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DRAFT Basin Setting Section

Groundwater Sustainability Plan for
Santa Rosa Plain Groundwater Subbasin

****Note to Reader: Text in Red indicates information that has not yet been developed and/or will be modified or further described in subsequent sections of the GSP****

Contents

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.

<u>Mark West Creek</u>
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.

<u>Santa Rosa Creek</u>
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).

<u>Laguna de Santa Rosa, Peripheral Streams and Drainages</u>
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.

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).

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 year 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.

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 each principal aquifer:

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

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.

<u>Shallow Aquifer System Materials and Properties</u>

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).

<u>Deep Aquifer System Materials and Properties</u>

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 hestimated 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, boron, iron, and manganese 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

3.2.1 Climatic Conditions and Trends

3.2.2 Groundwater Elevations and Trends

3.2.3 Estimated Changes in Groundwater Storage

3.2.4 Land Surface Subsidence

3.2.5 Groundwater Quality Conditions and Trends

3.2.6 Surface Water and Groundwater Connectivity

3.2.6.1 Interconnected Surface Water

3.2.6.2 Groundwater Dependent Ecosystems

3.3 Water Budget

3.4 Management Areas