs for select monitoring wells in this area are shown on **Figure 3-13j**. Monitoring wells A-1, A-2, A-4, B-2, and C-5 range in total depth from 24 to 35 feet. Data collected from these wells from 2014 to present indicate the following:

- seasonal fluctuations in the Copeland Creek shallow monitoring wells range from approximately 10 to 25 feet;
- groundwater levels in the monitoring wells respond rapidly to precipitation events and changes in streamflow in Copeland Creek; and
- the timing of seasonal high and seasonal low groundwater levels is highly variable with seasonal high levels observed from December to April, and seasonal low levels observed from August to December.

3.2.3 Estimated Changes in Groundwater Storage

Under development – will be assessed as part of water budget development.

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 SRP 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 Santa Rosa Plain Subbasin (**Figure 3-14a**). This station (SRP0496; P197) has been actively monitored since 2006 and results are shown in **Figure 3-14b**.

From late 2005 to 2019 the GPS station in the Santa Rosa Plain has shown vertical changes of +0.1 inches (**Figure 3-14b**). From 2015 to 2019 the vertical change for the station is 0.01 inches, with yearly changes of +0.003 inches per year. The positive ground height changes observed in Santa Rosa stand in contrast to other nearby stations. The other stations in Bodega Bay, Marin, Napa, and in the Russian River areas exhibit longterm declines in ground height. Regional interannual variation in hydrologic isostatic loading is likely the best explanation for the observed regional trends. As described in Section 3.2.2, reductions in municipal groundwater pumping beginning in 2002 have resulted in significant recovery of groundwater levels in the Rohnert Park-Cotati area and is likely the cause of the rebound in ground-heights observed in SRP0496 GPS data.

Two studies conducted to assess the Rodgers Creek fault for evidence of creep have revealed potential evidence of land surface subsidence and subsequent uplift in the southern portions of the Subasin related to groundwater pumping patterns (Funning et. al., 2007 and Jin and Funning, 2017). The studies used Permanent Scattering Interferometric Synthetic Aperture Radar (PS-InSAR) technique from satellite data from 1992-2001 and from 2003 to 2010 to analyze the area for land surface deformation related to fault movements (**Figure 3-14c and 3-13d**, respectively). 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 surface subsidence due to groundwater pumping, the fault studies identified an area in the southern portions of the Subbasin where the ground surface subsided and subsequently rebounded coinciding with an area of groundwater-level declines and subsequent recovery. As shown on **Figure 3-14c**, during the 1992 to 2001 timeframe ground surface elevations declined at a rate of about 6 mm (0.2 inches) per year over the ten year study period in the vicinity of Rohnert Park and Cotati (Funning, et al, 2007)**.** This timeframe coincides with the previously described period of increased municipal groundwater pumping and groundwater-level declines in the same area. During the subsequent study period of 2003 to 2010, the ground surface elevations in the same area exhibited an uplift (or rebound) of approximately 6 mm (0.2 inches) per year over the eight years, as shown on **Figure 3-14d** (Jin and Funning, 2017), coinciding with the period of reduced municipal groundwater pumping and increasing groundwater levels. The subsequent rebound of the land surface following the reduction in groundwater pumping and recovery of groundwater levels provides evidence that the relatively minor historical land surface subsidence in this area represents elastic land surface subsidence, which has not caused permanent (or inelastic) collapse of fine-grained units within the aquifer system.

Recent spatial variation of ground surface change (albeit with a lower level of vertical resolution) within the Subbasin is shown in **Figure 3-14e**. This dataset has been 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.

3.2.5 Groundwater Quality Conditions and Trends

Groundwater quality sampling has been performed throughout the Subbasin 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 2013 study
- 2013 Salt and Nutrient Management Plan (RMC, 2014)
- Data from regulated public water supply system sampling
- Regulated contaminant sites

Groundwater quality is highly variable throughout the Subbasin and contributing watershed area and is generally acceptable for beneficial uses, although some constituents pose challenges on a localized basis within the study area. Localized areas of poor groundwater quality within the Subbasin and contributing watershed areas are primarily related to the following potential sources of impairment: (1) anthropogenic inputs associated with certain land use activities (e.g., industrial, agricultural, or urban land uses; (2) deep connate waters associated with ancient seawater entrapped during deposition of Tertiary Era sedimentary units; and (3) hydrothermal fluids associated with portions of the Sonoma Volcanics and/or fault zones.

The following sections describe general groundwater quality characteristics and the occurrence and distribution of naturally occurring and anthropogenic constituents of interest. This section also includes a discussion of special focus parameters, including stable isotopes and trace elements used for age-dating and tracers to provide insights on groundwater movement. Summary results are provided for general minerals major-ion data, total dissolved solids and specific conductance, and arsenic, nitrate, and chloride, which are constituents that have been identified as constituents of interest in previous studies within the Subbasin and/or serve as indicators for thermal or deep connate groundwater. All these constituents of interest occur naturally in groundwater systems, although nitrate also tends to be strongly associated with land use practices. Other anthropogenic constituents associated with land use practices, such as releases of fuel hydrocarbons and solvents, also occur in localized areas.

Much of the data summarized below is from public drinking water systems that provide treatment to remove these and other constituents of potential concern to levels below applicable regulatory standards. The concentrations presented for these wells are prior to such treatment, so as to allow for a characterization of native (or ambient) groundwater quality conditions. Additionally, since much of the data comes from public supply wells that typically are completed in deeper aquifer zones, the data largely represents deeper aquifer zones. Therefore, the data may not adequately represent the water quality of the more shallow aquifers being accessed by most domestic wells.

3.2.5.1 General Groundwater Quality Characteristics

Major ion concentrations and stable isotopes were used to help classify and characterize the groundwater quality within the Subbasin and contributing watershed areas.

Major-Ion Concentrations

Major ion concentrations are assessed by evaluating relative proportions of common ions and anions and are used to group and classify by a water type. These data can help indicate groundwater flowpaths and interconnection with surface water. The major-ion composition of groundwater is controlled by the natural chemistry of the recharge water, geochemical reactions in the subsurface and anthropogenic factors. As groundwater flows through the subsurface, it assumes a characteristic chemical composition as a result of interaction with the aquifer matrix (solid) materials and length of time in the subsurface. Typically, the longer the groundwater flows along a pathway following the hydraulic gradient (groundwater flowpath) in contact with and flowing through the aquifer matric materials, the higher the dissolved solids concentrations and major constituent concentrations. This helps explain why it is common to find higher dissolved solids concentrations in groundwater with depth. Most groundwater in the Subbasin is bicarbonate type water and range from sodium-potassium type water to calcium-magnesium type water.

General groundwater characteristics have been classified on the basis of groundwater quality data analyses by area (Nishikawa et al, 2013). The following summarizes the general groundwater classification of the five hydrogeologic subareas:

1. Eastern upland areas (generally east of the Rodgers Creek Fault)
    - Mixed cation-bicarbonate and calcium/magnesium bicarbonate type
    - Mean dissolved solids concentration of 330 mg/L

2. Rincon/Bennett Valley areas (east of the Rodgers Creek Fault)
    - Dominantly contains mixed cation-bicarbonate type groundwater with relatively higher sodium
    - Median dissolved solids concentration of 392 mg/L

3. Northern portions of Subbasin (north of Trenton Fault)
    - Dominantly a mixed cation-bicarbonate and sodium-bicarbonate type groundwater
    - Median dissolved solids concentration of 321 mg/L

4. Southern portions of the Subbasin (south of the Trenton Fault)
    - Mixed cation-bicarbonate and sodium-bicarbonate type groundwater
    - Median dissolved solids concentration of 362 mg/L

5. Western margins of Subbasin and contributing water shed area (primarily Wilson Grove Formation)
    - Calcium-bicarbonate and mixed cation-bicarbonate type groundwater
    - Dissolved solids concentrations less than 300 mg/L

Additionally, water samples from wells completed within the shallow aquifer system generally exhibit greater proportions of calcium and magnesium, while deep zone samples exhibit greater proportions of sodium and potassium, which is consistent with increasing mineralization and ion exchange between clays and groundwater with increasing distance and depth from recharge sources (Nishikawa, 2013).

Age-dating constituents and isotopic tracers

Stable environmental isotopes are measured as the ratio of the two most abundant isotope types of a given element, and in hydrologic studies, oxygen and hydrogen are used commonly. For oxygen it is the ratio of Oxygen-18 (^{18}O) to Oxygen-16 (^{16}O), and for hydrogen, it is the ratio of deuterium (^{2}H or D) to hydrogen (^{1}H). These data provide information on the potential source, evaporative history, and movement of water. Water that condensed at cooler temperatures (precipitation that condenses at higher altitudes, cooler climatic regimes, or higher latitudes) tends to be isotopically lighter than precipitation that condenses at higher temperatures (precipitation that condenses at lower altitudes, warmer climatic regimes, and lower latitudes) (Muir and Coplen, 1981). Water that has been partially evaporated is enriched in the heavier (less negative) isotopes; these values plot to the right of the meteoric water line, along a line known as the evaporative-trend line. Results from the stable isotope analyses suggest that groundwater recharge in the Subbasin is primarily from infiltration of precipitation and the infiltration of seepage from water courses.

Isotopic values of groundwater samples collected within the Subbasin generally plotted slightly below the global meteoric water line (GMWL), indicating that the samples could have been subject to some evaporation, been mixed with evaporated surface water, or been derived from recharge source areas with somewhat different meteoric water lines because of differing altitudes. Within the Subbasin, the heavier isotopic values, which only deviated slightly from the GMWL, indicated that at least some of the recharge to the Subbasin originates as precipitation directly falling on the lower elevations of the Subbasin. In general, the isotopic values of samples east of the Rodgers Creek Fault grouped together and were in the lighter range of all measured isotopic values. The isotopic values for well samples from the western margins of Subbasin and contributing watershed area also grouped together but fell within the heavier range of all isotopic values from wells in the study area (Nishikawa et al, 2013).

Measured carbon 14 ages in groundwater samples collected from the Subbasin and contributing watershed areas 1,000 to 34,000 years before present (Nishikawa et al, 2013). As determined by carbon 14 dating or the presence of tritium, the shallow and deep aquifers exhibit different groundwater ages, with the deep well samples all exhibiting water ages of 4,000 years or older and the shallow aquifer generally containing waters recharged within the last 50 years (Nishikawa et al, 2013).

3.2.5.2 Naturally Occurring Consituents of Interest

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

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 (µg/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.

Water sample analyses for arsenic were available from 89 wells within the Subbasin and contributing watershed areas between 2010 and 2019. The occurrence and distribution of arsenic in groundwater is displayed on **Figure 3-15a**. Groundwater samples from 15 of the 89 wells (17%) exceeded the MCL of 10 µg/L for arsenic. Areas of elevated arsenic concentrations are most notable in the northeaster portions of the Subbasin, immediately south of the City of Santa Rosa, in the vicinity of the City of Sebastopol and along the Trenton Fault near Mark West Creek. Many areas of higher arsenic concentrations appear to be associated with known or inferred faults.

Chloride and Total Dissolved Solids

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 or the presence of older connate water.

Anthropogenic sources of chloride commonly include manufacturing, power generation, landfill leachate, and wastewater. Chloride has a secondary maximum contaminant level of 250 mg/L based on taste and odor thresholds.

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

Water sample analyses for chloride were available from 95 wells within the Subbasin and contributing watershed areas between 2010 and 2019. The occurrence and distribution of chloride in groundwater is displayed on **Figure 3-15b**. No groundwater samples exceeded 100 mg/l chloride.

Water sample analyses for TDS (and SC as a surrogate for TDS) were available from 97 wells within the Subbasin and contributing watershed areas between 2010 and 2019 (18 within the shallow aquifer system and 121 within the deep aquifer system). The occurrence and distribution of TDS in groundwater is displayed on **Figure 3-15c**. Groundwater samples from three of the wells exceeded the secondary MCL of 500 mg/L for TDS (500 mg/L).

The USGS study found that, while concentrations of chloride and specific conductance are predominantly well below secondary drinking water standards, concentrations of these two constituents appear to be increasing with time in the Subbasin (Nishikawa et al, 2013). Chloride concentrations increased similarly in about two-thirds of the wells, and just more than half increased by more than 10 percent. Not all wells had increases: a more than 10 percent decrease in concentration was measured in 15 percent of the wells for specific conductance and 30 percent for chloride. The greatest increases in concentrations of specific conductance, chloride or both were in wells located in the vicinity of the cities of Rohnert Park and Cotati. Possible causes of the increased specific conductance and chloride include groundwater underflow of high dissolved solids concentration groundwater present along the Rodgers Creek fault zone, historic irrigation return flow, septic tank effluent or leaky sewer pipes (Nishikawa et al, 2013). Depth-dependent hydrologic, chemical and isotopic data are needed to better understand the cause of the increased specific conductance and chloride concentrations.

Figures 3-15e and 3-15f display more recent time-concentration plots of chloride and TDS, respectively, for wells with the longest periods of records based on available historical data. As indicated on the time-concentration plots, the majority of wells exhibit relatively stable concentrations of chloride and TDS over time. The absence of increasing trends in this more recent data, may be related to samples from different wells than the USGS study or indicate that concentrations have stabilized since the USGS study. It is important to note that many of the time-concentration plots do not include very complete records over time (sampling for several of the wells which were sampled in the 1950s through 1970s were discontinued and many of the wells with more complete recent data do not have data extending back over time). Additionally, spatial data gaps occur in both the shallow and deep aquifer system.

3.2.5.3 Anthropogenic Constituents of Interest

Nitrate

Nitrate is a widespread contaminant and its occurrence in groundwater systems is commonly associated with 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 ingants and pregnant women (SWRCB, August 2010) and the MCL for nitrate as N is 10 mg/L.

Only two of the 92 groundwater samples analyzed for nitrate as nitrogen exceeded or equaled the nitrate MCL of 10 mg/L (milligram/liter). The median concentration of nitrate in shallow wells was 0.9 mg/l in the northern portions of the Subbasin and 4.4 mg/l in the southern portions of the Subbasin. Medium concentrations for deeper wells were 0.2 mg/l in the northern portions of the Subbasin and 1.0 mg/L in southern portions of the Subbasin.

Regulated sites

The Subbasin and contributing watershed contains a number of currently regulated contaminant release sites (Figure 3-18), many of which are under active cleanup order by the State Water Resources and Regional Water Quality Control Boards. These include leaking underground tanks from gasoline and solvent storage, land disposal and military facilities. These releases, which include petroleum and chlorinated solvent contaminants and metals, are generally of limited areal extent, although impacts to water-supply wells from a number of sites have occurred within the study area.

The SWRCB GAMA Priority Basin Project study of the North San Francisco Bay Groundwater Basins has included two studies by the USGS which evaluated evaluated inorganic and organic constituents in groundwater, which includes constituents associated with regulated contaminant release sites. The first study conducted in 2004 included samples from 18 public water supply wells in the Subbasin and contributing watershed areas. The second study conducted in 2012 included samples from seven private domestic wells in the Subbasin and contributing watershed areas. 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 and Bennett et al, 2014). A small number of the 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 and Bennett et al, 2014).

3.2.6 Surface Water and Groundwater Connectivity

Subsection under development.

3.2.6.1 Interconnected Surface Water

3.2.6.2 Groundwater Dependent Ecosystems

3.3 Water Budget

3.4 Management Areas