DRAFT Basin Setting Section

Groundwater Sustainability Plan for
Sonoma Valley Groundwater Subbasin

****Notes 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.**
Subsection 3.1 (in Gray Highlight) has already undergone review and revisions and is included with this version for completeness**

Contents

3. Basin Setting

This section provides information about the physical setting, characteristics and current conditions of the Sonoma Valley Groundwater 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 Sonoma Valley Subbasin and contributing watershed areas:

- 2014, Sonoma Valley Groundwater Management Program. Five-Year Review and Update Report.
- http://sonomavalleygroundwater.org/wp-content/uploads/5-year-Review-and-Update-2014.pdf2007, Sonoma County Water Agency. Sonoma Valley Groundwater Management Plan.
- http://sonomavalleygroundwater.org/wp-content/uploads/Sonoma-Valley-Groundwater-Management-Plan-2007.pdf2006, U. S. Geological Survey. Geohydrological Characterization, Water-Chemistry, and Ground-Water Flow Simulation Model of the Sonoma Valley Area, Sonoma County, California. https://pubs.usgs.gov/sir/2006/5092/

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 Sonoma Valley Subbasin is located in the North Coast Ranges geomorphic province of California. The North Coast Ranges are characterized by predominantly northwest trending mountains and valleys formed in response to regional tectonic stresses that produced northwest-trending faults related to the San Andreas Fault system. The Subbasin is adjacent to and north of San Pablo Bay and is approximately 20 miles in length, encompassing the majority of Sonoma Valley between the Sonoma Mountains to the west and the Mayacamas Mountains to the east, as shown on **Figure 3-1**.

The Sonoma Mountains separate the Subbasin from the Petaluma Valley and Santa Rosa Plain to the west and are of moderate relief sloping gently from a few hundred feet in the southern part to greater than 2,000 feet southwest of Glen Ellen and reaching a maximum elevation of about 2,295 feet on Sonoma Mountain. The Subbasin is bounded on the east by the Mayacamas Mountains that range from less than 100 feet elevation in the Carneros area increasing from south to north to a maximum elevation of 2,730 feet at Hood Mountain northeast of the Subbasin.

The Subbasin between the two ranges is not uniform in width or slope, and can be subdivided into two portions on the basis of topography. The upper portion of the Subbasin is much narrower than the lower portion and has a hilly topography. This portion of the valley is sometimes referred to as the Valley of the Moon and includes the Glen Ellen area and extends southward to near Boyes Hot Springs. In this part of the valley, elevations drop from about 400 feet to about 100 feet over an approximately 5-mile distance, from north to south. The remainder of the valley southward to San Pablo Bay has a flat topography and ranges as much as 5 miles in width and includes the City of Sonoma, El Verano and Schellville areas. In this area, the elevation of the Subbasin floor gradually slopes from about 100 feet to sea level over a distance of about 12 miles.

3.1.2 Surface Water and Drainage Features

The Subbasin and contributing watershed area are drained by Sonoma Creek and its tributaries, which discharge into San Pablo Bay in the northern part of San Francisco Bay, as shown on **Figure 3-1**. Sonoma Creek flows for approximately 33 miles and begins in the Mayacamas Mountains outside of the Subbasin in the northeastern portions of the Sonoma Creek watershed, at an elevation of about 1,600 ft within Sugarloaf Ridge State Park. The creek flows generally westward through a narrow canyon with a steep gradient from the headwaters to the edge of the Kenwood Valley Basin near the community of Kenwood. In this 3-mile reach, the creek drops about 1,100 ft to an elevation of about 500 ft. The course of the creek turns to the south near Kenwood and then turns to the southeast where it enters the Sonoma Valley Subbasin near Glen Ellen. The gradient is much less steep in the 6.5-mile reach between the mountain front and Glen Ellen, dropping in elevation by about 280 ft. The gradient flattens further between Glen Ellen and San Pablo Bay. As it passes through the city of Sonoma, it is an urban creek that emerges into agricultural areas to the south. South of State Route 121 where Sonoma Creek flows through tidal marshland to San Pablo Bay, the stream drops only about 10 feet in 9 miles (USGS, 2006). Primary tributaries to Sonoma Creek within the Subbasin include Calabazas Creek, Yulupa Creek, Carriger Creek, Fowler Creek, Nathanson Creek, Arroyo Seco, Schell Creek, Tolay Creek and Fryer Creek.

3.1.3 Soil Characteristics

Soil types and characteristics in Sonoma Valley have been mapped by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), which developed a spatial database of soils for the entire United States (the Soil Survey Geographic Database or SSURGO) (USDA NRCS, 2007). The SSURGO database defines 17 different soil textures (excluding variable and unknown textures) present in the study area (USDA, 1997), which are shown on **Figure 3-2a**. 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. Gravelly and sandy soils are primarily limited to narrow stream channels within the Subbasin.

The SSURGO database also assigns saturated hydraulic conductivity values to soil groups, which are shown on **Figure 3-2b**. Saturated hydraulic conductivity is a measurement of the representative or average water transmitting properties of soils and is a good indicator of the soil’s infiltration potential.. As indicated on **Figure 3-2b**, the loams and clayey loam soils that predominate the floor of the 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 northwest of Glen Ellen and west of El Verano (Carriger Creek alluvial fan area). The highest saturated hydraulic conductivities (rapid to very rapid) on the order of 12 to 40 feet per day primarily occur within streambed channels.

3.1.4 Regional Geologic Setting

Sonoma Valley is located within a region of geologic complexity caused by long periods of active tectonic deformation, volcanic activity and sea level changes. Geologic formations within the 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. **Figure 3-3a** presents a geologic map of the Subbasin and contributing watershed areas showing the surficial distribution of these geologic units, with the legend and relative ages for the units shown on **Figure 3-3b**. The inferred subsurface distribution of the geologic units is displayed on the hydrogeologic cross-sections shown on **Figures 3-4a-d**. **Note to Reader**: The hydrogeologic cross-sections are in development and 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

In Sonoma Valley, these geologic formations have undergone several episodes of folding and faulting that have resulted in a general synform (or U-shaped) structure to the valley with unit layering tilted towards the valley axis. This general structure is not uniform and is disrupted by many minor folds and faults (Farrar et al, 2006). As shown on **Figure 3-3a**, both inactive and active faults are prevalent in the region and numerous faults and fault systems have been mapped within the hills surrounding Sonoma Valley particularly within the southwestern hills and northwestern hills associated with the Rodgers Creek/Tolay Faults and the Bennett Valley Fault, respectively. Faults are generally not evident on the valley floor where they are concealed by younger sediments. However, along the east side of the valley, a fault termed the Eastside Fault has been mapped based on geophysical studies and the outcrop pattern of Tertiary sediments of the Huichica Formation. 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

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. The Mesozoic basement rocks are only exposed outside of the Subbasin within the northeast portions of the contributing watershed where rocks of the Franciscan Complex and Coast Range Ophiolite occur around Hood Mountain. The depth to the Mesozoic basement rocks is inferred to range from approximately 1,000 feet in the northern portions of the Subbasin near Glen Ellen to greater than 10,000 feet adjacent to San Pablo Bay based on gravity data modelled by the USGS, as indicated on **Figure 3-5**. Beneath the majority of the Subbasin, the modeling indicates that the depth to the Mesozoic basement rocks generally ranges from 3,000 to 6,000 feet (Langenheim, 2006).

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. Geologic units that are of greatest importance for groundwater resources within Sonoma Valley

(Farrar et al, 2006) 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 western, eastern and northern groups based on their age (Sweetkind et al, 2011). The western age group consists of five volcanic-sedimentary assemblages within Sonoma Valley: the Sonoma Mountain, Sonoma Creek, Arrowhead Mountain, Bismarck Knob, and Sugar Loaf assemblages. The majority of the volcanic materials associated with these assemblages appear to have been sourced predominantly from local volcanic vents and domes located within the Mayacamas Mountains east of the Subbasin (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. **Figure 3-6** displays the inferred top of the Sonoma Volcanics based on lithologic data obtained from well completion reports for approximately 2,000 water wells in Sonoma Valley. As shown on **Figure 3-6**, the depth to the top of the volcanics ranges from less than 50 feet to at least 750 feet and is generally shallowest along the margins and northern portions of the Subbasin and is deepest in the southern portions of the Subbasin and within and north of the El Verano area. 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 the sedimentary units of the Glen Ellen and Huichica Formations in places further complicating the 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).

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 Sonoma Valley. Estimated specific-yield values for the Sonoma Volcanics vary from 0 to 15 percent and well production yields generally range between 10 and 50 gallons per minute (gpm) and occasionally as much as several hundred gpm.

Specific yield is defined as the ratio of the volume of water that a saturated rock or soil will yield by gravity and is usually expressed as a percentage.

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 occurrence of the Petaluma Formation in the Subbasin is limited to the upper member which is exposed in fault-bounded blocks along the western hills south of Sonoma Mountain.

The vertical extent of the Petaluma Formation is unknown owing to its limited distribution in Sonoma Valley. 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. Domestic wells drilled into the Petaluma Formation yield on average about 20 gpm and vary from 10 to 50 gpm.

Huichica Formation

The Huichica Formation is a Pliocene- to Pleistocene-aged (approximately 3.5 to 4 million years old) fluvial sedimentary unit deposited by small streams into alluvial fans, lakes and lagoons. The unit consists of massive yellow silt and yellow and blue clay with interbedded lenses of sands, gravels, and tuff beds. The Huichica Formation crops out primarily in the hills along the southeastern part of Sonoma Valley in the Carneros region and underlies younger deposits beneath much of the southern valley floor. The unit overlies and is partly interbedded with the Sonoma Volcanics and may interfinger with the Glen Ellen Formation beneath the central portions of the Subbasin and may be indistinguishable in well logs and in outcrops.

The total thickness of the Huichica Formation is likely greater than 1,000 feet beneath parts of the valley floor (USGS, 2006). Well yields of the formation are low, typically 2 to 20 gpm, however, in some areas, the lower part of this formation can be higher yielding. The specific yield range for the Huichica is between 3 and 7 percent.

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. This unit interfingers with the Huichica Formation and lies on top of the Sonoma Volcanics in some regions and on the Franciscan Complex in other regions. The Glen Ellen Formation is primarily exposed along the northern margins of the Subbasin and within the Kenwood Valley north of the Subbasin.

The Glen Ellen Formation is estimated to be about 600 feet thick near Glen Ellen, but the thickness may be greater beneath some portions of the Subbasin. The relatively high content of clay-sized material, degree of compaction, and cementation tend to limit the permeability of the Glen Ellen. 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. Glen Ellen Formation wells typically produce a few tens to hundreds of gpm, with well yields generally less than 20 gpm. The specific yield range for the Glen Ellen is between 3 and 7 percent.

Quaternary Sedimentary Deposits

Quaternary Alluvial Deposits

Quaternary alluvial deposits cover much of the valley floor and include Holocene (younger than 100,000 years) to modern stream channel and stream terrace deposits (loose alluvial sand, gravel and silt) and surrounding late Pleistocene to Holocene undissected stream terrace deposits, older alluvium, and alluvial fan deposits. These deposits form a broad blanket in the lower valley, a narrower band and discontinuous patches through the hilly middle valley, and a wide blanket in the Kenwood Valley outside the Subbasin. In general, the alluvial materials nearest the valley margins and directly along major stream courses contain the greatest proportions of coarse-grained sediments.

The Quaternary alluvial units are inferred to range in thickness from near zero at the valley margins to as much as 300 feet near the center of the valley. Where these deposits are thick and saturated, they are the highest yielding aquifers in the valley, with well yields of more than 100 gpm. The specific yield range for the Quaternary alluvial units is 3 to 15 percent.

Quaternary Bay Muds

Quaternary bay mud deposits of Holocene age cover the southern tidal marshlands of the Subbasin. These deposits are primarily composed of organic rich muds and silts with small amounts of sand. The bay muds were deposited during a higher stand of sea level and, as such, contain entrapped brackish and saline water.

The thickness of the bay muds ranges from near zero at its margins to an estimated 200 feet along the shore of San Pablo Bay (USGS, 2006). Due to the low permeability and poor water quality associated with the bay muds, they are generally not tapped for groundwater supply and their specific yield is estimated to be less than 3 percent.

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. In general, the lateral extent of the Subbasin is defined based on the surficial distribution of the Tertiary sedimentary units and their contact with the Tertiary Sonoma Volcanics based on the 1982 Geologic Map of the Santa Rosa Quadrangle (CDMG, 1982). The boundary does not precisely match up with these contacts on the more recent geologic map shown on Figure 3-3a, which is more detailed and refined than the 1982 map (California Geologic Survey, 2017). Additionally, the southeastern portions of the Subbasin are defined based on the county boundary between Sonoma and Napa counties. The lateral extent and boundaries of the Subbasin are defined as follows:

- The southernmost corner of the basin is aligned with Tolay Creek for 5 miles, from the mouth of Tolay Valley to Tubbs Point. The shoreline of San Pablo Bay is the boundary from Tubbs Point to the outlet of Sonoma Creek. From Sonoma Creek to near Highway 121, the boundary is the Sonoma and Napa county boundary.

- The depositional contact between the topographically higher Sonoma Volcanics and the Tertiary sedimentary units (Glen Ellen, Huichica, and Petaluma Formations) and overlying Quaternary alluvial deposits defines the remaining eastern, western and northern boundaries, with portions of the boundary also coinciding with the Eastside and Bennett Valley faults.

The vertical extent 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 1,200 feet and no existing known water wells extending deeper than 1,500 feet. At depths exceeding approximately 1,500 feet, aquifers are likely not usable for water supply due to a combination of: (1) lower well yields related to increased consolidation and cementation of aquifer materials at these depths; and (2) poor quality water related, in part, to the presence of brackish connate water and geothermal fluids.

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

In order to characterize the aquifer systems within the Subbasin 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. While previous investigators have evaluated and described hydraulic properties associated with the geologic formations discussed above, insufficient information and data is available to correlate distinct aquifer systems based solely on geologic information. The limitations on available information and data with which to draw correlations is due, in part, to the high degree of heterogeneity associated with the geologic units, deformation related to folding and faulting of Tertiary-aged units which are difficult to discern in the subsurface, similarities in texture and composition of many of the sedimentary units, and related lack of high quality lithologic descriptions for the subsurface.

A fairly high degree of correlation and distinctions can be made based on aquifer depth. As described below, the shallow and deep aquifer systems exhibit properties and features that allow for their grouping into separate aquifer systems, including 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.

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 within the sedimentary units of the Glen Ellen and Huichica Formations.
- The shallow aquifer system is generally present under unconfined to semi-confined conditions, while the deep aquifer system is nearly always present under confined or semi-confined conditions.
- The shallow aquifer system generally exhibits stable long-term groundwater levels, while in southern Sonoma Valley many wells completed within the deep aquifer system have exhibited long-term declining groundwater levels (some important exceptions to this attribute are further described in Section 3.2.2)
- Wells completed in the shallow aquifer system near streams exhibit sharpseasonal increases in groundwater-levels highly correlative with precipitation and runoff

events, while sharp increases and decreases in groundwater levels within the deep aquifer system appear to correlate more closely with groundwater pumping events.

- In many areas the shallow aquifer system is locally and seasonally connected to Sonoma Creek and other tributaries within 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. Water samples from wells within the shallow aquifer system are 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 vastly different groundwater ages, with the deep aquifer containing water that was recharged up to 50,000 years before present, and the shallow aquifer generally containing waters recharged within the last 50 years.

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 Shallow Aquifer System

The shallow aquifer system is generally present under unconfined or semi-confined conditions from the water table to depths ranging from 100 to 220 feet. The shallow aquifer system is present over the entire lateral extent of the Subbasin and primarily occurs within Quaternary alluvial deposits. However, in areas where these units are absent or thin, the shallow aquifer system locally occurs within sedimentary units of the Glen Ellen and Huichica Formations and in some areas, most notably in the northernmost portions of the Subbasin, occurs within the Sonoma Volcanics. 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.

<u>Shallow Aquifer System Materials and Properties</u>
The materials of the shallow aquifer system are primarily heterogeneous deposits of sand, silt, clay and gravel deposited along alluvial fans, stream channels and floodplains, with sand and gravel sequences forming the more permeable and transmissive portions. The heterogeneity and variability associated with these materials is displayed on **Figure 3-7a**, which was created from a lithologic textural model developed by Sonoma Water using lithologic data from well completion reports for approximately 2,000 water wells in Sonoma Valley. The distribution of primary lithologic textural components (clays, coarse sands or gravels, volcanic, and mixtures) are shown for the shallow aquifer system and provide an indication of where higher and lower aquifer storage and transmission values

can be expected. In general, higher values are expected where the primary textures are either coarse sands and gravels or mixtures in comparison with clays. Areas with volcanic lithologic textures are expected to exhibit a high variability in aquifer storage and transmission values. As shown on **Figure 3-7a**, the coarser-grained materials within the shallow aquifer system primarily occur west and south of the El Verano area (Rodgers Creek, Felder Creek and Carriger Creek drainages and alluvial fans) and in the Agua Caliente area. Clays make up the primary lithologic texture in the vicinity of and southeast of the City of Sonoma and east of El Verano. Volcanic lithologic textures primarily occur along the margins of the Subbasin in some areas, such as near the Rodgers Creek drainage and most significantly in the northernmost areas of the Subbasin, north of Glen Ellen, and within the Kenwood Valley outside of the Subbasin.

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 driller 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 and none have been documented within the shallow aquifer system; therefore estimates for the shallow aquifer system are primarily based on lithologic texture data and numerical model calibration.

The specific yield of the shallow aquifer system is estimated to vary from approximately 3 to 15 percent based on the estimates for the Quaternary sedimentary deposits and Huichica and Glen Ellen Formation described above (DWR, 1981). An estimate of 10% for specific yield for the shallow aquifer system has been derived through numerical modeling (Farrar, et al 2006 and Bauer, 2008). Estimates of hydraulic conductivity for the shallow aquifer system derived through numerical modeling range from 1 to 60 feet per day (Farrar, et al 2006 and Bauer, 2008).

Shallow Aquifer System General Water Quality Characteristics

Groundwater samples collected from wells within the shallow aquifer system are most commonly characterized as a mixed-bicarbonate type water with relatively low dissolved solid concentrations (Farrar et al, 2006). Additionally, water samples from wells completed within the shallow aquifer system typically exhibit fairly young ages based on carbon 14 dating or the presence of tritium. Anthropogenic constituents, such as nitrate, are more commonly found in the shallow aquifer system in comparison to the deep aquifer system. These characteristics are typical of shallow aquifer systems in general and consistent with water derived either directly from precipitation or indirectly from precipitation through infiltration from streams (Farrar et al, 2006).

Additional details on data and groundwater quality conditions and trends are included in Section 3.2.

Shallow Aquifer System Primary Uses
The shallow aquifer system serves numerous 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 also provides a significant amount of baseflow to Sonoma Creek and some of its tributaries, 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.

3.1.5.2 Deep Aquifer System

Aquifer zones beneath the shallow aquifer system are characterized collectively as the deep aquifer system and are generally separated from the shallow aquifer by thick sequences of clay aquitards, as described below. The deep aquifer is generally present beneath approximately 400 feet below ground surface (i.e., below the shallow aquifer system and clay aquitard described below) 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 (e.g., distinct water quality signature or appreciable differences in piezometric heads), although 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.

Deep Aquifer System Materials and Properties
The deep aquifer system is primarily composed of relatively thin sand and gravel sequences interspersed within variable amounts of clay. The deep aquifer system generally occurs under confined conditions within sedimentary deposits of the Glen Ellen, Huichica and, to a lesser degree, Petaluma Formations. Locally, the deep aquifer system also occurs within volcaniclastic sediments, tuffs, and fractured volcanic rocks of the Sonoma Volcanics where the volcanic units present within the hills extend beneath the alluvial fill of the valley floor. The heterogeneity and variability associated with these materials is displayed on **Figure 3-7b**, which was created from a lithologic textural model described in Section 3.1.5.1, above. As shown on **Figure 3-7b**, in comparison with the shallow aquifer system, the deep aquifer system exhibits a much higher percentage of volcanic materials which nearly entirely make up the deep aquifer system from near Boyes Hot Springs to the northern Subbasin boundary. Clay and mixtures of gravelly and sandy clays are pervasive throughout the southern portions of the Subbasin and coarser-grained materials occur either as a predominant texture or mixed with clay in the central portions of the Subbasin.

There have been a limited number of aquifer tests conducted within the Subbasin's deep aquifer system to estimate aquifer properties. Transmissivity estimates from these tests have ranged from approximately 3,000 to 30,000 gallons per day per foot (gpd/ft) for tests on wells within the Sonoma Volcanics and from approximately 1,000 to 10,000 gpd/ft for wells in the Glen Ellen and Huichica Formations (GHD, 2012 and LSCE, 1999). Estimates for storativity (a dimensionless parameter defined as the volume of water released from storage per unit decline in aquifer) from the tests were 0.0007 within the Sonoma Volcanics and ranged from 0.001 to 0.008 within the Glen Ellen Formation (GHD, 2012 and LSCE, 1999). These values are generally reflective of confined aquifer conditions. Estimates of hydraulic conductivity from these tests is limited to the Sonoma Volcanics within the City of Sonoma, which yielded a range of approximately 5 to 34 feet per day (GEI et al, 2017).

Estimates of specific storage for the deep aquifer system derived through numerical modeling range from 0.0001 to 0.0000015 (Farrar, et al 2006 and Bauer, 2008). Estimates of hydraulic conductivity for the deep aquifer system derived through numerical modeling range from 0.5 to 25 feet per day (Farrar, et al 2006 and Bauer, 2008).

Deep Aquifer System General Water Quality Characteristics

Groundwater samples collected from wells within the deep aquifer system are most commonly characterized as sodium-mixed anion or sodium-bicarbonate type water with relatively higher dissolved solid concentrations in comparison with the shallow aquifer system (Farrar et al, 2006). Additionally, water samples from wells within the deep aquifer system typically exhibit pre-modern ages (older than 50 years) based on carbon 14 dating or the presence of tritium. Additionally, in many areas of the deep aquifer system, particularly areas near the Eastside Fault and Sonoma Volcanics, warm geothermal fluids occur within the deep aquifer system (Youngs et al, 1982). Further data and discussion of groundwater quality conditions and trends are included in Section 3.2.

Deep Aquifer System Primary Uses

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

3.1.5.3 Aquitards

Aquitards composed of clay deposits or volcanic flow rocks typically separate the shallow and deep aquifer systems and serve to locally confine the deeper aquifer system. In the southern portion of the Subbasin, thick sequences of clay generally present between approximately 200 and 400 feet below ground surface (bgs) form an effective aquitard, generally limiting hydraulic communication between shallow and deeper aquifer zones. The confining unit in this area is composed of clay-rich sediments of the Glen Ellen and Huichica Formations with thin interspersed lenses of sand and gravel and generally ranges from 160 to 350 feet thick. In some areas, the clay aquitards are thinner and/or interspersed with lenses of sand and gravel. In such areas, the shallow and deeper aquifer systems may exhibit a stronger degree of hydraulic connection. In the northern portions of the Subbasin (from approximately Boyes Hot Springs to the northern boundary), the aquitard(s) separating the shallow and deep aquifer systems are likely comprised of relatively impermeable volcanic flow rocks.

The heterogeneity and variability associated with materials of these confining aquitards is displayed on **Figure 3-7c**, which was created from a lithologic textural model described in Section 3.1.5.1, above. As shown on **Figure 3-7c**, clays or mixtures of gravelly or sand clays make up much of the aquitard in the central and southern portions of the Subbasin and volcanics are the predominant component north of Boyes Hot Springs and in a small area along the Subbasin margin east of the City of Sonoma. Interspersed coarse-grained units occur within the aquitard primarily within the Felder and Rodgers Creek drainages, which is an area where greater hydraulic communication may occur between the shallow and deep aquifer systems.

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.

Several faults have been mapped in the Sonoma Volcanics within the uplands surrounding the Subbasin, with the Tolay, Rodgers Creek and Bennett Valley faults being the primary fault zones. One northwest-striking fault has been mapped along the eastside of the valley floor. This fault, referred to as the Eastside Fault, is a high angle fault with vertical offset that has down-dropped geologic units on the west side of the fault. The fault may act as a hydrologic barrier to horizontal groundwater flow and may be a conduit for the upward circulation of deeper thermal waters (Farrar et al, 2006). Alignment of thermal wells and springs located along the fault, mainly on its east side in the Boyes Hot Springs area are indicators that the fault is a conduit for warm water and/or groundwater barrier for warm water (Youngs et al, 1983). While it appears that the fault has offset aquifers, additional groundwater level data is needed to further assess the fault’s effect on groundwater flow.

Other faults which border portions of the Subbasin may also serve as groundwater flow barriers and limit the amount of subsurface inflows from aquifer zones of the Sonoma

Volcanics along these Subbasin boundaries, such as along Carriger Creek where groundwater levels west of a splay of the Bennett Valley Fault zone are much higher than groundwater levels east of the fault zone. Groundwater data needed to make this determination in other areas along the Subbasin boundaries is limited.

3.1.7 Natural Groundwater Recharge and Discharge

Groundwater Recharge

Recharge to aquifers in the Subbasin primarily occurs through streambed recharge along portions of Sonoma Creek and its tributaries, as well as through direct infiltration of precipitation and along the margins of the valley areas (mountain front recharge). 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.

Previous estimates of groundwater recharge in Sonoma Valley have primarily included qualitative assessments. Qualitative relative potential groundwater recharge mapping included a desktop study conducted by the Sonoma Ecology Center and the Sonoma County Water Agency based on soil type, slope, vegetation, and underlying geology (Sesser et al, 2011). The potential recharge map developed as part of this study is shown on **Figure 3-8a**. 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 Quaternary alluvial deposits and volcanic tuffs and sediments. 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.

To further qualitatively assess groundwater recharge potential in the Subbasin, **Figure 3-8b** was developed to show other lines of evidence for recharge potential, including depth to groundwater within the shallow aquifer system, locations of losing stream reaches, lithologic texture of the shallow aquifer system, and groundwater ages. As shown on **Figure 3-8b**, areas identified as having a higher recharge potential based on two or more of these additional lines of evidence include the Carriger Creek, Felder Creek, and Rodgers Creek drainages and alluvial fans (coarser-grained texture of the shallow aquifer system, losing stream reaches and some younger groundwater ages). Areas identified as having a lower or medium potential for recharge include areas east of the Eastside Fault where very old groundwater ages are observed, the northern portions of the Subbasin where shallow volcanic rocks likely impede recharge, and the central portions of the Subbasin in the vicinity of and south of the City of Sonoma where relatively shallow groundwater conditions occur in the shallow aquifer system.

Groundwater Discharge

Groundwater discharge occurs in the Subbasin as stream baseflow (gaining streams), discharge at springs and seeps, and 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 water surface in stream channels. Figure 3-9 shows the location of potential natural groundwater discharge areas, including the location of springs and seeps, from the USGS' National Hydrography Dataset or National Water Information System (USGS, 2019), gaining stream reaches based on seepage run datasets collected intermittently from Sonoma Creek and its tributaries between 2003 and 2019 (SEC, 2019), and wetlands mapped by the Sonoma County Vegetation Mapping and LiDAR Program (Tukman Geospatial LLC, 2018).

As shown on **Figure 3-9**, the majority of springs and seeps occur outside of the Subbasin along fault traces within the Sonoma Volcanics. Springs and seeps located inside or along the margins of the Subbasin occur at the northern end of the Subbasin (at and in the vicinity of the Sonoma Developmental Center property) and along the southeastern boundary of the Subbasin. Gaining stream reaches are most prevalent along the mainstem of Sonoma Creek and some of its tributaries including Calabazas Creek, Mill Creek and Nathanson Creek. Gaining stream reaches also occur periodically along Carriger Creek, Felder Creek, Rodgers Creek, and Arroyo Seco. Wetlands that represent potential locations of groundwater discharge are located in small areas throughout the Subbasin and are most prevalent within and around the tidal marshlands at the southern portions of the Subbasin.

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 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 are 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.
- Improving estimates of aquifer properties, including hydraulic conductivity and storage coefficients through aquifer testing.
- 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 Eastside Fault and Bennett Valley 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.
- Improving the understanding of groundwater flowpaths near areas of brackish water in southern Sonoma Valley will support the appropriate setting of Sustainable Management Criteria in this area. Potential methods for addressing this data gap could include the construction of dedicated nested monitoring wells and/or and geophysical surveys in this area.

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

Improved understanding of recharge and discharge mechanisms within the Subbasin for both the shallow and deep aquifer systems, as specified below, 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. These studies can help better understand both recharge and discharge mechanisms to both the shallow and deep aquifer systems, as well as surface water/groundwater interaction within the 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

The climate of the study area is Mediterranean, with moderate temperatures and distinct wet and dry seasons. About 90 percent of the annual precipitation typically occurs during the months of November through April. Precipitation is highly affected by atmospheric rivers, which concentrate rainfall and runoff along narrow bands, typically a few hundred kilometers (km) wide and several thousand km long. Nearly 50% of the precipitation in the Sonoma County area is due to atmospheric rivers (Dettinger, et al, 2011). While the rainfall pattern is generally consistent, rainfall amounts can vary considerably throughout Sonoma Valley based on elevation and geographic location within the valley. Estimates of mean annual precipitation for the period 1981 through 2010, obtained using the

Parameter-elevation Regressions on Independent Slopes Model (PRISM; Daly and others, 2004), were used to indicate the spatial and temporal distribution of precipitation in Sonoma Valley. The PRISM model provides an estimate of spatial and temporal variability in precipitation in response to distance from moisture sources, average storm track, aspect of land surface in relation to storm tracks, and the effect of elevation (Daly and others, 2004). The average annual rainfall distribution for the Sonoma Valley Watershed for 1981 through 2010 estimated using the PRISM model is presented in **Figure 3-10a**. Annual rainfall varies from a low of 22 inches on the valley floor to up to 47.5 inches in the highest areas of the Sonoma and Mayacamas Mountains.

Mean annual precipitation at Sonoma has been assessed using both observed data from Climate Station "SONOMA.C" (NCDC #8351, Sonoma), which is located at the General Valleyo Home State Park near the City of Sonoma at an elevation 97 ft (NGVD 29), as well as yearly averages calculated using the PRISM model for the Subbasin and contributiong watershed area. The General Vallejo Home station has operated from 1953 to present, with some periods of missing and incomplete records. The yearly averaged precipitation measured from this station from 1953 to present is 28.80 inches, compared with 28.82 inches, as calculated by the PRISM model, as shown on **Figure 3-10b**. 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 Vallejo Home 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 General Vallejo Home and the PRISM data were aggregated by water year (**Figure 3-10b and 3-10c**). Nearby stations in Bodega Bay, Petaluma and Santa Rosa Plain are included to verify that historical PRISM output compare reasonably when General Vallejo data are absent. There are 21 wet years in the period from 1950 to 2017, and 12 dry years in the same period (Table 3-1). The 1990's and 2010's are the decades with the most dry years, with four and five years, respectively, whereas the 1980's and 1990's have 5 or more wet 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.

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

3.2.2 Groundwater Elevations and Trends

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:

- Groundwater-level contour maps for each principal aquifer (**Figures 3-11a-b**)
- Long-term groundwater-level hydrographs (**Figures 3-12b-f**)
- Groundwater-level trend maps (**Figure 3-13a-b**)
- Short-term groundwater-level hydrographs (**Figures 3-14b-i**)

Groundwater-Level Contour Maps

Groundwater level elevation contour maps for Spring 2015 for the shallow and deep aquifer systems are shown in **Figures 3-11a and 3-11b**, respectively. Groundwater-level elevation contour maps are under development for Fall 2015 (previous analysis of fall and spring contour maps for the Subbasin indicate that the general groundwater flow patterns in spring and fall are similar. Spring 2015 groundwater level elevations ranged from approximately:

- 363 feet mean sea level (msl) in the north end of the Subbasin to 3 feet msl in the south end within the shallow aquifer system; and
- 592 feet msl in the north end of the Sonoma Valley to 126 feet msl southeast of the City of Sonoma within the deep aquifer system.

The Spring 2015 groundwater-level contour maps for both the shallow and deep aquifer systems indicate that groundwater flows from recharge areas in the mountains toward the valley axis, in a generally southern direction towards San Pablo Bay. Comparison of the shallow and deeper groundwater-levels indicates that groundwater elevations in the deep aquifer system: (1) are approximately equivalent to groundwater elevations in the shallow aquifer system in the northern portions of the Subbasin; and (2) range up to 160 feet lower than groundwater elevations in the shallow aquifer system in portions of southern Subbasin.

There are two persistent groundwater pumping depressions in the southern Sonoma Valley, which are most apparent in the deeper zone groundwater level contour maps (**Figure 3-11b**), first identified in a 1999 report prepared for the VOMWD (LSCE, 1999) and further described in the 2006 USGS report (Farrar et al) and subsequent monitoring performed for the GMP. Southeast of the City of Sonoma, measured groundwater levels were as deep as approximately 126 feet below sea level and southwest of El Verano groundwater levels were as deep as approximately 28 feet below sea level in the deep aquifer system. These areas exhibiting declining groundwater levels (pumping depressions) have persisted and expanded in some portions based on data collected through 2018.

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 Sonoma Valley). Therefore, the associated groundwater level contour maps represent generalized groundwater level flow patterns and should not be used to interpret more localized or site-specific conditions.

Groundwater Level Trends

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 from wells within the monitoring program and short-term trends were evaluated using data collected on a more frequent basis (e.g., 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 valley (**Figure 3-12a**) are provided in **Figures 3-12b through 3-12f** for the shallow and deep aquifer systems. 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). On the hydrographs, spring groundwater-level data are depicted in green and fall groundwater-level data are shown in red, along with wet and dry periods described in Section 3.2.1.

As indicated on **Figures 3-12b through 3-12d**, groundwater level trends for shallow-zone wells are generally stable and predominantly remain above sea level. Long term groundwater-level declines in shallow-zone wells appear to be limited to a well located in the El Verano area (Son0078) where groundwater levels have declined approximately 60 feet from 1999 to 2012, then generally stabilized through 2018. As indicated in Figure 3-12f, declining groundwater level trends are more pervasive in deeper-zone wells, with wells in the El Verano Area and southeast of the City of Sonoma trending below sea level. Numerous well hydrographs shown on Figure 3-12f exhibit groundwater level declines ranging up to 60 feet (Son0167) over the last 30 years.

Many of the hydrographs have less than 15 years of monitoring record, making it unclear whether these are long-term trends, recent accelerated declines, a reflection of the dry years over the past decade or some combination. To help address this issue, groundwater level changes were further evaluated for a larger subset of wells and displayed in **Figures 3-13a-b**. For wells that have a minimum of five years of groundwater-level data, five year or ten year trend lines (based on the span of available data) were applied to springtime groundwater levels on the hydrographs to depict overall trends for these time periods. The slope of the trend lines was computed using the method of ordinary least squares linear regression to estimate the change in groundwater level in feet per year. These computed groundwater-level changes are provided in **Figures 3-13a and 3-13b** for the shallow and deep aquifer systems, respectively, to display the average groundwater level change per year at selected wells over 2005 to 2015 (displayed as circles) and 2010 to 2015 (displayed as squares).

As shown on **Figure 3-13a**, 32 of the 49 shallow aquifer system wells exhibit declining groundwater level trends exceeding 0.5 feet per year. Eleven of the 49 wells exhibited declining trends of 0.5 to 1.0 feet per year, 14 of the 49 wells exhibited declining trends of 1.0 to 2.0 feet per year and 7 of the 49 wells exhibit declining trends of over 2 feet per year. The majority of wells exhibiting declines exceeding one foot per year are located in the El Verano/Fowler Creek area. Thirteen of the 49 shallow-zone wells exhibited a change of less than 0.5 feet per year and four exhibited increasing trends.

As indicated in **Figure 3-13b**, declining groundwater level trends are more prevalent in deep aquifer system wells with 53 of the 70 wells exhibiting declining trends exceeding 0.5 feet per year. Eleven of the 70 wells exhibited declining trends of 0.5 to 1.0 feet per year, 19 of the 70 wells exhibited declining trends of 1.0 to 2.0 feet per year and 23 of the 70 wells exhibit declining trends of over 2 feet per year. The most pronounced long-term declines are within the El Verano/Fowler Creek and southeast of the City of Sonoma and are located within or near areas where groundwater levels have declined below sea level. Eleven of the 70 deep-zone wells throughout Sonoma Valley exhibited a change of less than 0.5 feet per year while 6 exhibited an increasing trend.

Most of the groundwater level declines are considered likely to have resulted from increased groundwater withdrawals in localized areas (USGS, 2006, and Sonoma Valley Groundwater Management Program, 2014). Declining levels of precipitation over last few decades has also contributed to groundwater level declines, but to a smaller degree. In the vicinity of groundwater level pumping depressions located within the City and El Verano/Fowler Creek subareas, groundwater demands are primarily a combination of agricultural and rural domestic pumping (Sonoma Valley Groundwater Management Program, 2014).

The two areas of decline (pumping depressions) have persisted for the last decade or more and may be expanding. While the magnitude of the declining rate may be influenced in part by the lower than average rainfall that has occurred within the past decade, many of the wells with declining groundwater levels exhibit persistent declines, which do not recover during relatively wetter years, indicating that groundwater withdrawals are occurring at a rate exceeding the rate of recharge or replenishment within the deeper zones.

Short-Term Trends

High-frequency groundwater-level data has been collected utilizing pressure transducers at a number of dedicated monitoring wells, private wells, and City of Sonoma and VOMWD wells over the past several years. **Figure 3-14a** shows the locations of wells that are currently instrumented with electronic pressure transducers and datalogger systems. Pressure transducer data is collected at intervals of minutes or hours, and the data is downloaded periodically and converted to groundwater elevations. The high frequency data collected at these locations provides information on short-term groundwater-level responses to hydraulic stresses such as recharge or pumping, as well as insights into the interaction between surface water and groundwater (where shallow wells near streams are instrumented).

As shown in Figure **3-14a**, wells currently instrumented with pressure transducers include the following:

- Four shallow dedicated monitoring wells (50 feet or less in depth) located adjacent to Sonoma Creek and Agua Caliente Creek (Agua Caliente-1, W. Thompson, Napa St. Piezo, and Verano St. Piezo);
- Five dedicated monitoring well clusters located in the El Verano/Fowler Creek area (CYMW-1[A and B], SV-MON-[92, 563, and 674], and FC-MW-[2s and 2d]) and the southern portions of the Subbasin (SVMW-1-[95, 233, 365, and 455] and SVMW-2-[52, 100, 220, 409, and 480]);
- Three shallow dedicated monitoring wells (25 feet or less in depth) located adjacent to Nathanson Creek at Sonoma Valley High School (SVHS-MW-01s, SVHS-MW-01d, and SVHS-MW-02);
- One shallow dedicated monitoring well (80 feet deep) located adjacent to Carriger Creek (upstream of the FC-MW-2s/2d cluster) on Fowler Creek Road (Fowler Creek-1);
- Three shallow dedicated monitoring wells (127 feet or less in depth) just outside the Subbasin, at the Montini Open Space Preserve (SV-MON-1s, SV-MON-1d, and SV-MON-3s);
- One deep Aquifer Storage and Recovery test well (230 feet deep) just outside the Subbasin, north of the Sonoma Plaza (TW-6a);
- One deep inactive private well (355 feet deep) in the El Verano/Fowler Creek areaa (K15-2);
- One shallow dedicated monitoring well (50 feet deep) north of the Subbasin, in the Kenwood Valley Groundwater Basin within the contributinv watershed area (Adobe Canyon-1); and
- The City of Sonoma's inactive deep Well No. 7 (860 feet deep) located at the Sonoma Garden Park on 7th Street East south of the City of Sonoma.

Hydrographs for these wells are presented in **Figures 3-14b through 3-14f** and discussed below. Daily precipitation recorded at the General Vallejo Home climate station is included on the hydrographs to facilitate assessment of groundwater-level responses to precipitation (and recharge) and where applicable, the nearest streambed and surface water elevation is included on hydrographs for shallow monitoring wells located near streams to assess the interaction between surface water and groundwater.

Shallow Monitoring Wells Sonoma and Agua Caliente Creeks
Dedicated monitoring wells Agua Caliente-1, W. Thompson, Napa St. Piezo, and Verano St. Piezo monitor the shallow aquifer (wells are less than 50 feet deep) near Sonoma Creek and Agua Caliente Creek. As illustrated on **Figure 3-14b**, data collected from January 2013 (Agua Caliente-1 and W. Thompson) and July 2014 (Napa St. Piezo and Verano St Piezo) to May 2019 indicate:

- Groundwater levels in the shallow aquifer respond rapidly to precipitation events and changes in streamflow;
- Seasonal groundwater level fluctuations typically range from approximately 5 to 20

feet at these locations;

- Seasonal high groundwater levels are typically observed in December to April and seasonal low groundwater levels are typically observed in October to November at these locations; and
- Seasonal fluctuations are most pronounced in Verano St. Piezo and least pronounced in W. Thompson.

Nested Monitoring Wells SVMW-1 and SVMW-2

Nested groundwater monitoring wells SVMW-1 and SVMW-2 were constructed in 2011 as part of the Local Groundwater Assistance Grant received from DWR. The wells are completed with multiple discrete screened zones:

- SVMW-1 with discrete well screens located at the following nominal depths: 85 to 95, 223 to 233, 355 to 365, and 440 to 455 ft bgs; and
- SVMW-2 with discrete well screens located at the following nominal depths: 32 to 52 (separate borehole), 80 to 100, 200 to 220, 374 to 409, and 460 to 480 feet bgs.

Groundwater-level data collected from these wells is shown in **Figures 3-14c and 3-14d** Primary observations from the groundwater-level data collected from the nested monitoring wells indicate:

- At both locations, groundwater levels (hydraulic heads) are appreciably higher within the shallow aquifer than in the deeper aquifer zones. The degree of separation (between groundwater levels in the shallow and deeper aquifer zones) is greater at nested groundwater monitoring well SVMW-2, which is closer to the central portions of the groundwater pumping depression where groundwater levels in the deeper aquifer are lowest;
- Groundwater levels in the shallow aquifer, particularly at SVMW-2, respond rapidly to precipitation events and changes in streamflow;
- Sonoma Creek is predominantly a gaining stream near Watmaugh Road where groundwater from the shallow aquifer locally discharges to the creek, except during precipitation events when the stream level rises above groundwater and recharges groundwater short-term. In late August/September 2013, and again in late September/October 2015 groundwater levels in the upper portions of the shallow aquifer at SVMW-2 (SV-MW2-52) declined to levels approaching the streambed elevation in nearby Sonoma Creek. Water level data from SVMW-2-SW indicate that the stage level within Sonoma Creek also began to decline corresponding with the lower groundwater levels suggesting a strong connection between groundwater levels within the shallow aquifer and baseflow in the creek. During other years, the groundwater-level at SV-MW2-52 declined to levels approaching the surface water elevation in Sonoma Creek without causing a noticeable change in surface water elevation in the creek. It appears that the reductions in surface water flow in this are are triggered when the groundwater-level approaches or falls below the streambed elevation;
- Rapid groundwater level fluctuations that appear to be related to localized pumping

are observed in several of the deep aquifer monitoring wells, particularly SVMW-1-365 and SVMW-2-409;

- Seasonal groundwater level fluctuations typically range from approximately 7 to 18 feet in the shallow aquifer, and from approximately 3 to 30 feet in the deep aquifer; and
- Seasonal high groundwater levels are typically observed in February to April and seasonal low groundwater levels are typically observed in September to October at these locations.

K15-2 Inactive Private Well
K15-2, an inactive deep well in the El Verano/Fowler Creek area, was instrumented in November 2013 and is screened within the deep aquifer system from 255 feet bgs to 355 feet bgs. Primary observations from the groundwater-level data collected from this well (**Figure 3-14e**) indicate:

- Seasonal groundwater level fluctuations typically range from approximately 12 to 17 feet at this location;
- There do not appear to be major fluctuations associated with nearby groundwater pumping at this location; and
- Seasonal high groundwater levels are typically observed in May. Seasonal low groundwater levels are typically observed in early September to early October.

Nested Monitoring Wells CYMW-1 and SV-MON-[92, 563, & 674]
Nested groundwater monitoring well CYMW-1 consists of one shallow monitoring well (CYMW-1a, screened from 110-135 feet bgs) and one deep monitoring well (CYMW-1b, screened from 580-665 feet bgs). Nested groundwater monitoring well SV-MON-[92, 563, & 674] consists of one shallow monitoring well (SV-MON-92, screened from 72-92 feet bgs) and two deep monitoring wells (SV-MON-563, screened from 542-562 feet bgs and SV-MON-674, screened from 654-674 feet bgs). Groundwater-level data collected from these wells is shown in **Figure 3-14f.** Data collected from February 2013 to May 2019 (SV-MON) and July 2016 to May 2019 (CYMW-1) from these wells indicate the following:

- Seasonal groundwater level fluctuations typically range from approximately 15 to 33 feet in the shallow aquifer system with slightly larger seasonal fluctuations observed at CYMW-1a;
- Seasonal high groundwater levels are typically observed in April to May and seasonal low groundwater levels are typically observed in October to December in CYMW-1a and SV-MON-92;
- Seasonal groundwater level fluctuations typically range from approximately 15 to 55 feet in the deep aquifer zones located at SV-MON;
- From December 2017 to present, SV-MON-563 and SV-MON-674 exhibit substantial short-term fluctuations indicative of influence from local groundwater pumping;
- Data from deep monitoring well CYMW-1b does not indicate significant seasonal groundwater level fluctuations (only about 4 feet of fluctuation in nearly three years of monitoring). This observation coupled with water quality data collected from

this well, which indicate that the deep aquifer system tapped by CYMW-1b contains thermal groundwater (elevated temperature, elevated arsenic levels and presence of dissolved gases), may indicate the presence of a fault or other conduit nearby that is providing a pathway for the upwelling of warmer thermal waters; and
- Groundwater levels and trends between SV-MON-563 and SV-MON-674 are very similar and these wells likely monitor a single connected aquifer system.

Shallow Monitoring Wells SVHS-MW-01s, SVHS-MW-01d, and SVHS-MW-02
Dedicated groundwater monitoring wells SVHS-MW-01s, SVHS-MW-01d, and SVHS-MW-02 monitor the shallow aquifer (all are 25 feet deep or less) adjacent to Nathanson Creek at Sonoma Valley High School. Groundwater-level data collected from June 2014 to May 2019(Figure 3-14g) from these wells indicate the following:

- Seasonal groundwater level fluctuations typically range from approximately 5 to 10 feet in the shallow aquifer at these locations;
- Seasonal high groundwater levels are typically observed in December to March and seasonal low groundwater levels are typically observed in October to November at these locations; and
- Groundwater levels in the shallow aquifer respond rapidly to precipitation events and changes in streamflow. There appears to be significant interaction between the shallow aquifer and surface water in Nathanson creek, particularly during the winter months, in the vicinity of these wells with the stream exhibiting primarily losing conditions in the summer and fall and gaining conditions for portions of the winter and spring.

City of Sonoma Inactive Well No. 7
City of Sonoma Well No. 7 is an inactive well constructed by the City of Sonoma, which has never been placed into production due to the low yield from the well and water quality issues. The well is constructed within the deeper aquifer zones, with several well screen intervals ranging from 473 to 666 feet bgs. Groundwater-level data collected from the well from January 2013 to present (**Figure 3-14h**) indicate:

- Groundwater levels exhibit large seasonal fluctuations ranging from approximately 50 to 100 feet in City Well No. 7;
- Seasonal high groundwater levels are typically observed in March to April and seasonal low groundwater levels are typically observed in September to October at this location; and
- Groundwater-level elevations in City Well No. 7 are consistently below mean sea level.

Shallow Monitoring Wells Fowler Creek-1, FC-MW-2s, and FC-MW-2d
Dedicated groundwater monitoring well Fowler Creek-1 (80 feet deep) and nested wells FC-MW-2s (17 feet deep) and FC-MW-2d (80 feet deep) are located adjacent to Carriger Creek in the El Verano/Fowler Creek area. FC-MW-2s is completed within a perched aquifer that may be limited in extent and only seasonally saturated. Due to the short period

of record for FC-MW-2s and FC-MW-2d, seasonal observations of trends in these wells are not discussed in this document but will be assessed moving forward. Groundwater-level data collected from August 2016 to May 2019 (**Figure 3-14i**) from Fowler Creek-1 and from July 2018 to May 2019 at FC-MW-2s and FC-MW-2d indicate the following:

- Groundwater-level elevations in Fowler Creek-1 do not appear to respond rapidly to precipitation events;
- Seasonal groundwater level fluctuations at Fowler Creek-1 typically range from approximately 10 to 20 feet at this location; and
- Seasonal high groundwater levels at Fowler Creek-1 are typically observed in April to May and seasonal low groundwater levels are typically observed in November to early December at this location;
- Groundwater-levels at Fowler Creek-1 range from approximately 38 to 58 feet below the streambed of Carriger Creek at Fowler Creek-1 and from approximately 20 to 30 feet below the streambed of Carriger Creek at FC-MW-2d, indicating the stream is a losing reach and locally disconnected from the shallow aquifer system. The perched zone monitored by FC-MW-2s does locally interact with surface water in Carriger Creek at this location during periods of high precipitation and/or streamflow.

Test Well 6a

Test Well 6a (TW-6a) was installed in 2016 as part of an Aquifer Storage and Recovery (ASR) Pilot Test. This well is located within the Sonoma Creek watershed, just outside of the Subbasin in the City of Sonoma. The total depth of TW-6a is 230 feet and it is screened primarily within the Sonoma Volcanics. Groundwater-level data collected from June 2016 to May 2019 (**Figure 3-14j**) from TW-6a indicate the following:

- From June 2016 through January 2018, short-term drawdown of approximately 10 to 22 feet is observed due to monthly pumping and sampling of nearby City Well #6;
- Drawdown ranging from approximately 5.0 to 6.5 feet is observed for longer periods of time (three to four weeks in duration) during production pumping of City Well #8 (located approximately 850 feet to the west of TW-6a);
- Rapid groundwater-level fluctuations are observed during the ASR Pilot Test between March and September 2018;
- Seasonal groundwater level fluctuations typically range from approximately 12 to 18 feet in TW-6a; and
- Seasonal high groundwater levels are typically observed in March to April and seasonal low groundwater levels are typically observed in October to November at this location.

Shallow Monitoring Wells SV-MON-1s, SV-MON-1d, and SV-MON-3s

Dedicated groundwater monitoring wells SV-MON-1s (76 feet deep), SV-MON-1d (127 feet deep), and SV-MON-3s (50 feet deep) monitor shallow groundwater conditions within the Sonoma Creek Watershed, just outside of the Sonoma Valley Groundwater Subbasin in the City of Sonoma. Groundwater-level data collected from December 2013 to May 2019

(**Figure 3-14k)** from these wells indicate the following:

- Seasonal groundwater level fluctuations typically range from approximately 6 to 12 feet at these locations;
- Seasonal high groundwater levels are typically observed in March to April and seasonal low groundwater levels are typically observed in October to November at these locations;
- Short-term drawdown of approximately 5 feet is observed throughout the observation period in SV-MON-1s and SV-MON-1d due to local groundwater pumping;
- Localized confining conditions or a perched water table appear to be present at SV-MON-3s causing groundwater-level elevations to be approximately 20 to 35 feet higher than elevations in SV-MON-1s and SV-MON-1d; and
- SV-MON-1s and SV-MON-1d appear to monitor the same aquifer zone as groundwater-level elevations and trends are nearly identical for the two wells.

Adobe Canyon-1
Dedicated monitoring well Adobe Canyon-1 (50 feet deep) monitors shallow groundwater conditions within the Sonoma Creek watershed, north of the Sonoma Valley Subbasin in the Kenwood Valley Groundwater Basin. Groundwater-level data collected from August 2016 to present (**Figure 3-14l**) indicate the following:

- Shallow groundwater levels in the vicinity of Adobe Canyon-1 respond rapidly to precipitation events;
- Seasonal groundwater level fluctuations range from approximately 14 to 23 feet at this location; and
- Seasonal high groundwater levels are typically observed in February to April and seasonal low groundwater levels are typically observed in late September to October at this location
- Groundwater-levels in Adobe Canyon-1 are generally below the streambed of Sonoma Creek (located approximately 1,350 feet away), except during short durations of high precipitation and/or streamflows, indicating that Sonoma Creek is primarily a losing reach in this area.

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, and increases in effective stress caused by excessive groundwater pumping. 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.

From 2006 to 2019 the three GPS stations in Sonoma Valley (described in Section 2.4 and shown on **Figure 3-15a**, along with other regional GPS stations) have shown vertical changes of - 0.75 inches (**Figure 3-14b**). From 2015 to 2019 the vertical change for the three stations is -0.15 to -0.25 inches, with yearly changes of -0.05 to -0.08 inches per year. It is not possible to conclusively determine the cause of these (small) changes in land surface elevation. If groundwater pumping within Sonoma Valley were causing subsidence in the groundwater basin, there would be a deviation from the regional trend with greater ground height change in those stations. This deviation is not observed, but rather there is a coherence in the observed data from stations in Bodega Bay, Marin, Napa, and in the Russian River area similar to that of Sonoma Valley. Based on these observations, regional interannual variation in hydrologic isostatic loading is likely the best explanation whereas groundwater pumping is a smaller contributor to the observed subsidence.

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

These findings do not suggest that land surface subsidence due to groundwater extraction has occurred. However, it is noted that measurement stations are not located over areas within the Subbasin most susceptible to subsidence (i.e., areas exhibiting groundwater level declines with extensive clay deposits in southern Sonoma Valley) and the time period of analysis for available processed InSAR data does not extend back far enough to assess any long-term or historical subsidence that may have occurred.

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 2006 study
- 2014 Salt and Nutrient Management Plan (RMC, 2014)
- USGS 2016 water quality sampling
- Data from regulated public water supply system sampling
- Regulated contaminant sites

Groundwater quality is generally adequate to support existing beneficial uses within most areas of the Subbasin and contributing watershed areas. Localized areas of poor groundwater quality within the Subbasin and contributing watershed areas are primarily related to the following potential sources of impairment: (1) brackish waters of San Pablo Bay and associated tidal marshland areas; (2) hydrothermal fluids associated with portions of the Sonoma Volcanics and/or fault zones; (3) deep connate waters associated with ancient seawater entrapped during deposition of Tertiary Era sedimentary units; and (4) anthropogenic inputs associated with certain land use activities (e.g., industrial, agricultural, or urban land uses).

The following sections describe general groundwater quality characteristics and the occurrence and distribution of naturally occurring and anthropogenic constituents of interest. Summary results are provided for general minerals major-ion data, total dissolved solids and specific conductance, and arsenic, nitrate, boron 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, brackish or saline groundwater. 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.

The following descriptions of these constituents within the Subbasin and contributing watershed areas is based on publically available data collected within the last ten years from public water supply wells and special studies by the USGS and DWR, which included sampling of both public and private water supply wells, as well as a limited number of dedicated monitoring wells. For wells that have been sampled multiple times within the past ten years, the most recent sampling result is used in this analyses. The analytical results represent samples of native groundwater collected prior to any water treatment systems and are not representative of the drinking water delivered by the public water systems which are required to treat the water to below applicable drinking water standards prior to delivery.

3.2.5.1 General Groundwater Quality Characteristics

Major ion concentrations and stable isotopes were used to help classify and characterize the groundwater in the Sonoma Valley.

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. The general composition of groundwater in Sonoma Valley has been evaluated using a trilinear ("Piper") diagram, which shows the relative proportions of common cations and anions for comparison and classification of water samples independent of total analyte concentrations, and are used to group samples that have similar relative ionic concentrations. Most groundwater in the Subbasin is bicarbonate type water and range from sodium-potassium type water to calcium-magnesium type water. Farrar et al (2006) subdivided water samples from the Subbasin and contributing watershed area into the following three general groups, as indicated on **Figure 3-16a**:

- Group 1, a mixed -bicarbonate type water, which generally occurs within the shallow aquifer system in the Subbasin, with the exception of a few wells completed within the deeper aquifer system in the El Verano Area. It is indicative of water derived either directly from direct infiltration of precipitation or indirectly from precipitation by means of groundwater losses to streams or streamflow losses to groundwater.
- Group 2, a mixed-cation chloride water that includes hydrothermal waters and water influenced by brackish water from San Pablo Bay. Wells that produce Group 2-type water are generally less than 500 feet deep and occur sporadically near the alignment of fault zones and in the southern portions of the Subbasin near San Pablo Bay.
- Group 3, a sodium-bicarbonate type water, which generally occurs within the deep aquifer system in the Subbasin and appears to represent waters that may have acquired their sodium bicarbonate composition through cation exchange along groundwater flow paths and are generally older waters that have undergone relatively long travel times and/or distances within the groundwater system .

As indicated above, water samples that plot within the same group may be indicative of waters that are of similar origin or have undergone similar hydrogeochemical processes of transformations. In general, results of the major ion concentrations analyses suggests groundwater in the Sonoma Valley is a more mixed-cation bicarbonate moving south to a sodium-bicarbonate type until reaching Highway 121 where chloride becomes a dominant anion associated with brackish water of the tidal marshlands at the south end of the valley.

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.

Groundwater in shallow- and intermediate-depth wells near Sonoma Creek and in the southern portions of the Subbasin (Schellville vicinity) is generally isotopically heavier and contains water that is at least partly evaporated suggesting a connection with a surface water source prior to infiltration and recharge (Farrar et al, 2006).

Groundwater from wells completed within the deep aquifer system is generally isotopically lighter, which may indicate older groundwater with a colder, wetter climatic source or water originating from a higher elevation in the watershed. Wells producing isotopically lighter groundwater, which was less affected by evaporation prior to infiltration and recharge, include wells located near Sonoma Creek or its tributaries in the northern portions of the Subbasin and contributing watershed area, in and along the margins of the Mayacamas and Sonoma Mountains (both areas where streams exhibit coarser sediments and steeper gradients allowing for faster runoff and infiltration and minimal evaporation), near mapped or inferred faults and in areas of higher salinity water (Farrar et al, 2006). The USGS also noted that the relatively light isotopic composition of waters from several wells within the area of higher salinity groundwater in the southeaster portions of the Subbasin is not characteristic of water influenced by modern saltwater or brackish waters, but rather is consistent with older connate waters which originated during a cooler and wetter climatic period (Farrar et al, 2006).

In the El Verano area, sampling of ten domestic wells conducted by Lawrence Livermore National Laboratory (LLNL) suggest that the main source of groundwater recharge is primarily dispersed infiltration of local precipitation with no significant component of water from higher elevations or evaporation before recharge (Carle et al, 2010). The study also found that the domestic wells sampled, which are primarily completed across the shallow aquifer system, produce a mixture of modern (less than 50 years old) and pre-modern (more than 50 years old) water with the pre-modern component making up the majority and modern water ranging from 16 to 43 years old comprising between 2 to 25% based on tritium-helium age dating (Carle et al, 2010). The youngest ages in the study were found in wells closest to Carriger Creek indicating that the creek and/or associated Carriger Creek alluvial fan is likely an important source of groundwater recharge to the shallow aquifer system in this area.

Age-dating analyses conducted by the USGS in 2015 and 2016 in the southern portions of the Subbasin found that tritium (indicative of modern water) was detected in water from all of the shallow aquifer system wells that were sampled and was generally not detected in deep aquifer system wells. Minor tritium concentrations were detected from a deep aquifer system well located in the El Verano area and near Sonoma Creek at Watmaugh Road. These wells likely contain mixtures of pre-modern and modern water. The data suggest that in general, water from the deeper aquifer system is pre-modern and was recharged prior to 1952 and water from the shallow aquifer system contains components of modern water. This finding is further corroborated by uncorrected carbon-14 age estimates which indicate that waters with the oldest carbon-14 signatures of greater than 11,000 years old occur within the deep aquifers system southeast of the City of Sonoma. On the basis of trace-element data, water in these wells is likely influenced by deep water from consolidated marine sediments (connate water), or a mixture of connate water and thermal water (N. Teague, personal communication, August 2016).

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 112 wells within the Subbasin and contributing watershed areas between 2010 and 2019. The occurrence and distribution of arsenic in groundwater is displayed on **Figure 3-16b**. Groundwater samples from 19 of the 112 wells (17%) exceeded the MCL of 10 μg/L for arsenic. Areas of elevated arsenic concentrations are most notable north of Highway 121 along the 8th Street East corridor and in the vicinity of the Eastside Fault (which likely serves as a source of upwelling thermal water in this area). Other areas of higher arsenic concentrations are also associated with thermal water sources and/or known or inferred faults.

Figure 3-16c displays time-concentration plots of arsenic for wells with the longest periods of records based on available historical data. As indicated on the time-concentration plots, the majority of wells do not exhibit readily discernable long-term increasing or decreasing trends. Many of the wells do exhibit significant fluctuations in arsenic concentrations over time, which may be related to sampling procedures or short-term changes in groundwater quality, as arsenic concentrations are strongly influenced by pH and other redox changes.

Boron

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

Water sample analyses for boron were available from 56 wells within the Subbasin and contributing watershed areas between 2010 and 2019. The occurrence and distribution of boron in groundwater is displayed on **Figure 3-16d**. Groundwater samples from 10 of the 56 wells (18%) exceeded the State Notification Level of 1,000 µg/L for boron. Groundwater wells exhibiting elevated boron levels are commonly coincident with wells that exhibit elevated arsenic levels (Forrest et al, 2013), which indicate the distribution and occurrence of boron is likely also influenced by the presence of thermal water and faults.

Chloride

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

Water sample analyses for chloride were available from 111 wells within the Subbasin and contributing watershed areas between 2010 and 2019. The occurrence and distribution of chloride in groundwater is displayed on **Figure 3-16e**. No groundwater samples exceeded the secondary MCL of 250 mg/L for chloride. Concentrations of chloride in excess of 100 mg/L are limited to the southeastern portions of the Subbasin from wells in the Carneros area and east of the Eastside Fault. These wells are either wholly or primarily completed within the Huichica Formation and the elevated chlorides in these wells are likely associated with deep connate waters associated with ancient seawater entrapped during deposition of the Tertiary Era Huichica Formation, which is consistent with the findings from the age-dating and trace element data described above.

Figure 3-16f displays time-concentration plots of chloride 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 over time. 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.

Total Dissolved Solids

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

TDS concentrations can also be approximated by measuring the specific conductance (SC) of water, which is the measurement of the ability of the water to conduct electricity, in microseimens per centimeter (µs/cm) and is dependent upon the amount of dissolved solids in the water. The relationship between TDS in mg/L usually ranges from approximately 0.5 to 1.0 times the SC, dependent upon nature of the dissolved solids and the temperature. In Sonoma Valley, because SC data is more readily available, previous studies have developed a relationship between SC and TDS using wells which contain measurements for both consitituents, where the TDS value is equated to 0.63 times the SC value (Farrar et al, 2006 and RMC, 2013). For this GSP, the measured and converted TDS values are primarily used for displaying and describing water quality conditions related to dissolved solids.

Water sample analyses for TDS (and SC as a surrogate for TDS) were available from 139 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 **Figures 3-16g and 3-16h** for the shallow and deep aquifer systems, respectively. Groundwater samples from three of the 18 shallow aquifer system wells and groundwater samples from 19 of the 121 deep aquifer system wells exceeded the secondary MCL of 500 mg/L for TDS (500 mg/L).

For the shallow aquifer system wells, the highest concentrations of TDS (greater than 1,000 mg/L) are from shallow wells completed within Quaternary Bay Muds in the tidal marshlands near San Pablo Bay, which is consistent with the brackish water present within the tidal marshlands. The only other sample within the shallow aquifer system which exceeds 500 mg/L for TDS occurs just south of Highway 121 in the vicinity of Hyde/Burndale roads. The distribution of TDS within the shallow aquifer system is not well constrained due to the relatively sparse amount of available data.

For the deep aquifer system, the highest concentrations of TDS (greater than 1,000 mg/L) occur outside of the Subbasin within the contributing watershed areas northeast of Glen Ellen and near Sears Point in the southwesternmost portions of the watershed. Given that these wells are located within upland areas of the watershed within the Sonoma Volcanics and near fault zones, the elevated TDS in these wells is likely attributed to highly mineralized thermal groundwater sources or highly mineralized old groundwater upwelling along faults or fractures. The most widespread area of elevated TDS within the deep aquifer system occurs within the the southeastern portions of the Subbasin from wells in the Carneros area and east of (or in the vicinity of) the Eastside Fault consistent with the occurrence of elevated chloride in groundwater. In these areas, concentrations of TDS ranging between 750 and 1,000 mg/L occur east of the Eastside Fault in the vicinity of Arroyo Seco with somewhat lower concentrations (500 to 750 mg/L) occurring in the Carneros area and west of the Eastside Fault. These wells are either wholly or primarily completed within the Huichica Formation and the elevated TDS in these wells are likely associated with deep connate waters associated with ancient seawater entrapped during deposition of the Tertiary Era Huichica Formation, which is consistent with the findings from the age-dating, isotopic and trace element data described above.

Figure 3-16i displays time-concentration plots of TDS (and SC as a surrogate for TDS) for wells with a sufficient amount of available historical data. As indicated on the time-concentration plots, the majority of wells exhibit relatively stable concentrations of TDS over time. 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.

Water sample analyses for nitrate were available from 133 wells within the Subbasin and contributing watershed areas between 2010 and 2019. The occurrence and distribution of nitrate in groundwater is displayed on **Figure 3-16j**. No groundwater samples exceeded the MCL of 45 mg/L for nitrate. Concentrations of nitrate in excess of 10 mg/L occur sporadically in limited areas of the Subbasin and contributing watershed areas, with the majority of these occurring within the shallow aquifer system. The majority of wells (approximately 88%) sampled for nitrate within the Subbasin and contributing watershed areas exhibit very low (<2 mg/L) to non-detectable concentrations of nitrate.

Regulated sites

The Subbasin and contributing watershed area contains a number of currently regulated contaminant release sites, many of which are under active cleanup order by the Regional Water Quality Control Boards or County of Sonoma Department of Health Services, Environmental Health and Safety. These include leaking underground tanks from gasoline and solvent storage. The SWRCB's Geotracker website identifies eight open site cases within the Subbasin and contributing watershed area**.** These releases, which include petroleum and chlorinated solvent contaminants and metals, are generally of limited areal extent, although impacts to private water-supply wells have occurred. No known impacts to public water supply wells have occurred related to these release sites.

The SWRCB GAMA Priority Basin Project study of the North San Francisco Bay Groundwater Basins has included two studies by the USGS 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 isootopes (Kulongoski et al, 2010 and Bennett et al, 2014). Three of the 25 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).

3.2.5.3 Hydrothermal System

In Sonoma Valley, hydrothermal fluids with temperatures greater than 20° C (68° F), have been identified in wells and thermal springs across an area that extends north from the City of Sonoma, and includes Fetter's Hot Springs, Boyes Hot Springs, and Agua Caliente (Waring, 1915; California Division of Mines and Geology, 1984). The north Sonoma hydrothermal system was constrained to depths from 50–550 ft below land surface based on temperature gradient data from wells (Farrar et al., 2006). Hydrothermal fluids in the southern part of Sonoma Valley may be separate from the northern Sonoma hydrothermal system, and could be related to upflow along fractures in the Rodgers Creek Fault Zone (Farrar et al., 2006). The Eastside fault is thought to form the western boundary for the hydrothermal systems (California Division of Mines and Geology, 1984).

Hydrothermal fluids in the Sonoma area generally are sodium-chloride type waters and often contain arsenic, boron, fluoride, and lithium in concentrations that exceed drinking-water standards (California Division of Mines and Geology, 1984; Farrar et al., 2006; Kulongoski et al., 2010). Hydrothermal fluids are significant components in some wells in the Sonoma Valley, particularly in the area between Fetters Hot Springs and the City of Sonoma (Farrar et al., 2006).

Forrest et al (2013) developed a mixing model based on multivatiate statistical analysis using trace elements to broadly classify fresh groundwater, saline-impacted groundwater, hydrothermal fluids and mixed hydrothermal/meteoric waters.

3.2.5.4 Seawater/Freshwater Interface

The seawater/freshwater interface likely occurs beneath the tidal marshlands near the boundary with San Pablo Bay. While the specific location of the interface has not been determined, historical sampling of water wells south of Highway 37 showed high concentrations of TDS potentially indicative of seawater intrusion (e.g., chloride levels approaching or exceeding 1,000 mg/L and TDS levels exceeding 1,500 mg/L) (RMC, 2014). Notwithstanding where the precise seawater/freshwater interface exists, the majority of groundwater beneath the tidal marshlands located south and east of Highway 121 is impacted with brackish groundwater and has an average TDS concentration of 1,220 mg/L (RMC, 2014). The poor water quality in these areas is reflected in the well density map (**Figure 2-6**), which shows that very few water wells have historically been completed in these areas.

Groundwater-level declines along the northern margins of the tidal marshlands and the tidal reaches of Sonoma Creek could trigger the inducement of brackish water into fresher groundwater aquifers and represent potential pathways for brackish water in these areas to impact water quality in the Subbasin. Limited historical monitoring of groundwater quality in these areas has revealed seasonal fluctuations, and some possible inland movement of brackish water (Kunkel and Upson, 1960, Farrar et al, 2006, RMC, 2014). These historical observations are based on water quality analyses from different monitoring networks and are primarily limited to TDS or SC, making it difficult to discern whether the potential water quality changes are due to either: (1) the differing distribution of sampled wells for the different timeframes; and/or (2) the presence of older connate or thermal water sources rather than recent brackish water, as discussed above. Additional data collection and monitoring in these areas will better inform the current conditions and provide future monitoring of this potential risk.

3.2.6 Surface Water and Groundwater Connectivity

As described in Section 2.4 and shown on Figure 2-7c, continuous streamflow monitoring currently occurs at 12 gages in the Subbasin and contributing watershed areas, although the period of record for all but two of the gages is less than two years. The two gages with the longest periods of record are the Agua Caliente gage (USGS station number 11458500) and the Kenwood gage (USGS station number 11458433). The Agua Caliente gage operated from 1955 through 1981 and was then temporarily discontinued until 2001 when it was restarted. The Kenwood stream gage was installed in the fall of 2008.

Discharge measured at the Agua Caliente gage varies considerably annually, as shown in the graph of total annual discharge in acre-feet. The mean annual discharge of Sonoma Creek at the Agua Caliente gage **(Figure 3-17a)** is 50,836 acre-feet, on the basis of records for water years 1956–1981 and 2002–2018. A maximum annual discharge of 123,402 AF was measured in 2006, and a minimum discharge of 1,002 AF was measured in 1977.

The mean annual discharge of Sonoma Creek at the Kenwood gage (**Figure 3-17b**) for the five years it has been operating is approximately 10,225 AF, ranging from approximately 4,283 AF in Water Year 2009 to approximately 19,495 AF in Water Year 2011. Between the two gauges, Sonoma Creek gains an annual average of approximately 32,000 AF, likely from a combination of tributary inflows and groundwater seepage between the two gauge locations.

In most water years, daily discharge does not increase significantly until November or December, after which it begins to rapidly decrease in April or May in response to the normal annual cycle of precipitation (**Figure 3-17c**). The discharge measured in Sonoma Creek contains two primary components, runoff and baseflow. The baseflow component is primarily derived from groundwater, which seeps into the stream's bed and banks through adjacent shallow aquifers. In order to assess the amount of baseflow entering Sonoma Creek above the Agua Caliente gage, hydrograph separation techniques were used to estimate the ratio of baseflow (groundwater discharge) to total streamflow, termed the baseflow index (BFI). The BFI may be thought of as a measure of the proportion of the stream runoff that comes from groundwater discharge into streams. Streams which exhibit a higher BFI generally indicate that shallow aquifers are relatively permeable and contain shallow groundwater levels that can sustain streamflow during periods of dry weather.

Previous estimates for BFI were derived for Sonoma Creek at the Agua Caliente gage for Water Years 1970 to 2006 and indicated that baseflow was approximately 50% of the total streamflow (Bauer, 2008). The BFI was extended to the total period of record for the Agua Caliente Bridge (1956 to 2013) and is provided in (**Figure 3-18**). For the data gap from 1981 to 2001, the BFI was estimated using linear regression (Bauer, 2008). The BFI for 1956 through 2013 was estimated to range from approximately 0.45 to 0.62, with an average of approximately 0.50. This indicates that in an average year approximately 50 percent of the flow of Sonoma Creek at Agua Caliente Bridge (approximately 25,000 AF) is derived from groundwater discharging from shallow aquifers upstream of the Agua Caliente gage (Bauer, 2008 and Sonoma Water, 2014). Annual precipitation is also plotted on **Figure 3-18** and shows that historically the BFI was highest (greater than 0.55) during the drier years (e.g., 1957, 1972, 1976 and 1977), which indicates that in years when precipitation and total flow are low, the baseflow component of streamflow is proportionally higher. The overall long-term trend of baseflow over time upstream of the Agua Caliente Gauge appears relatively stable, which is consistent with the relatively stable groundwater levels observed in wells completed within the shallow aquifers in northern portions of the Subbasin.

3.2.6.1 Interconnected Surface Water

Interconnected surface water is defined in the GSP Regulations as *surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted* (DWR, 2016). Areas of interconnected surface water in the Subbasin and contributing watershed areas are identified through several different lines of evidence, including (1) results of seepage run monitoring; (2) frequency of observed or measured streamflow; (3) comparison of interpolated groundwater levels within the shallow aquifer system and streambed elevations; and (4) high frequency groundwater level observations from shallow monitoring wells located near streams. The surface waters assessed using these datasets include Sonoma Creek and its primary tributaries within the Subbasin and contributing watershed areas, which have been monitored through these data collection efforts.

Synoptic streamflow measurements (seepage runs) have been conducted on Sonoma Creek and its tributaries in May 2003 and spring and fall of 2010 by the USGS and routinely since 2014 by the Sonoma Ecology Center, which measures discharge at more than 50 locations semiannually and around 20 locations on a monthly basis. These seepage runs consist of a series of streamflow measurements made at several sites over a short time period (e.g., single day to several days) along Sonoma Creek and its tributaries to quantify streamflow gains and losses for a specific time period. Stream reaches experiencing gaining groundwater conditions are strong indicators of interconnected surface water and groundwater. Gaining stream reaches are identified through seepage runs whereby the discharge is measured at an upstream and downstream location along a stream reach. A positive change in discharge in the downstream direction are gaining conditions whereas a negative change indicates losing conditions. It is assumed that seepage into the stream reach comes from groundwater discharge, whereas in losing conditions streamflow is percolating through the streambed causing a decline in flow. For groundwater inflow to occur, it is a reasonable assumption that groundwater levels adjacent to a stream are greater than the stream stage. In these conditions the stream is hydraulically connected with the groundwater system.

- Results from the stream seepage measurements collected between 2016 and 2018 are presented in **Figures 3-19a and 3-19b**. From the seepage run data it is clear that surface water groundwater interactions vary spatially, change within a given year from spring to fall, and respond to inter-annual variations in precipitation.

- **Figure 3-20** provides a comparison of streambed elevations with interpolated groundwater levels within the shallow aquifer system. Areas of interconnected surface water occur where unconfined groundwater levels exceed streambed or ground surface elevations. Such areas are mapped in Sonoma Valley subbasin by subtracting groundwater elevations from spring 2015 from the streambed elevations. The streambed elevations were extracted from the Sonoma County Vegmap 2013 LiDAR.

- **Figure 3-21** shows the percentage of measurements with nonzero discharge from the stream seepage runs. Stream reaches with zero discharge are indicative of the absence of interconnected surface waters.

- **Figures 3-22a through Figure 3-22f** show the semiannual seepage run results in terms of rate of seepage for 2016 through 2018.

Figure 23 shows the likely areas of interconnected surface water within the Subbasin and contributing watershed area based on evaluation of the above datasets. Reaches of Sonoma Creek north of Glen Ellen (S5 to S8) generally show strong gaining signal in the fall, have zero dry measurements and have daylighting groundwater elevations for much of the reach. Reach S9-S8-A has been observed to go dry, has deeper unconfined groundwater levels, and two of its spring measurements are losing conditions. However this reach still exhibits gaining conditions in March 2017 following an above average wet winter. Downstream of S9, Sonoma Creek gaining conditions generally occur in the spring measurements, groundwater levels exceed stream thalweg elevations, and the creek is observed to have zero dry measurements. From these lines of evidence the entire mainstem of Sonoma Creek is likely to be interconnected surface water.

In the southwest area, Dowdall Creek, Carriger Creek, Felder Creek, and Rogers Creek enter the basin in an east-southeast direction. No seepage measurements are taken on Dowdall Creek, but interpolated groundwater depths along these reaches are deep enough such that there is little interconnected surface water. Gaining conditions are documented along portions of Carriger Creek and Felder Creek– the lower reach (TCl-T20-A, TF-TFc-A) exhibit gaining in all of the seepage measurements, though there are the frequent dry conditions along the alluvial fan at T20, TCl, and Tf. The interpolated depth to water measurements at these locations corroborate the conclusion that the upper reaches are likely interconnected surface waters, whereas groundwater-level measurements collected from shallow wells near Carriger Creek (near Arnold Drive and at Tcn approximately half a mile upstream) are 30 to 50 feet below the streambed, indicating this reach is primarily disconnected.

The upper reaches of Nathanson Creek (TNp-TN-A) and Arroyo Seco (Tan-Tab-A) are losing reaches with interpolated depth to water greater than 26 feet. The lower reaches of Nathanson Creek and Arroyo Seco both are generally gaining reaches with relatively shallow groundwater (11-25 feet below thalweg), though are commonly dry. The lower reaches are likely interconnected surface waters.

3.2.6.2 Groundwater Dependent Ecosystems

Under Development

3.3 Water Budget

3.4 Management Areas