Vina Subbasin
Groundwater Sustainability Plan
Draft Basin Setting

Contents

Figures

1. Basin Setting

1.1 Hydrogeologic Conceptual Model

A Hydrogeologic Conceptual Model (HCM) identifies the major factors contributing to groundwater flow and movement and how physical features and characteristics affect conditions within a subbasin. This section describes the HCM for the Vina Subbasin (Subbasin). The HCM serves as an important component of the basin settings, providing the framework for understanding groundwater conditions and water budgets.

Much of the information in this section is drawn from existing reports detailing the hydrogeology of the Sacramento Valley and the formations making up the aquifer systems in the groundwater basin. These reports by the Department of Water Resources include the *Geology of the Northern Sacramento Valley, 2014 (DWR 2014)*, the *Butte County Groundwater Inventory Analysis, 2005 (DWR 2005)*, and the Butte County *Lower Tuscan Aquifer Monitoring, Recharge, and Data Management Project Final Report, 2013 (Brown and Caldwell 2013)*. Better understanding the hydrogeology, aquifer dynamics, and recharge paths of the aquifer systems in the Northern Sacramento Valley region is an area of active study and research.

1.1.1 Basin Boundaries

1.1.1.1 Lateral Boundaries

The Vina Subbasin lies in the eastern central portion of the Sacramento Groundwater Basin. It is bounded by the following subbasins: Los Molinos to the north, Corning to the west, Butte to the south. The lateral boundaries of the Subbasin are jurisdictional in nature, and it is recognized that groundwater flows across each of the defined boundary lines to some degree.

The northern boundary is the Butte-Tehama County line, the western boundary is the Butte-Glenn County line, the southern boundary is a combination of the property boundaries owned by the M&T Ranch, and the service area boundaries of RD 2106 and Western Canal Water District, and the eastern boundary is the edge of the alluvium as defined by the DWR Bulletin 118 Update 2003 (DWR 2003).

1.1.1.2 Bottom of Basin

Continental sediments of the Tehama, Tuscan and Laguna Formation compose the major fresh groundwater-bearing formations in the valley. The base of these continentally derived formations is generally accepted as the base of fresh water in the northern Sacramento Valley (Berkstresser 1973, Olmsted and Davis 1961, as cited in DWR 2014). DWR has corroborated this assertion through analysis of geophysical logs and water quality sampling results obtained from groundwater level observation wells that were drilled, installed, and tested since the year 2000 in the northern Sacramento Valley (DWR 2014).

Locally, the base of fresh groundwater fluctuates depending on local changes in the subsurface geology and geologic formational structure (DWR 2005). In the Vina Subbasin, this is especially the case in the southeastern area of the Subbasin where marine sediments occur at shallower depths on the margins of the valley. **Figure 1-1** shows the base of fresh groundwater in the Subbasin (DWR 1973).

1.1.2 Topography, Surface Water and Recharge

1.1.2.1 Terrain and Topography

Elevations within the Vina Subbasin generally decrease from the northeast to the southwest, with elevations ranging from about 700 feet above mean sea level (msl) in the low foothill area in the east to approximately 150 feet msl along the Sacramento River in the northwest area of the Subbasin and 130 feet above msl along the boundary of Western Canal Water District. The topography encourages drainage towards the Sacramento River and to the south. More significant topographic relief occurs along the eastern margin of the basin and in the southeastern area of the Subbasin, including the Butte Valley area. **Figure 1-2** shows the topography of the Vina Subbasin.

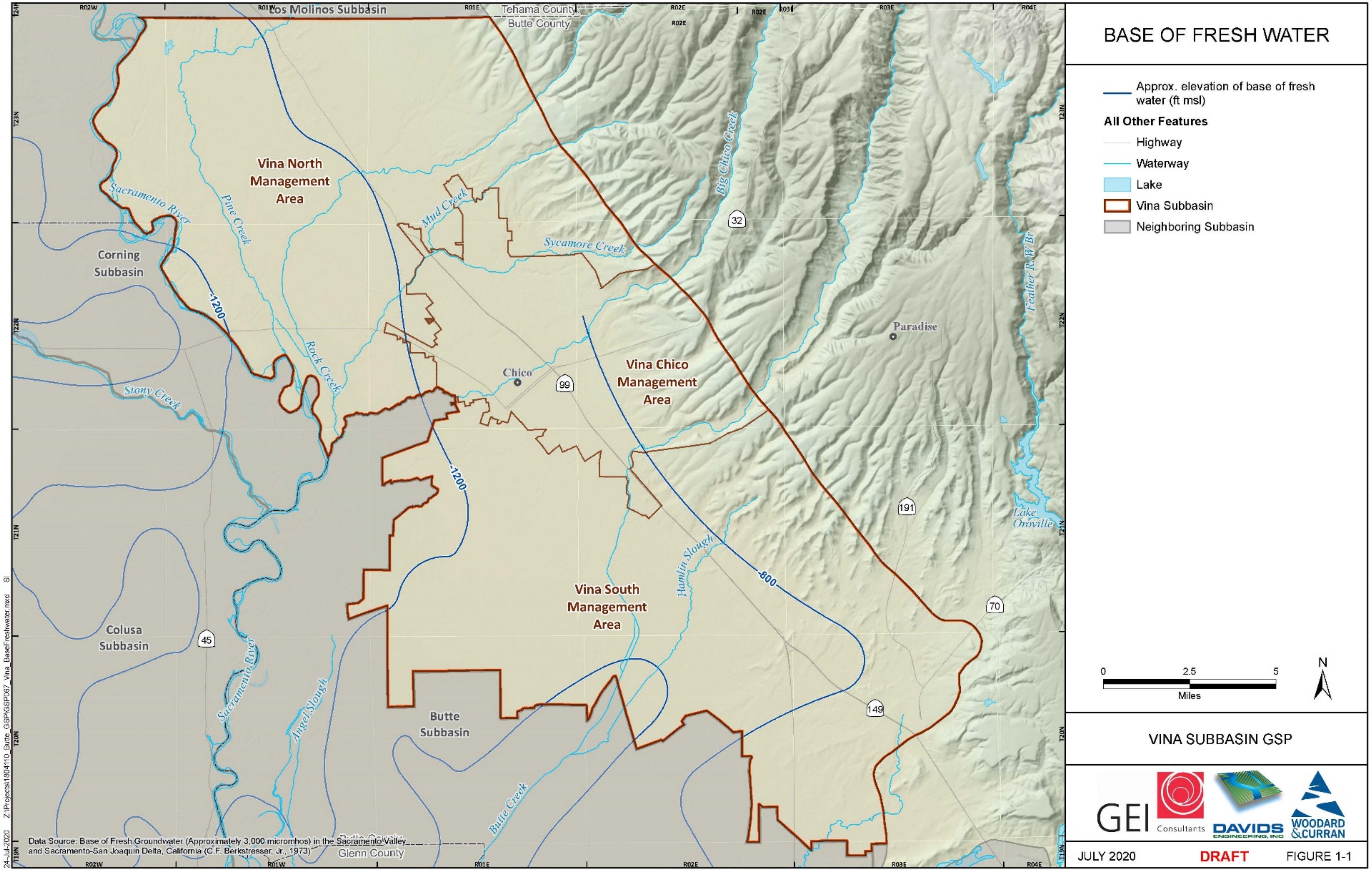


Figure 1-1. Base of Fresh Groundwater in the Vina Subbasin

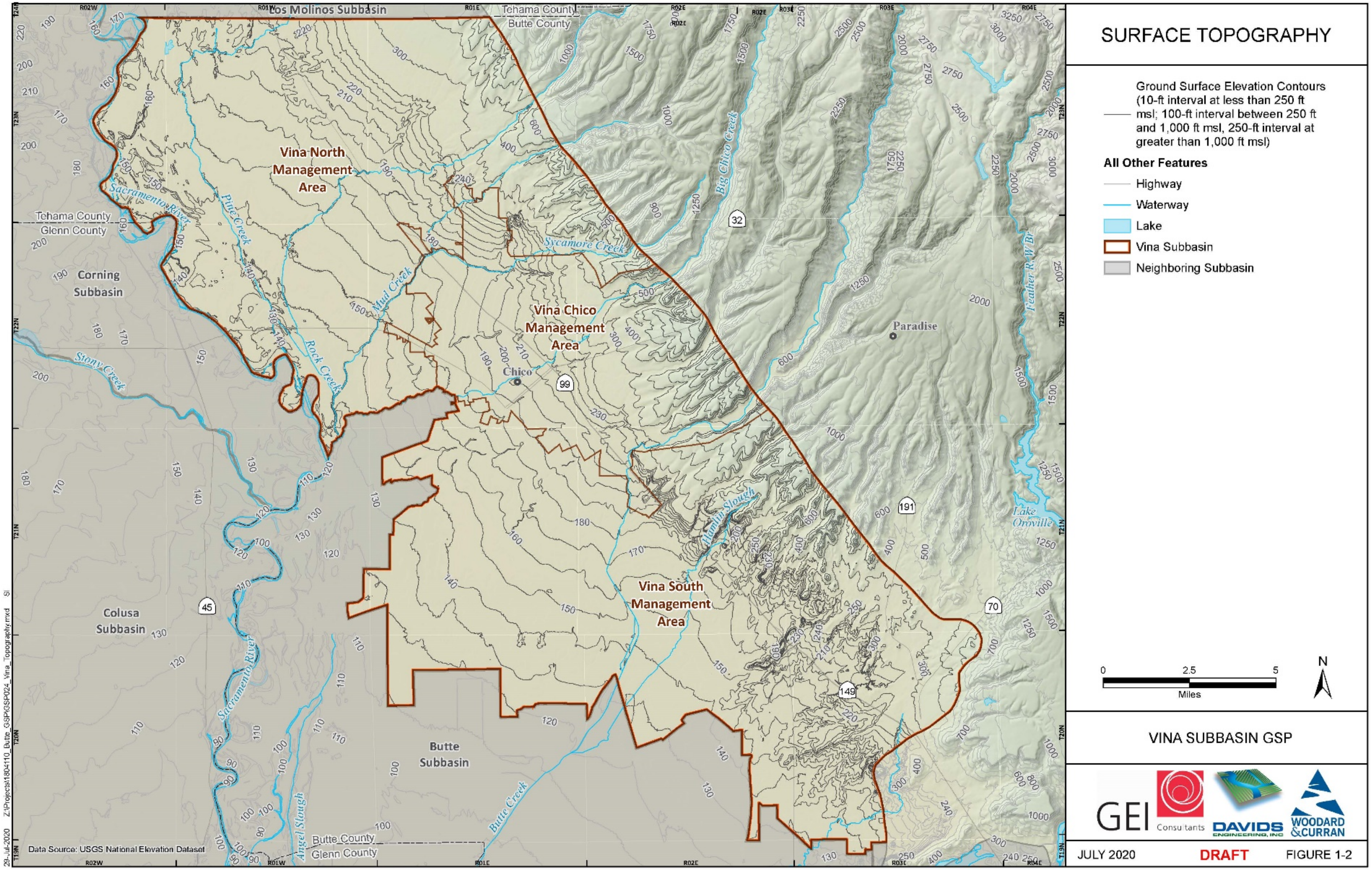
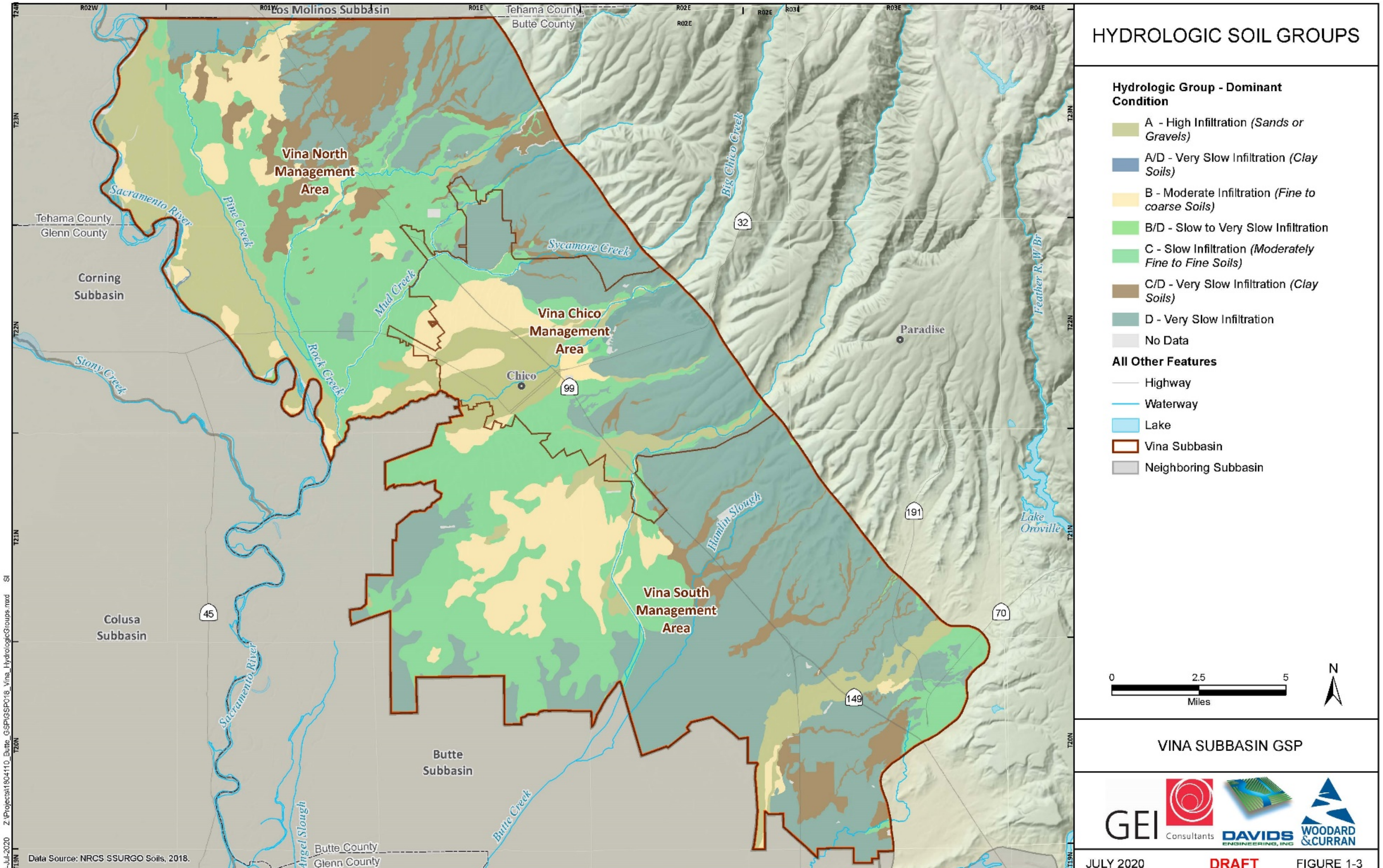


Figure 1-2. Surface Topography of the Vina Subbasin

1.1.2.2 Soils

The area generally west of Highway 99 and north of Butte Creek where the dominant crops are orchards, is underlain by lighter textured soils consisting of loamy sands and sandy loams. Heavier soils with slower infiltration or a restrictive layer located in the southeastern area of the Subbasin are well suited for growing rice. **Figure 1-3** shows the distribution of Hydrologic Soil Groups for the Vina Subbasin. Note that soils designated as C/D are lands having soils with that would have been classified as having very low infiltration rates (Group D) but have characteristics such as natural slope or management improvements that improved their drainage relative to that of similar soils.

Based on the Digital General State Soil Geographic dataset, or STATSGO2, soil data for the Vina Subbasin, the dominant soil mapping unit within the area is well-drained Vina-Brentwood (s642), which represents approximately 30.6% of the Vina Subbasin. Other common well drained soils within the Subbasin includes Toomes-Supan (16.6% of area), Vina-Riverwash-Reiff-Columbia (12.3% of area), and Stockton-Clear Lake-Capay (5.9% of area). The Corning-Anita (9.8% of area) is somewhat poorly drained. Characteristics of these soils are summarized in **Table 1-1**. The distribution of dominant soils (e.g., "map units") in the Vina Subbasin is shown in **Figure 1-4**.



216

217 **Figure 1-3. Hydrologic Soils Groups of the Vina Subbasin**

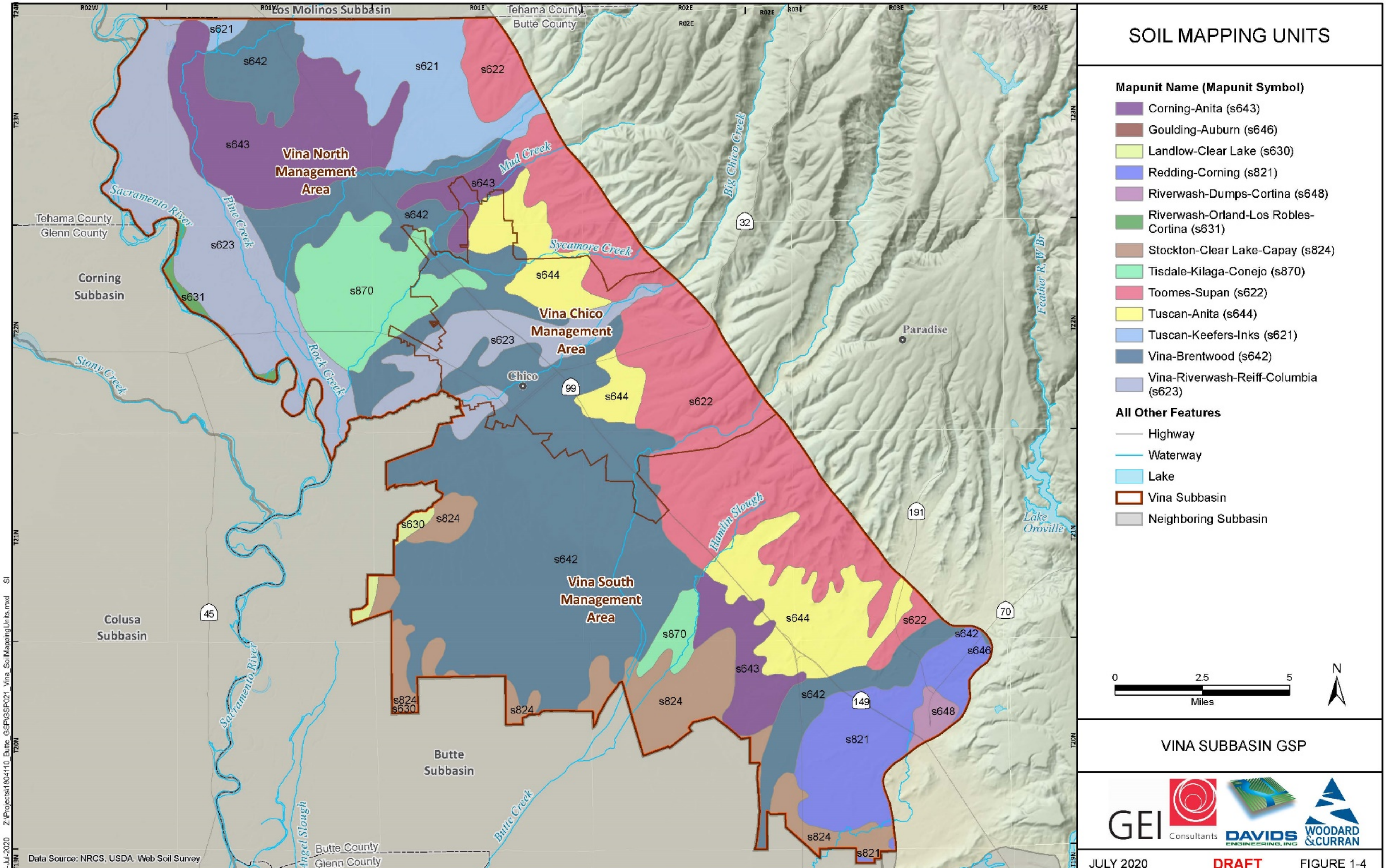


Figure 1-4. STATSGO2 Soil Mapping Units (see Table 1-1 for soil characteristics)

Table 1-1. STATSGO2 Soils Table for Vina Subbasin

Soil Map Unit	Percent of Area	Sum of Acres	Slope Range	Drainage
Vina Subbasin	**100%**	**184,918**		
Corning-Anita (s643)	9.8%	18,159	4.3	Somewhat poorly drained
Goulding-Auburn (s646)	0.0%	14	1	Somewhat excessively drained
Landlow-Clear Lake (s630)	0.4%	684	5.3	Moderately well drained
Redding-Corning (s821)	4.9%	9,121	2.6	Well drained
Riverwash-Dumps-Cortina (s648)	0.5%	936	1	Poorly drained
Riverwash-Orland-Los Robles-Cortina (s631)	0.4%	709	1	Well drained
Stockton-Clear Lake-Capay (s824)	5.9%	10,967	1.1	Poorly drained
Tisdale-Kilaga-Conejo (s870)	5.3%	9,868	2.6	Well drained
Toomes-Supan (s622)	16.6%	30,721	27.8	Well drained
Tuscan-Anita (s644)	7.6%	14,096	1.2	Well drained
Tuscan-Keefers-Inks (s621)	5.5%	10,244	25.8	Well drained
Vina-Brentwood (s642)	30.6%	56,675	3.1	Well drained
Vina-Riverwash-Reiff-Columbia (s623)	12.3%	22,723	9.4	Well drained

1.1.2.3 Surface Water

Surface Water Sources and Channels

The Sacramento River borders the Subbasin on its western side. Other larger surface water bodies traversing the Subbasin include Big Chico Creek and Butte Creek. Smaller local or ephemeral streams entering and traversing the Subbasin include Pine Creek, Rock Creek, Mud Creek, Sycamore Creek, Little Chico Creek, Hamlin Slough, Little Dry Creek, and Clear Creek. **Figure 1-5** shows the locations of rivers, streams, and major water supply, and drainage features.

Diversions from Butte Creek supply water for irrigation in portions of the Subbasin. Lindo Channel (Sandy Gulch) and the Sycamore Bypass Channel are flood control channels for the City of Chico.

At Oroville-Thermalito, Toadtown, and De Sabla-Centerville, water for power generation is transferred from the Feather River watershed to the Butte Creek watershed. Water from the West Branch of the Feather River is diverted to the Toadtown Canal for power generation and cold water for fish by PG&E. The Butte Canal carries Toadtown Canal and Butte Creek water to the De Sabla power plant forebay. Hydropower is also generated at several other locations. Operations at all of these sites affect the timing of water releases.

Stream-groundwater interaction is an important component of groundwater dynamics in the Vina Subbasin. In some areas, runoff and streamflow in creeks and streams provide a source of recharge to the aquifer system. Additionally, in some places and at times, groundwater contributes to streamflow and is an outflow from the groundwater system.

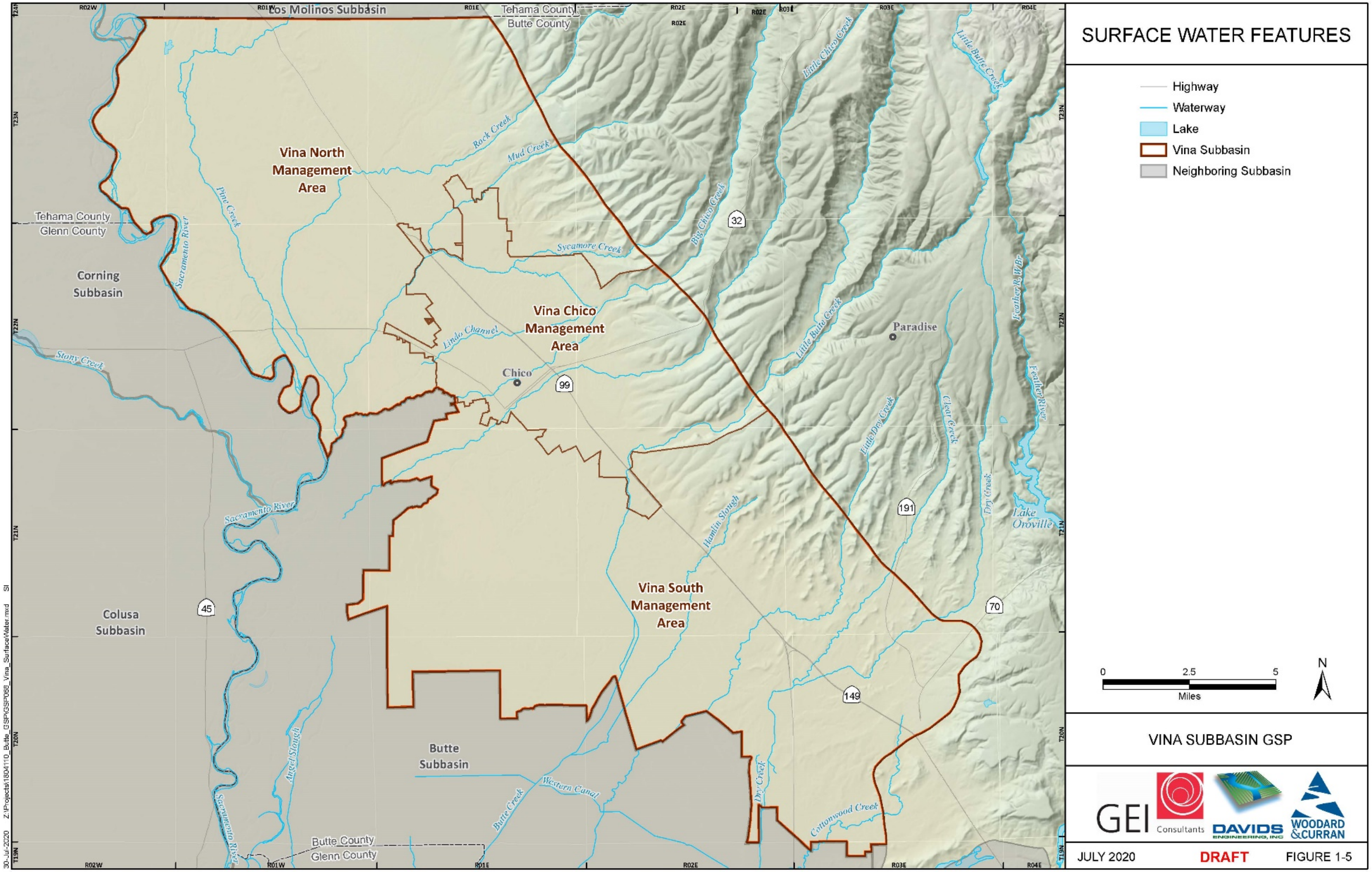


Figure 1-5. Surface Water Features of the Vina Subbasin

1.1.2.4 Groundwater Recharge Areas

Groundwater recharge is the downward movement of water from the surface to the groundwater system. This can include percolation of water from rainfall, irrigation, or water bodies (rivers, lakes). Several water sources and mechanisms recharge the groundwater system in the Vina Subbasin.

The Stable Isotope Recharge Study (Brown and Caldwell 2017) delineated three areas based on land surface elevation that are general sources of precipitation and serve as water sources to the surface water and groundwater systems in Butte County (**Figure 1-6**). Identifying these source areas and then observing the destination of that source water within the aquifer system using stable isotope analysis for samples from multi-completion wells led to insights about recharge sources and mechanisms in the Vina Subbasin.

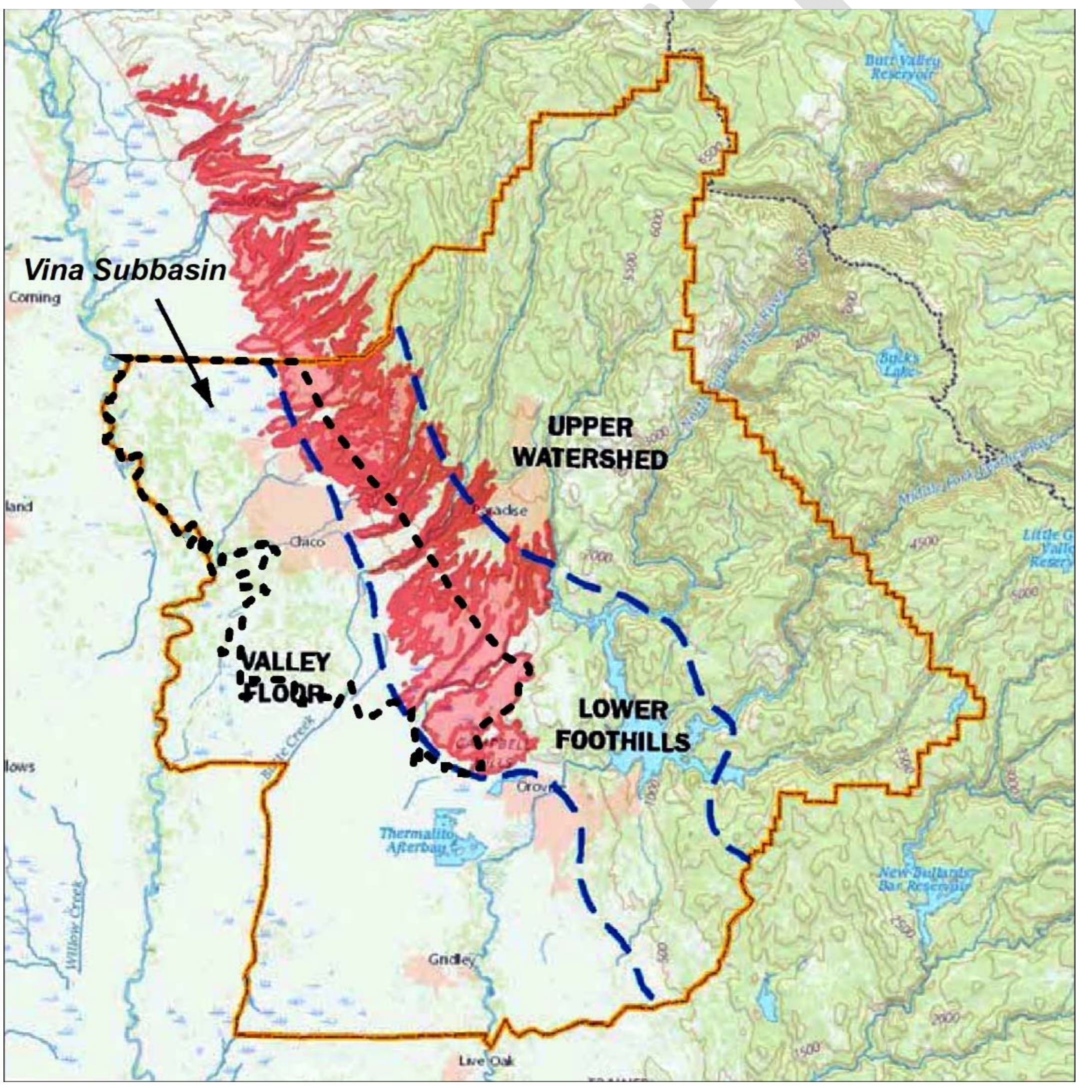


Figure 1-6. Precipitation Source Areas (Brown and Caldwell 2017 – modified to add Vina Subbasin)

The Vina Subbasin is located primarily within the Valley Floor area as shown in **Figure 1-6**. The Upper Watershed receives rain and snow, primarily during the winter and spring months. Rainfall runoff and snowmelt enters the Valley Floor via streamflow of major streams and rivers that originate at higher elevations, including Butte Creek and the Sacramento River. Geologically, the Upper Watershed consists primarily of volcanic, granitic, and metamorphic rocks that do not have any appreciable primary porosity. Fracturing within these rock units may occur locally but the fractures are not pervasive on a regional scale, which limits the amount of water that can percolate into the bedrock geologic units and the volume of groundwater available to migrate to other regions such as the valley alluvial groundwater basin on the Valley Floor (Brown and Caldwell 2017).

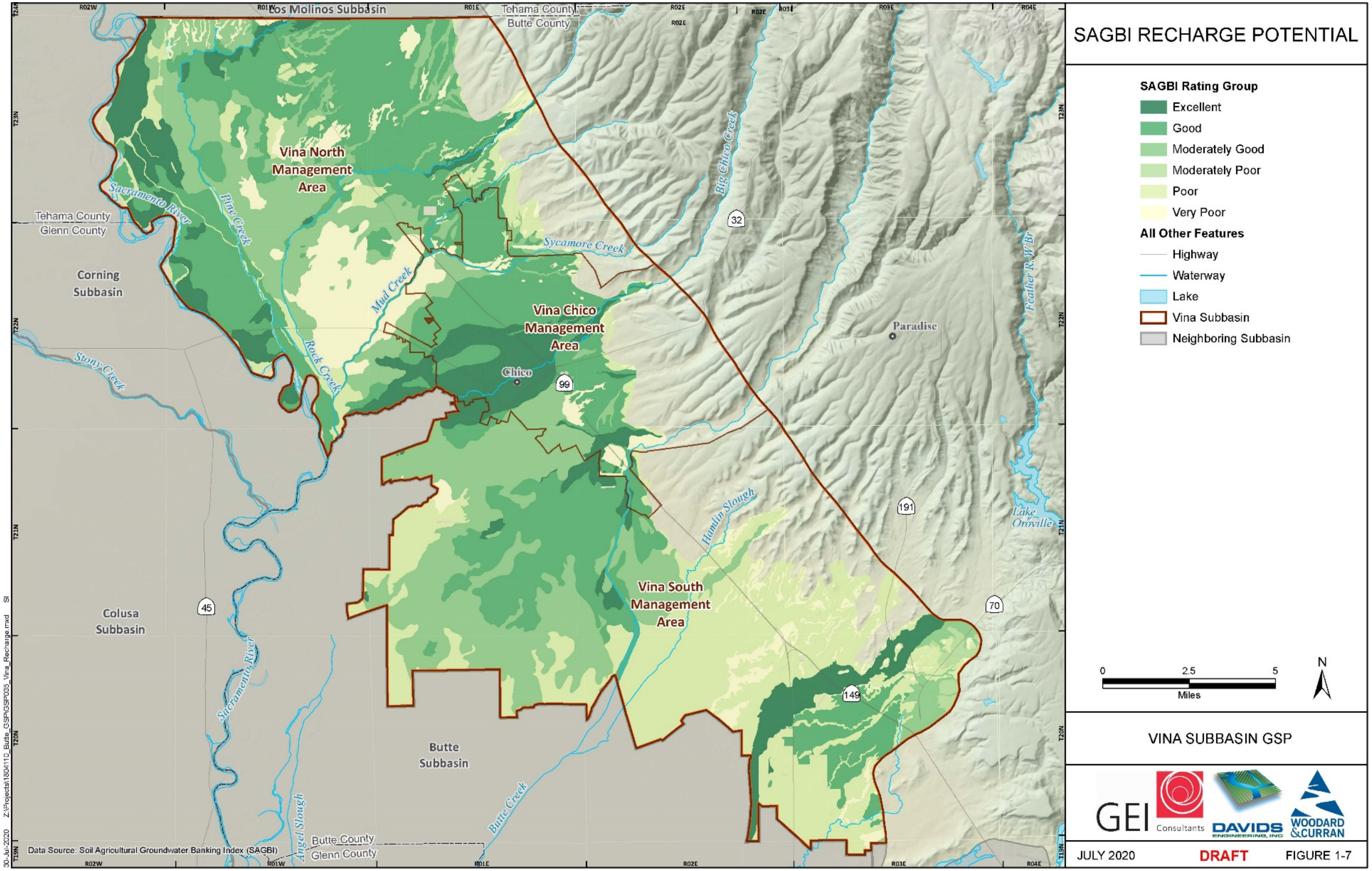
The Lower Foothills region occurs within a relatively narrow topographic band along the eastern edge of the Sacramento Valley and contains the outcrop of the Tuscan Formation in addition to small alluvial fans and other Recent sedimentary deposits that directly overlie the Lower Tuscan Formation. Rainfall that occurs in the Lower Foothills may percolate into the Tuscan Formation and the recent alluvial sediments or it may runoff through local, ephemeral streams to the Valley Floor. In both cases, this precipitation source is potentially a direct source of recharge to the aquifer system.

Recharge mechanisms vary both by depth and area across the Subbasin. Results from stable isotope data indicated the only route by which the Upper Watershed provides recharge to the groundwater system in the vicinity of Butte Creek in the Vina South Management Area is through percolation of water from water bodies (i.e., streamflow) at the surface within the Valley Floor. This includes percolation from Butte Creek and possibly the Sacramento River as they traverse the Subbasin, or via percolation of applied surface water for irrigation diverted from Butte Creek or the Sacramento River. Evidence of the Upper Watershed water source was observed in isotope data in relatively shallow portions of the aquifer system (400 feet below ground surface or shallower).

Isotope data from well samples indicated that intermediate and deeper depth intervals are recharged from rainfall and percolation in the Lower Foothills region. Rainfall in this region percolates directly into the Tuscan Formation at the outcrop or may percolate into the small alluvial fans and other sedimentary deposits in the Lower Foothills area. Aquifer testing conducted as part of the Lower Tuscan Aquifer study (Brown and Caldwell 2013) indicated there is also the potential for Upper Watershed recharge in the shallow aquifer interval to move down to greater depths due to irrigation pumping, causing a mixing of recharge sources in the intermediate and possibly deeper aquifer zones in the Vina South Management Area.

Further south and to the east in the area of the Esquon Ranch, the shallow aquifer intervals are likely to be recharged by direct percolation primarily from Valley Floor precipitation, supplemented by some rainfall recharge at the base of the Lower Foothills. The intermediate and deep aquifer intervals are recharged from the lowest elevation part of the Lower Foothills region, most likely from percolation directly into the Tuscan Formation at the outcrop or through recharge into the local alluvial fans and sedimentary deposits and subsequent downward vertical migration into deeper aquifer zones. This demonstrates that precipitation on the valley floor and in the Lower Foothill area is a predominant source of recharge for much of the Vina Subbasin.

Additional recharge through management activities of flood flows or irrigation practices has potential in the Vina Subbasin. The Soil Agricultural Groundwater Banking Index (SAGBI) is a suitability index for groundwater recharge on agricultural land based on five major factors: deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. This dataset can serve as a starting point indication for areas conducive to natural or managed recharge. Large portions of the Subbasin generally received a moderately good to good rating (**Figure 1-7**), except for in the southeastern area of the Subbasin. Additional considerations will be important for specific evaluation of any proposed recharge project.

330


331 **Figure 1-7. SAGBI Rating Group Recharge Potential**

1.1.3 Regional Geologic and Structural Setting

The regional structure of the Sacramento Valley groundwater basin consists of an asymmetrical trough tilting to the southwest with a steeply dipping western limb and a gently dipping eastern limb (Page 1986). Older granitic and metamorphic rocks underlie the valley forming the basement bedrock on which younger marine and continentally derived sediments and volcanic rock have been deposited. Along the valley axis and west of the present-day Sacramento River, basement rock is at considerable depth, ranging from 12,000 to 19,000 feet below ground surface. Overlying marine and continentally derived sediments have been deposited almost continuously from the Late Jurassic period to the present. Of these deposits, older sediments in the basin were emplaced in a marine environment and usually contain saline or brackish groundwater. Younger sediments were deposited under continental conditions and generally contain fresh groundwater. Sediments thin near the margins of the basin, exposing older metamorphic and granitic rocks underlying and bounding the Sacramento Valley sediments (DWR 2005).

1.1.4 Geologic Formations

The region is composed of a diverse mix of geologic units ranging from very productive water-bearing sedimentary units to non-water-bearing plutonic and metamorphic rocks. The main hydrogeologic unit and source of groundwater in the Subbasin is the Tuscan Formation. Other units that are less predominant are the Tehama, Riverbank, and Modesto formations (DWR 2005).

Groundwater occurs under both unconfined and confined conditions. Unconfined conditions are generally present in the surficial Quaternary Deposits and in the Pliocene deposits that are exposed at the surface. Confined conditions usually exist at a depth of 100 feet or more, where one or more confining layers rests above the underlying aquifer deposits. Although the Tuscan Formation is unconfined where it is exposed near the valley margin, at depth the Tuscan Formation is semi-confined or confined and forms the major aquifer system in the Subbasin.

Figure 1-8 is the Surficial Geologic Map for the Vina Subbasin, which shows the surface distribution of geologic units. The surface geology is composed mostly of alluvial deposits, including stream floodplains and channels. The Tuscan Formation outcrops on the eastern side of the basin and then is present at depth throughout the Subbasin as the source material of the aquifer system. **Table 1-2** provides brief descriptions of the significant geologic units that are found in the Subbasin.

The following is a discussion of groundwater producing geologic units found within the Subbasin and region.

Table 1-2. Geologic Units

System and Series		Geologic Unit	Lithologic Character	Maximum Thickness[a], ft	Water-bearing Character
Quaternary	Holocene	Alluvium, Qa	Unconsolidated unweathered gravel, sand, silt, and clay[a].	80	Deposits are moderately to highly permeable with high permeability gravelly zones yielding large quantities to shallow wells[b]. Although deposits along Chico Creek are important recharge areas[b], extensive water-bearing capacity is restricted by thickness and areal extent[a].
Quaternary	Holocene	Basin Deposits, Qb	Unconsolidated[e] fine-grained silts and clays, locally interbedded with stream and channel deposits along the Sacramento River[a].	150	Deposits are typically saturated nearly to the ground surface[b]. The low to moderate permeability results in yields of small quantity and poor groundwater quality to domestic wells[a,b].
Quaternary	Pleistocene	Modesto Formation, Qm	Poorly sorted unconsolidated weathered and unweathered gravel, sand, silt, and clay[c].	200	Moderately to highly permeable[a].
Quaternary	Pleistocene	Upper Member Modesto Formation Qmu	Unconsolidated, unweathered gravel, sand, silt and clay		
Quaternary	Pleistocene	Lower Member Modesto Formation Qml	Unconsolidated, slightly weathered gravel, sand, silt and clay		
Quaternary	Pleistocene	Riverbank Deposits, Qr	Poorly sorted unconsolidated to semi-consolidated[c] pebble and small cobble gravels interlensed with reddish clay, sand, and silt[a].	200	Water-bearing capability is limited by thickness. These poorly to highly permeable deposits supply moderate groundwater amounts to domestic and shallow irrigation wells. Deeper irrigation wells may be supplied if the wells contain multiple perforation zones[a].
Quaternary	Pleistocene	Upper Member Riverbank Formation Qru	Unconsolidated but compact, dark brown to red alluvium composed of gravel, sand, silt and with minor clay.		

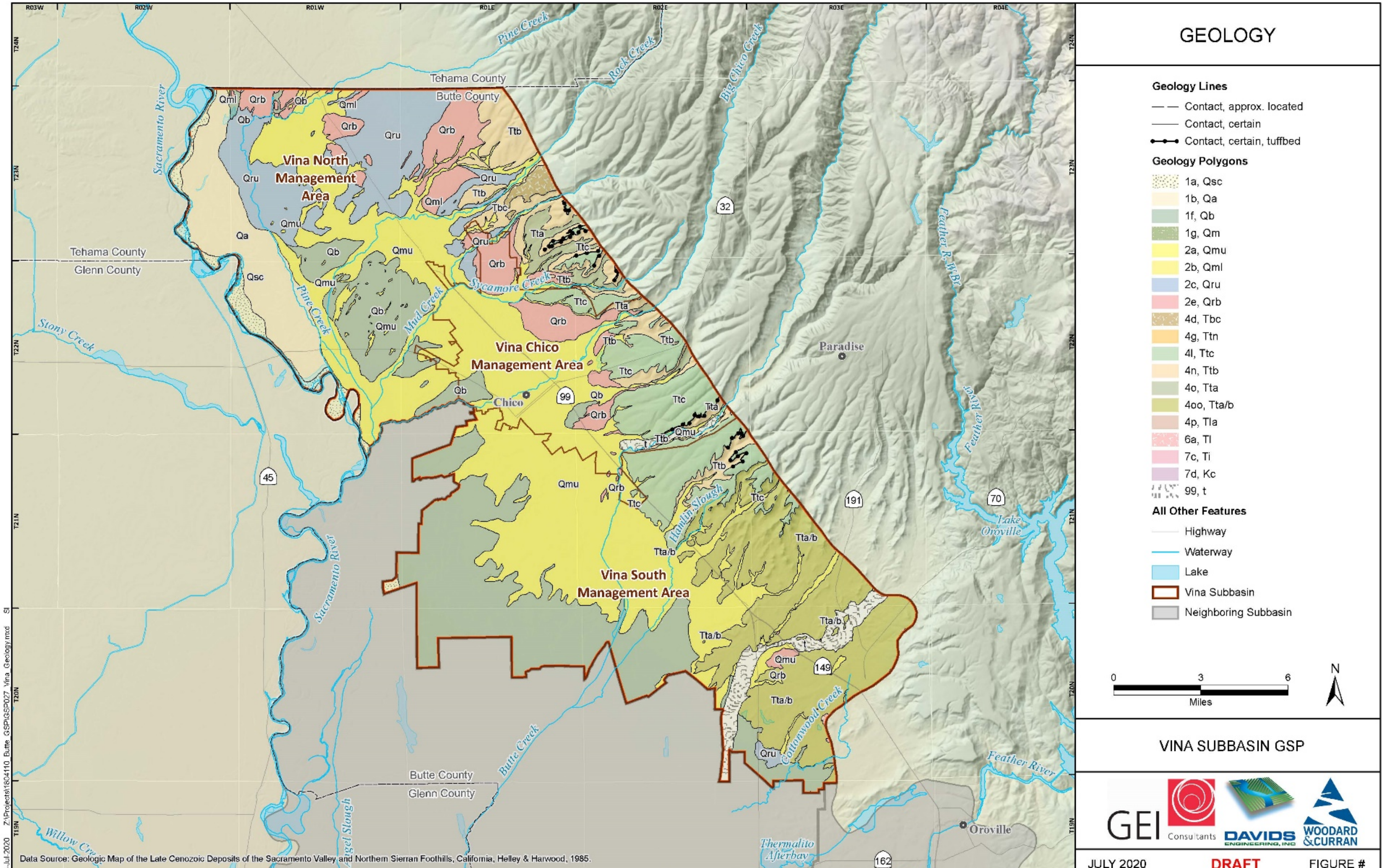
System and Series		Geologic Unit	Lithologic Character	Maximum Thickness[a], ft	Water-bearing Character
		Lower Member Riverbank Formation Qrl	Red semiconsolidated gravel, sand, and silt.		
		Red Bluff Formation Qrb	A thin veneer of distinctive, highly weathered bright-red gravels beveling and overlying the Tehama, Tuscan, and Laguna Formations		
Neogene & Quaternary	Pliocene & Pleistocene	Laguna Formation, Tla	Fluviatile moderately consolidated and poorly to well cemented; heterogeneous mixture of interbedded alluvial gravel, fine sand, silt, and clay of granitic and metamorphic origin[e].	500	Generally has low to moderate permeability, except in scattered gravels in the upper portion. Yields moderate quantities of water to wells along the eastern margin of the valley[e].
		Tehama Formation, Tte	Fluviatile moderately consolidated pale green, gray, and tan sandstone and siltstone enclosing lenses of sand and gravel; silt and gravel; and cemented conglomerate derived from the Coast Ranges[a,c].	2,000	Local high permeability zones within this characteristically low to moderate permeability unit, widespread distribution, and deep thickness cause this formation to be the principal water bearing unit in the area. Deep well yields are typically moderate but are highly variable[b].
		Olivine Basalt of Cohasset Ridge (Tbc)	Gray vesicular porphyritic basalt flows with olivine phenocrysts as much as 6 mm in diameter set in diktytaxitic matrix of plagioclase and clinopyroxene.		
		Nomlaki Tuff Member (Ttn)	White, light-gray, locally reddish-tan to salmon dacitic tuff and pumice lapilli tuff exposed in widely separated areas at or very near the bases of the Tuscan and Tehama Formations		

System and Series		Geologic Unit	Lithologic Character	Maximum Thickness[a], ft	Water-bearing Character
Neogene	Pliocene	Tuscan Formation, Tt	This series of volcanic flows, consolidated tuff breccia, tuffaceous sandstone, and volcanic ash derived from the Cascade Range interfingers with the Tehama Formation as it westerly grades into volcanic sands, gravels, and clays[a,b]. The formation is divided by layers of thin tuff or ash units into four lithologically similar units A-D[a].	1,500	Within this formation, moderately to highly permeable volcanic sediments are hydraulically confined by layers of tuff breccias and clays[b]. Units A and B are the primary water-bearing zones and are composed of volcanic conglomerate, sandstone, and siltstone layers interbedded with lahars. Stratigraphically higher, the massive lahar deposits of unit C confine groundwater in the permeable beds of units A and B1.
Neogene	Pliocene	Unit C, Tuscan Formation (Ttc)	Lahars with some interbedded volcanic conglomerate and sandstone locally, north of Antelope Creek, separated from overlying units by partially stripped soil horizon.		
Neogene	Pliocene	Unit B, Tuscan Formation (Ttc)	Defined along the Chico monocline as interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone similar to Unit C, but underlying the Ishi Tuff Member.		
Neogene	Pliocene	Unit A, Tuscan Formation (Tta)	Interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone all containing scattered fragments of metamorphic rocks.		
Neogene	Miocene	Lovejoy Basalt (Tl)	Black, dense, hard, microcrystalline to extremely grained, equigranular to sparsely porphyritic basalt.		
Neogene	Eocene	Ione Formation (Ti)	Light-colored, commonly white conglomerated, sandstone, and claystone. Argillaceous sandstone and claystone comprise about 75 percent of the Ione along the southeast side of Sacramento Valley; northward the rest of the unit consists of interbedded siltstone, conglomerate, and shale.		

System and Series		Geologic Unit	Lithologic Character	Maximum Thickness[a], ft	Water-bearing Character
	Cretaceous	Chico Formation (Kc)	Tan, yellowish-brown to light-gray, fossiliferous marine sandstone with lenticular beds of pebble to fine cobble conglomerate and minor siltstone.		

Notes:
(a) Department of Water Resources web page (www.wq.water.ca.gov).
(b) Department of Water Resources, Bulletin 118-6, 1978.
(c) Department of Water Resources, Bulletin 118-7 (Draft, not published).
(d) Department of Water Resources, Sacramento River Basin-Wide Water Management Plan-Draft, 2000.
(e) Department of Water Resources, Geology of the Northern Sacramento Valley, 2014.

364



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366 **Figure 1-8. Surficial Geology of the Vina Subbasin (units defined in Table 1-2)**

1.1.5 Groundwater Producing Formations

Groundwater resources come from the alluvial groundwater basin where spaces between gravel, sand, and clay particles of various formations store and transmit water in the aquifer systems. Principal hydrogeologic units of the Sacramento Valley groundwater basin consist of Pliocene sedimentary deposits, such as the Tuscan, Laguna, and Tehama formations, comprising primarily a semi-confined to confined aquifer system. Younger Quaternary deposits, such as the Riverbank and Modesto formations, overlie these and comprise a relatively shallow and generally an unconfined aquifer system (DWR 2005, as cited in Davids Engineering 2016). All post-Tuscan sediments in the area, including the Riverbank and Modesto formations and recent deposits of the various stream channels, are designated as Quaternary Deposits. Primary groundwater producing formations are described below.

Tuscan Formation

Tuscan Formation deposits are characterized by their Cascade Range origin and volcanic signature. The formation extends from Redding south to near Oroville, where surface exposures of the Tuscan formation are seen on the east side of the Sacramento Valley. In the subsurface, the volcanic sediments of the Tuscan Formation intermix with the metamorphic sediments of the Tehama Formation (Garrison 1962; Lydon 1968). The westward extent of the intermixed sediments generally occurs in the subsurface west of the Sacramento River (DWR 2014).

Overall, the Tuscan Formation is composed of a series of volcanic lahars (mudflows) that includes volcanic conglomerate, sandstone, and siltstone, and pumiceous tuff layers that were deposited over a period of about 1 million years (Lydon 1968; Helley and Harwood 1985). The source areas of the lahars were the eroded ancestral volcanoes, Mount Yana and Mount Maidu, that were historically located northwest and south of Lassen Peak in the Cascade Range (Lydon 1968). As the lahars flowed westward off of the ancestral volcanoes and onto the valley floor, they fanned out, causing deposition to vary in thickness and in topographic elevation. Over time, ancient streams and rivers flowed downslope over the lahars, forming channels which were then infilled with reworked volcanic sand and gravel sediments whose pore spaces contain fresh groundwater. Subsequent lahars flowed over and covered the reworked sediments, creating a confining layer over the sand and gravel aquifers (DWR 2014).

The Tuscan Formation has been divided into four units, A, B, C and D by Helley and Harwood (1985). The oldest and deepest unit, A is composed of interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone that contain minor amounts of metamorphic rocks. Overlying Unit A in places is Unit B, which is more widespread throughout the eastern part of the northern Sacramento Valley. It is composed of interbedded lahars, volcanic conglomerate, volcanic sand, volcanic sandstone, and siltstone, but no metamorphic rocks, and shows a more regularly layered sequence (Helley and Harwood 1985). Units A and B together are referred to as the "Lower Tuscan" (LT) unit. Units C and D overlie Unit B and are composed of a series of lahars with some interbedded volcanic conglomerate and sandstone (DWR 2014).

The Tuscan Formation is unconformably and intermittently overlain by the youngest deposits of the Tehama Formation toward the center of the valley; or by the Red Bluff, Modesto, or Riverbank formations; or by stream channel and basin deposits in varying locations (together, referred to as Quaternary Deposits). However, in some places the Tuscan Formation interfingers with the lower portion of the Tehama Formation in the center of the valley (Greene and Hoover 2015). In the south part of the valley, the tuff breccia of the Sutter Buttes overlies and possibly interfingers with the Tuscan Formation north of the Sutter Buttes (DWR 2014).

Tehama Formation

Exposures of the Tehama Formation are seen on the west side of the valley from Redding south to Vacaville. In the subsurface, the metamorphic and sedimentary deposits of the Tehama Formation intermix with the volcanic sediments of the Tuscan Formation (Helley and Harwood 1985). Previous studies inferred that the eastward extent of the intermixed sediments generally occurs in the subsurface west of the Sacramento River. Recent DWR efforts confirm the intermixing of Tehama and Tuscan formation sediments from analysis of lithologic cuttings and geophysical logs (DWR 2014).

The Tehama Formation is composed of noncontiguous layers of metamorphic pale green, gray, and tan sandstone and siltstone, with lenses of pebble and cobble conglomerate (Helley and Harwood 1985). The source area of the Tehama Formation sediments is the Coast Ranges to the west and, to a lesser extent, the Klamath Mountains to the north. Sediments were deposited by streams flowing from the west under floodplain conditions. These fluvial deposits are characterized by a series of poorly sorted sediments, by channels of coarser sediments in the finer-textured strata, and by the lenticular character of the coarser beds (Russell 1931 as cited in DWR 2014).

The Tehama Formation is unconformably overlain intermittently by the Tuscan Formation toward the center of the valley; or by the Red Bluff, Modesto, or Riverbank formations; or by the Stony Creek fan alluvium in varying locations. (DWR 2014)

Riverbank and Modesto Formations (Quaternary Deposits)

Together, the Riverbank and Modesto formations, along with other post-Tuscan deposits, will be referred to as Quaternary Deposits for hydrogeologic layering.

The Riverbank Formation consists of poorly to highly permeable pebble and small cobble gravels interbedded with reddish clay, sand, and silt. The formation is exposed throughout the Sacramento Valley and the San Joaquin Valley, extending discontinuously from Redding south to Merced (Marchand and Allwardt 1981). Terrace deposits of the Riverbank Formation appear in stream cuts that are topographically above the younger Modesto Formation terrace deposits. The terraces were formed by streams carrying eroded material from the surrounding mountain ranges to the base of the foothills, where they were deposited in wide alluvial fans and terrace deposits. Groundwater generally occurs under unconfined conditions. The Riverbank Formation is overlain by the Modesto Formation, basin deposits, or surficial alluvium.

The Riverbank Formation was formed by streams carrying eroded material from the Cascade Range, Sierra Nevada, and foothill areas to the base of the foothills where it was deposited in wide alluvial fans. It is present in discontinuous surface exposures, primarily from west of Oroville southward. In many places, the Riverbank Formation has been covered by more recent alluvial fan development. The thickness of the formation varies from less than 1 foot to over 200 feet, depending on location (Maps: California 1985). The Riverbank Formation primarily overlies the Laguna Formation in the southern portion of Butte County and the Tuscan Formation in the northern portion of the county (DWR 2005).

The Modesto Formation consists of moderately to highly permeable gravels, sands, and silts and is widespread throughout the Sacramento Valley, occurring from Redding south into the San Joaquin Valley. The most notable occurrences are found along the Sacramento and Feather rivers and their tributaries. The Modesto sediments were deposited by streams that still exist today, and they are seen in the terrace and alluvial fan sediments that border present-day streams (Helley and Harwood 1985). The source area for the formation sediments are the surrounding Coast Ranges, Klamath Mountains, Cascade Range, and Sierra Nevada. Fresh groundwater occurs under unconfined conditions (DWR 2014).

Wells penetrating the sand and gravel units of the Riverbank and Modesto Formations produce up to about 1,000 gpm; however, the production varies depending on local formation thickness. Wells screened in the Riverbank and

Modesto Formations are generally domestic and relatively shallow irrigation wells (DWR 2004).

1.1.6 Cross Sections

1.1.6.1 Airborne Electromagnetic (AEM) Survey

Figure 1-9A was developed using data from a 2018 study (The Stanford Groundwater Architecture Project (GAP)), which used the Airborne Electromagnetic (AEM) method calibrated to existing well data added considerable detail to the known aquifer-bearing units in portions of the Vina Subbasin (Kang et al., in preparation). Therefore, preliminary interpretations from the AEM study are presented here that have not yet been applied to areas outside the study area to contrast the value of these types of studies to understanding the overall hydrogeologic structure.

Pre-existing ideas about the aquifer units have not changed substantially, however, more detail into delineating the properties of the shallower units is now possible. In addition, all of the layers can now be represented as having more realistic lateral changes in sediment type (gravel/sand vs. silt/mud), which can be related to hydraulic conductivity and confined/unconfined conditions for more detailed groundwater studies.

Figure 1-9A is a general east-west cross-section spanning two main AEM acquisition areas. Superimposed with lithology and electric-logs from well completion reports (WCR) and monitoring wells (MW) is the AEM interpretation showing the relative probability of encountering coarse-dominated material (i.e., sand/gravel) along the cross-section (see Kang et al., in preparation, for methodology). Warm colors represent zones that have a high probability of being coarse-dominated; inversely, cold colors represent zones that have a lower probability of being coarse-dominated but have a high probability of being fine-dominated (e.g., silt/clay). The cross-section represents the overall knowledge gained from examining all 800 line-kms of the AEM study, but greater detail is available for certain individual areas.

The AEM cross-section depicts three main units previously described: 1) Tuscan Formation, 2) Tehama Formation, and 3) Quaternary Deposits. It is important to realize the Tuscan and Tehama formations interfinger within individual layers toward the western side of the cross-section. In the upper portions of the Tuscan and Tehama formations it is often not possible to know the location of that boundary; those layers are called UTT1, UTT2, and UTT3 (UTT=Upper Tuscan/Tehama). However, the lower portion of the Tuscan Formation (LT) is readily noticeable with no lower Tehama represented in the cross-section. Overlying all of these units is the Quaternary Deposits (Qd) unit which includes the Riverbank and Modesto formations.

The Lower Tuscan (LT) layer is mostly coarse-grained material that thickens to the west to 500-600 feet thick. The overlying UTT3 layer only exists in the western portion (200-500 ft. thick) and is fine-dominated with intermittent coarse-dominated channels. UTT2 is mostly a coarse-dominated unit 100 to 200 feet thick that combines with the LT in the eastern portion of the cross-section. UTT1 is mostly fine-dominated (~50 ft. thick) that has rare occurrences of coarse-dominated material within it. The Quaternary Deposits unit (Qd) is 50 to 100 feet thick and consists of mostly coarse-dominated with small zones of fine-dominated material. Finally, there is an interpreted ancient valley that formed during the time of Tuscan deposition that filled with coarse-dominated material in the vicinity of Butte Creek. This valley fill was then buried by UTT2, UTT1 and Qd sediments.

1.1.6.2 Additional Cross-Sections

Figure 1-9B is a cross-section key which shows the location of Vina cross-sections developed from studies performed by DWR (DWR 2014) and GEI Consultants (GEI 2018) and the extensions of these sections into the adjacent Wyandotte Creek and Butte subbasins. **Figures 1-9C** shows a southwest to northeast cross-section in the northern portion of the Subbasin, and **Figure 1-9D** shows a southwest to northeast cross-section in the southern portion of the Subbasin.

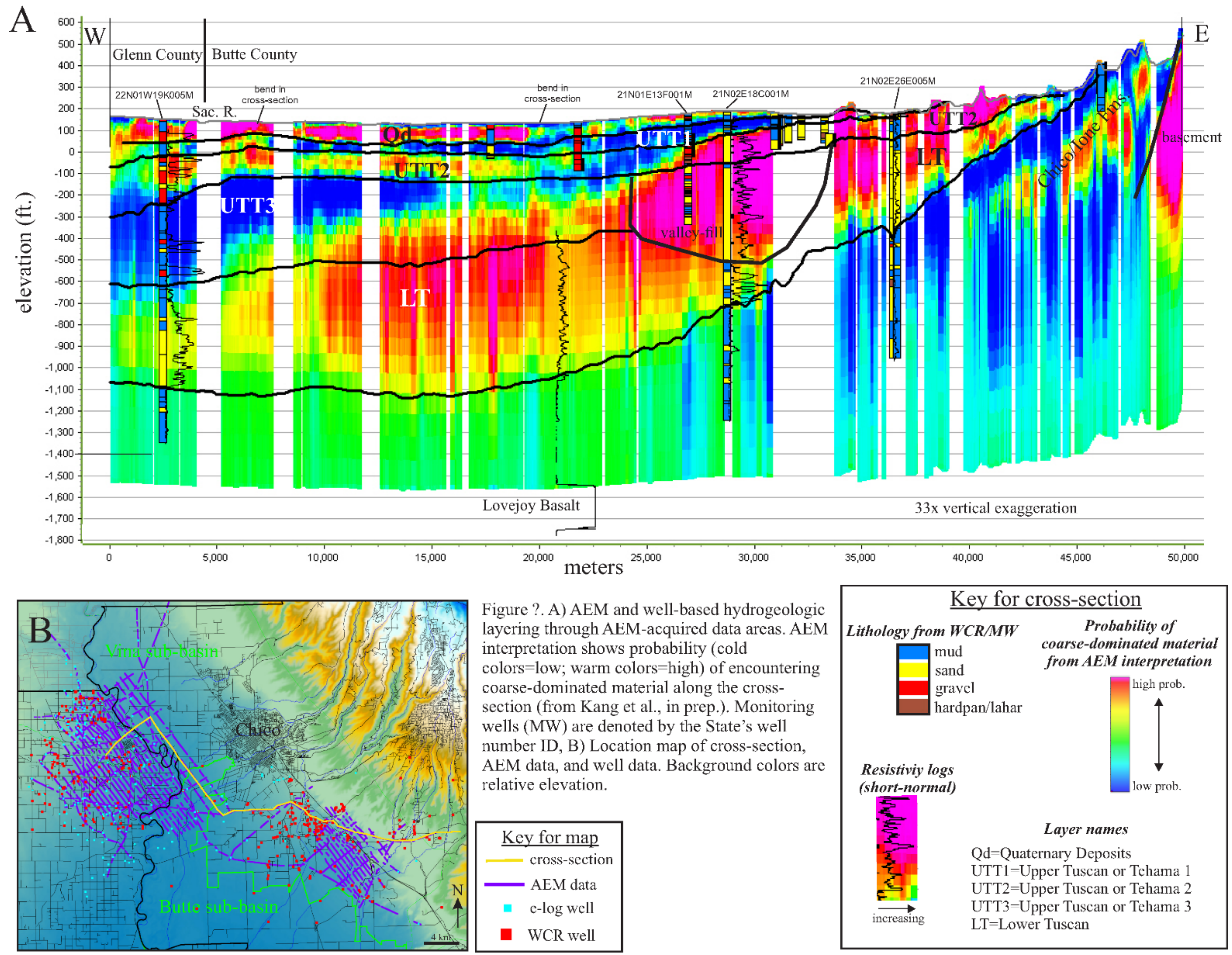


Figure 1-9A. Vina Subbasin East-West AEM Cross-Section

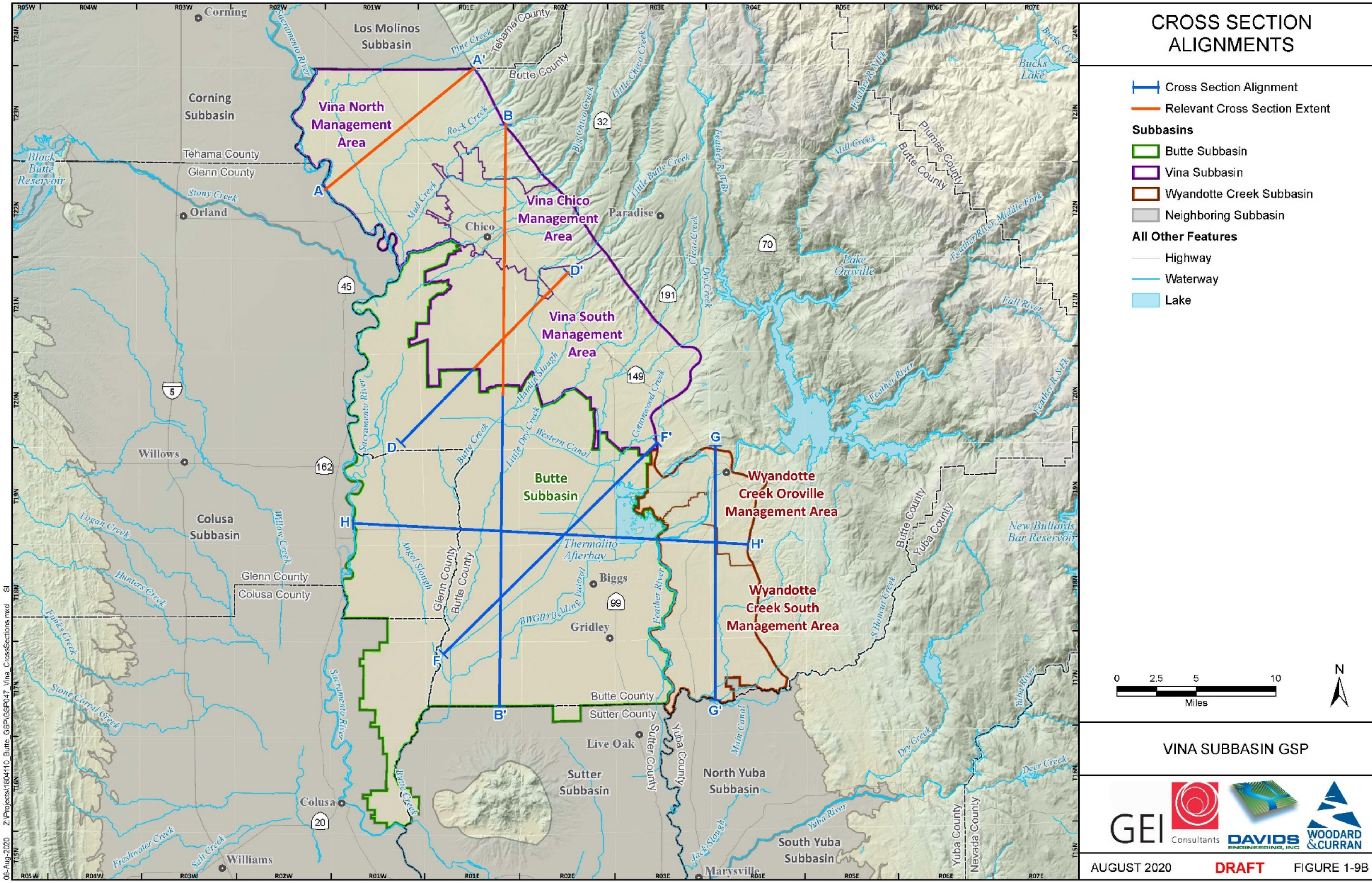


Figure 1-9B. Vina Subbasin Cross-Section Key

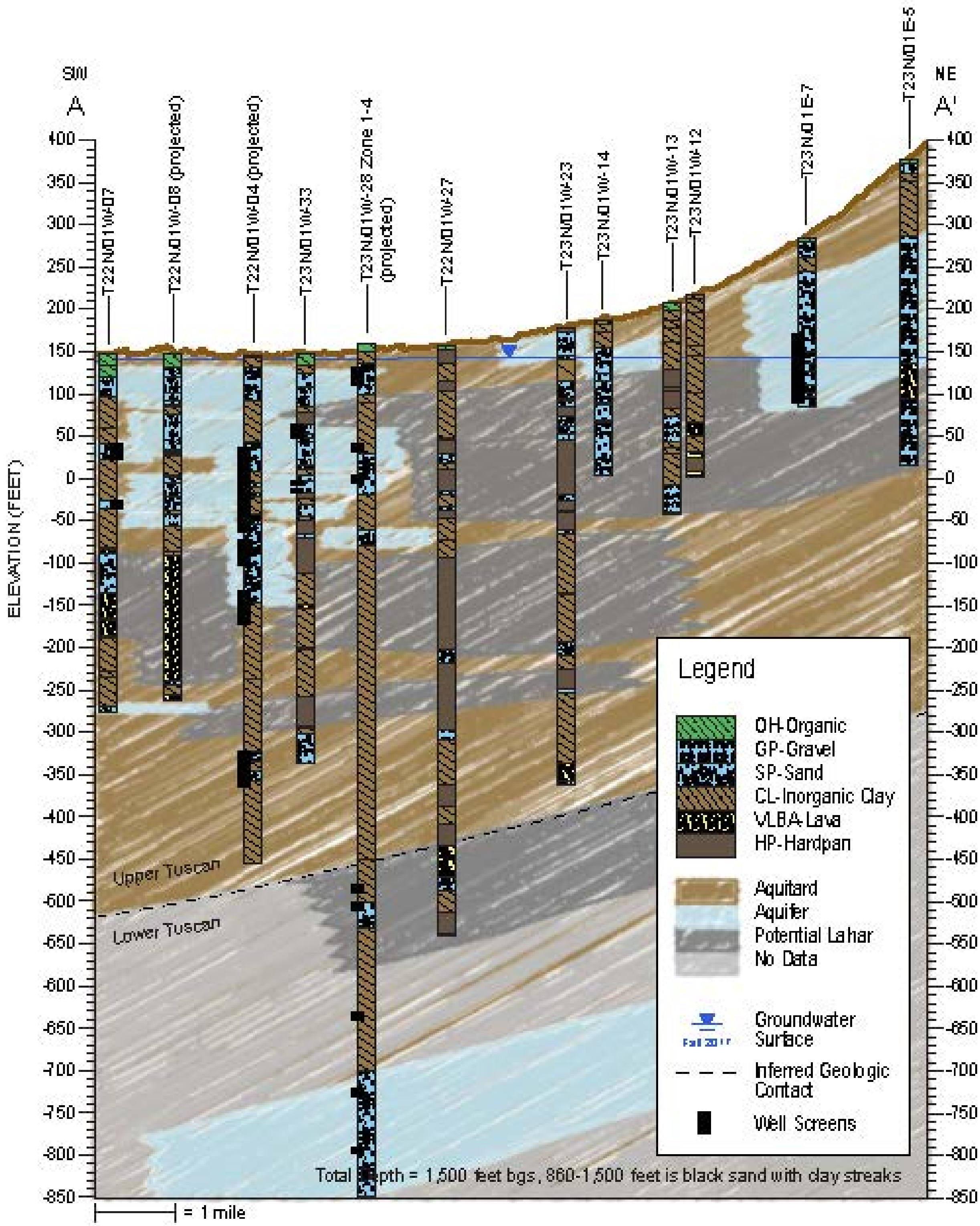


Figure 1-9C. Geologic Cross Section A-A’ (Vina North MA)

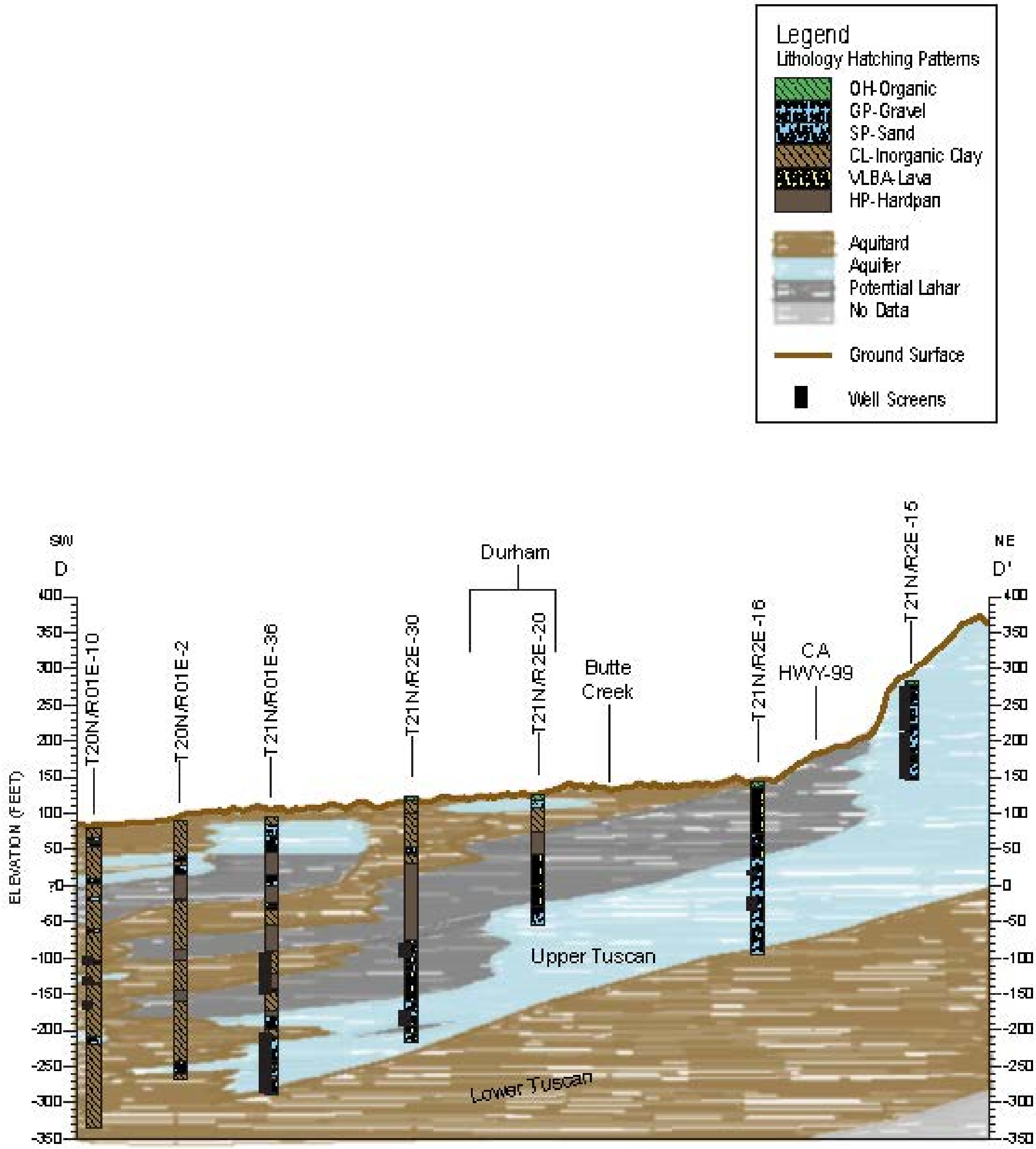


Figure 1-9D. Geologic Cross Section D-D' (Vina South tMA)

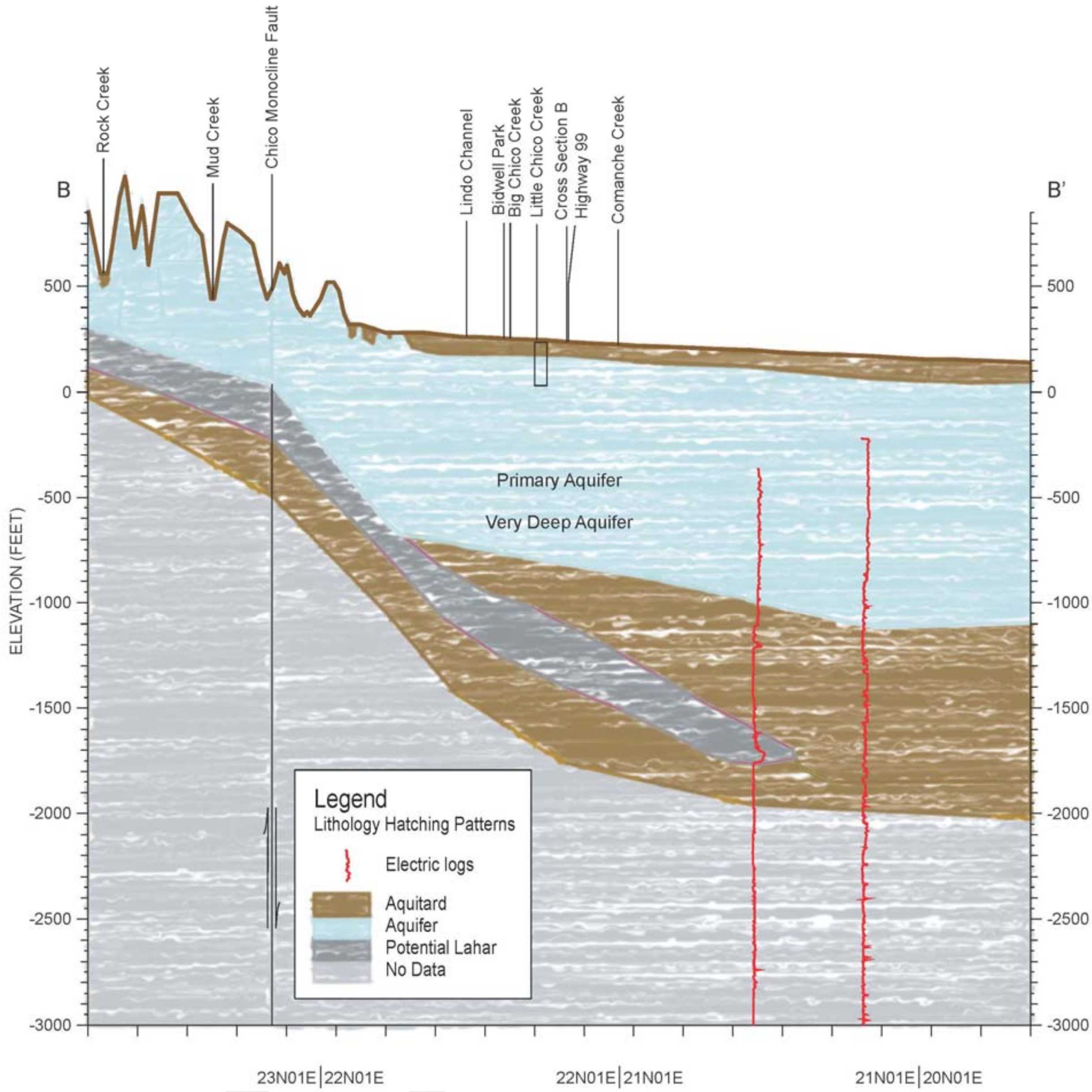


Figure 1-9E. Geologic Cross Section B-B’ (north-south section)

1.1.7 Key Geologic Features

Barriers to groundwater flow in the northern Sacramento Valley include geologic structures such as the Red Bluff Arch, the Corning domes, the Sutter Buttes, and the buried Colusa dome. In the northern part of the valley, the Red Bluff Arch acts as a groundwater divide separating the Sacramento Valley groundwater basin from the Redding groundwater basin. South of Corning, the surface expression of the Corning domes influences the flow patterns of Stony Creek and Thomes Creek. Stony Creek flows southeast of the domes, with regional flow to the confluence of the Sacramento River, whereas Thomes Creek flows northeast of the domes, against regional flow to the Sacramento River (Blake et al. 1999). In the southern part of the valley, groundwater mounds up on the north side of the Sutter Buttes before it flows westward around the Buttes and between the buried Colusa dome and southward (DWR 2014).

Chico Monocline

The Chico monocline is a northwest-trending, southwest-facing flexure that roughly follows the northeastern boundary of the Sacramento Valley, extending from Chico to Red Bluff. The monocline was formed under an east-west compressive stress regime that steeply thrust up the Sierra Mountains (Helley and Harwood 1985). This late Cenozoic tectonic feature was formed after deposition of the Ishi Tuff member of the Tuscan Formation, about 2.6 million years ago (Ma), and prior to the Deer Creek olivine basalt eruption, which has been age-dated at 1.08 + 0.16 Ma (Helley and Harwood 1985). North of Chico, the Chico monocline deforms the Tuscan Formation and has a dip of up to 25 degrees where it becomes the eastward alluvial aquifer boundary (California Department of Water Resources 1978). South of Chico, beds have a gentler slope of approximately 2 to 5 degrees, and evidence of the monocline disappears north of Oroville (DWR 2014).

1.1.8 Principal Aquifers and Aquitards

1.1.8.1 Overview

The Vina Subbasin groundwater system is comprised of a single principal aquifer composed of the Quaternary Deposits, Upper Tuscan/Tehama (UTT1, UTT2, UTT3) and Lower Tuscan (LT) units creating various zones with different hydrogeologic properties and both unconfined and semi-confined conditions. This leaky aquifer system has varied hydraulic connectivity between different depth zones in different areas of the subbasin. Due the localized variation of vertical connectivity, this is identified as a data gap.

Characteristics of the groundwater system vary from the northeast to the southwest as the Tuscan Formation materials become more reworked and less consolidated with distance from their geologic source. The aquifer system also changes in characteristics in the vicinity of the Sacramento River, Butte Creek, and the base of the eastern foothills as different processes deposited materials that make up the aquifer system at depth.

Hydrographs from nested wells show vertical gradients in the subsurface (*see* **Section 1.2.2.2**). A pump test in the northeastern area of the Subbasin (at monitoring well 23N01W03H02-04) demonstrated that in some cases low permeability lahar units caused different discrete aquifer zones to be hydraulically disconnected while in other cases the lahar layers functioned as a leaky aquitard, allowing a delayed hydraulic connection between aquifer zones (Brown and Caldwell 2013, Appendix E).

In the central area of the valley near the Sacramento River, thick fine-dominated layers of the UTT3 separate coarser-dominated materials of the UTT2 from the coarse-dominated zone of the LT (**Figure 1-9A**). Yet a pump test in the area (on M&T Ranch) demonstrated hydraulic connectivity between these zones and significant storage in the aquitard of the UTT3 separating them (Brown and Caldwell 2013, Appendix E). A pump test in the vicinity of Rancho Esquon demonstrated hydraulic connectivity between an intermediate and deeper aquifer zone of the LT unit with 100 feet or more of low permeability fines separating them. However, in the same monitoring well no connectivity was observed between the shallower aquifer zone of the UTT2 (80-150 feet below ground surface) and the LT unit's intermediate zones despite 100 feet of low permeability fines separating them (Brown and Caldwell 2013, Appendix E).

Due to the variance in hydraulic connectivity between zones in different areas of the Subbasin and between different depths, a single principal aquifer is defined. In most cases, patterns of groundwater levels in nested wells suggest some degree of connectivity. DWR defines "principal aquifers" under SGMA as the "aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems" (Cal. Code of Regs., title 23, § 351(aa)).

There are no known structural properties (i.e., faults) that significantly restrict groundwater flow within the Subbasin within the portion of the aquifer that stores, transmits, and yields significant quantities of water.

1.1.8.2 Primary Uses

Water produced from the principal aquifer is primarily used to meet irrigation, domestic, and municipal water demand. Domestic supply is largely used to meet rural residential demands. Municipal supply is largely used to meet demand from cities and towns such as Chico and Durham. Irrigation demands in the Subbasin primarily rely upon wells for applied water. Relatively shallow groundwater in some areas of the subbasin support Groundwater Dependent Ecosystems and stream flows.

1.1.8.3 Storage Coefficient

Specific yield or storativity quantifies the ability of the aquifer to hold or store water. Estimates of specific yield for areas in the Vina Subbasin range from 5.9 to 7.1 percent (DWR 2005, DWR 2004). Specific Yield applies to unconfined aquifer conditions.

Aquifer tests conducted for the Lower Tuscan Aquifer Study (2013) estimated values for storativity (S) (**Table 1-3**) for three locations within or adjacent to the Vina Subbasin. Storativity is a property of a confined or semi-confined aquifer and is typically several orders of magnitude less than specific yield as seen here.

Values for specific yield and storativity used in the calibrated Butte Basin Groundwater Model throughout the subbasin are 10 percent and 0.00001, respectively (BCDWRC 2020).

Table 1-3. Table taken from Lower Tuscan Aquifer Study Final Report (Brown and Caldwell 2013)

Summary of aquifer parameters calculated using Moench (1985) solutions			
	T (feet^2/day)	S (unitless)	K (feet/day)
Hackett Property	2,322 to 3,078	0.00004 to 0.00009	66 to 88[1]
M&T Ranch	11,550 to 20,540	0.0003 to 0.0005	321 to 571[2]
Esquon Ranch	12,230 to 23,650	0.00004 to 0.001	41 to 79[3]

1. *Assumes aquifer thickness of 35 feet.*
2. *Assumes aquifer thickness of 36 feet.*
3. *Assumes aquifer thickness of 300 feet.*

1.1.8.1 Transmissivity

Transmissivity (T) quantifies the ability of water to move through aquifer materials. The aquifer hydraulic conductivity (K) quantifies the rate of groundwater flow and is related to the transmissivity and aquifer thickness (b) by the following formula: T = K x b. Aquifer tests conducted for the Lower Tuscan Aquifer Study (2013) estimated values for hydraulic conductivity (K) and transmissivity (T) (Table 1-3) for three locations within or adjacent to the Vina Subbasin.

Estimates for transmissivity can vary widely in different areas of the Subbasin. Results from an aquifer performance test utilizing a well designed and constructed to draw water only from the lower confined portion of the Tuscan Formation calculated aquifer transmissivity to be approximately 75,000 gpd/ft (10,026 $feet^2$/day). From the same test, storativity was estimated between 0.0001 and 0.00001. This test was conducted in the Butte County portion of the Bulletin 118-2003West Butte Subbasin (CDWR 1995, as cited in DWR 2005).

In the Lime Saddle area, transmissivity values in the confined portion of the Tuscan Formation were estimated to be low: 1,100 gpd/ft (147 ft^2/day) (Slade, July 2000 as cited in DWR 2005).

1.1.8.2 Water Quality

The DWR Bulletin 118 Vina Subbasin Report (DWR 2004) characterized the water quality of groundwater in the Subbasin as predominantly Calcium-magnesium bicarbonate and magnesium-calcium bicarbonate. Total dissolved solids range from 48- to 543-mg/L, averaging 285 mg/L (DWR unpublished data as cited in DWR 2004). Impairments include localized high calcium and high nitrates and total dissolved solids in the Chico area. **Section 1.2.4** contains a more extensive description of water quality conditions in the Subbasin.

The Lower Tuscan Aquifer study also conducted water quality analysis on monitoring well and pumping wells used in the study and constructed piper diagrams. They show groundwater samples from these wells indicate Calcium bicarbonate waters (Brown and Caldwell 2013).

1.1.9 HCM Data Gaps

1.1.9.1 Identify areas in the County where additional monitoring would help increase understanding of the aquifer

Determine the best approach for increasing monitoring in these areas such as installation of new wells or increased monitoring at existing wells.

1.1.9.2 Assess Interaction between Sacramento and Other River Stage Response to Changes in Groundwater Levels

It is recommended additional studies be conducted to better assess the interaction between the river stage on the Sacramento River, Feather River, and other major tributaries with changes in groundwater levels in the Lower Tuscan Aquifer and other aquifers that may also provide water to the Lower Tuscan Aquifer.

1.1.9.3 Expand Isotopic Analysis to Further Assess Groundwater Recharge

Future recharge and aquifer studies should include the collection and interpretation of stable isotope data. Methodology considerations include: 1) Seasonal sampling should be performed as part of future surface water and groundwater isotope studies for purposes of assessing groundwater recharge. 2) Monitoring wells with multiple screened intervals (multi-completion monitoring wells) are recommended to assess stable isotope data at different depths. Sampling locations in this study with a single well-screen interval do not provide nearly as much insight as sampling locations with wells screened at multiple depths in discrete zones. 3) Monitoring wells with relatively short screened zones (20 ft. or less) are preferred to minimize mixing between aquifer zones or between aquifer zones and residual water retained within the aquitard zones between aquifers. The Lower Tuscan Aquifer study determined that the aquitards can release large volumes of water to the aquifer in areas where large volumes of groundwater are extracted.

1.1.9.4 Characterize recharge source with general water quality analysis

Conduct general mineral analysis on groundwater samples to evaluate whether elevated electrical conductivity (EC) values observed during sampling are due to irrigation influences (e.g., elevated nitrate, calcium, sulfate) or due to proximity to the Ione Formation (e.g., elevated sodium, chloride, and boron).

1.1.9.5 Contribution of recharge from rainfall directly on the Lower Tuscan outcrop

Stable isotope abundances indicate that a substantial proportion of local recharge is derived from elevations consistent with the outcrop of the Lower Tuscan Formation (i.e., within the Lower Foothills in **Figure 1-6**). Thus, it is recommended that local precipitation be collected during an entire precipitation season at varying elevations across the outcrop and analyzed for stable isotopes to better correlate or calibrate the groundwater isotope values with local precipitation sources.

1.1.9.6 Recharge rate

Most well locations and depths should be sampled and analyzed for presence of tritium to help distinguish whether recharge to individual aquifer zones is occurring over periods shorter than about 60 years, or whether recharge is occurring over longer timeframes. This can help better understand the nature of hydraulic connection between different zones in the aquifer system.

1.1.9.7 Field testing and monitoring equipment installation to understand the recharge rates and stream losses in the recharge zone

Expansion of stream gauging locations should occur to document and better understand changes in stream-aquifer interactions. In addition to the stream gauging, a series of shallow dedicated monitoring wells with temperature sensors installed along stream courses in the recharge corridor and downstream to the Sacramento River may help identify what sections of streams are losing or gaining.

1.1.9.8 Additional AEM data collection

Expanding the extent of aerial electromagnetic (AEM) surveys is recommended to help address uncertainty in the structure of the Subbasin and to refine the 3D hydrogeological conceptual model of the subsurface. AEM data may also help identify and better characterize recharge mechanisms and the connectivity between aquifer layers.

1.2 Groundwater Conditions

1.2.1 Description of Current and Historical Conditions

Groundwater conditions in the Vina Subbasin are continually monitored and are comprehensively described in the 2001 and 2016 Water Resource Inventory and Analysis Reports produced by Butte County. These documents and other reports portray a subbasin that has adequate groundwater resources to meet demands under most hydrologic conditions. However, comparison of the reports illustrates how in the period between their issuance, groundwater conditions have tightened, and as forces ranging from population growth to climate change play out, the value of well-informed water management policies and practices is likely to increase. In short, while as shown below, groundwater conditions in the Subbasin remain stable, maintaining this posture in the future may become less the result of a state of nature and more the reward for thoughtful management. The water budget analysis presented in this section provide a quantitative assessment of how conditions have changed in the Vina Subbasin and an indication of how conditions may change in the future.

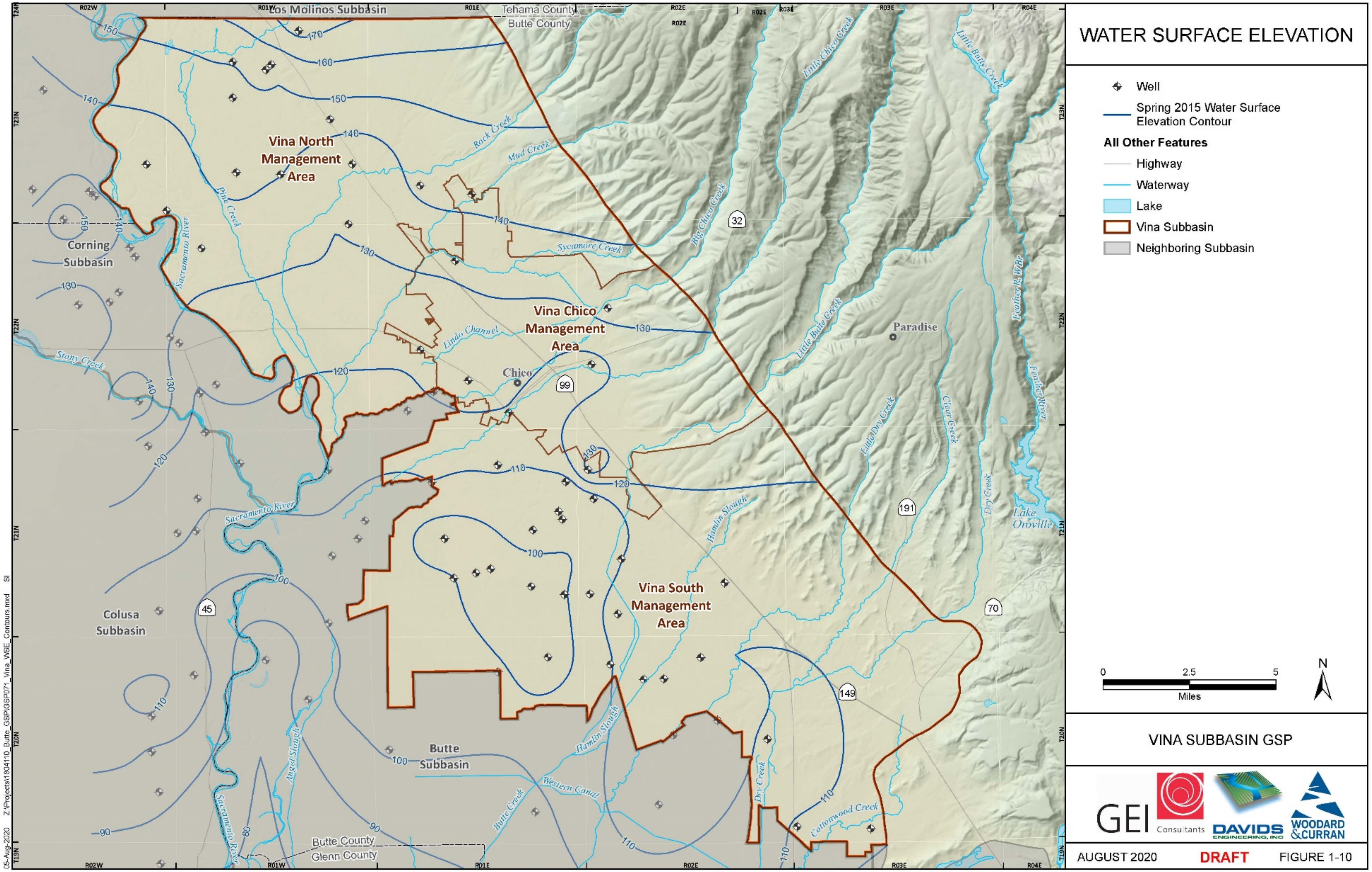
1.2.2 Groundwater Trends

1.2.2.1 Elevation and flow directions

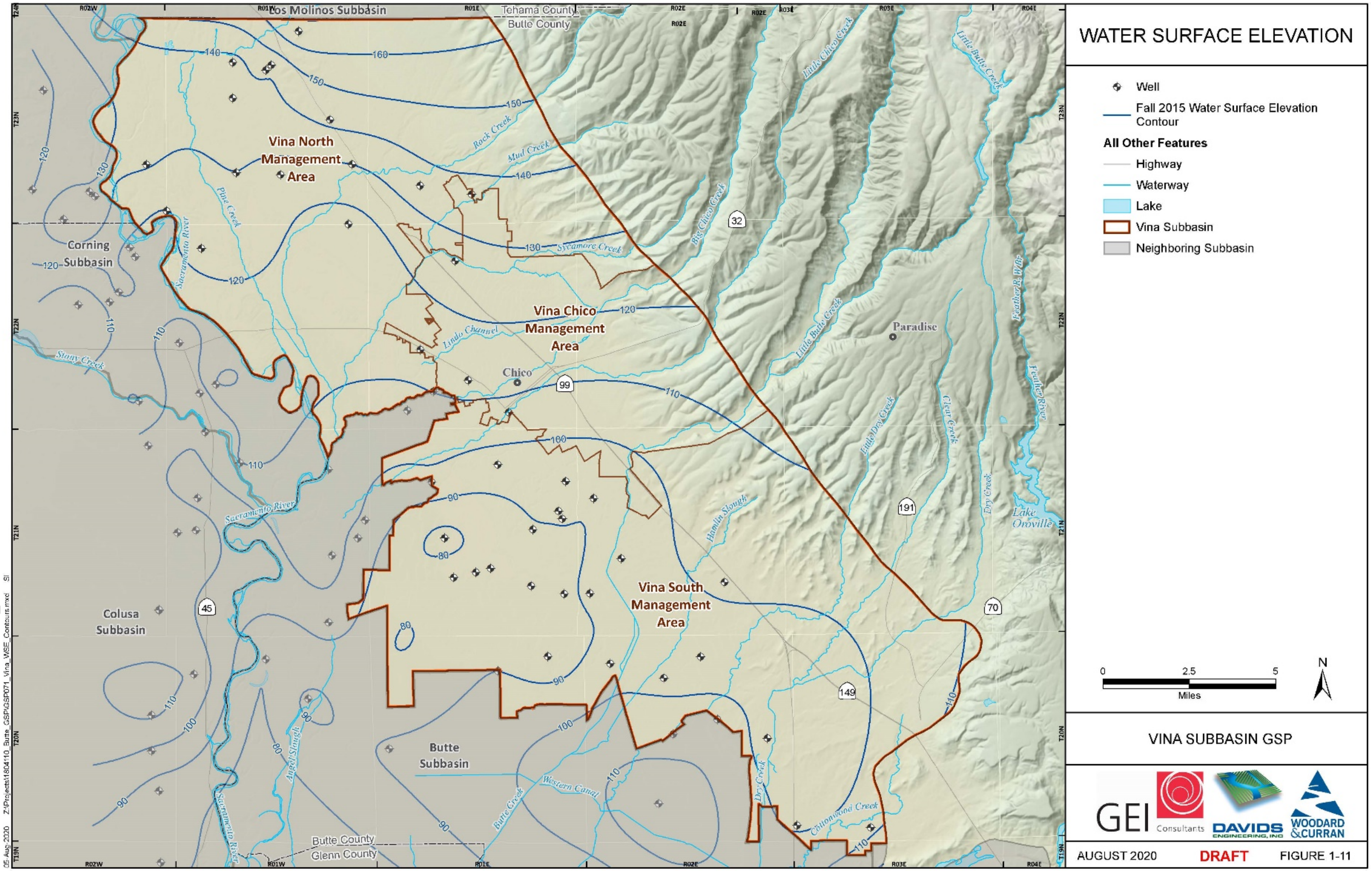
Figures 1-10 and **1-11** show groundwater elevation contours in the Vina Subbasin for the spring and fall of 2015 and **Figures 1-12** and **1-13** show elevation contours for the spring and fall of 2019. These contours show first encountered groundwater as reported by the California Statewide Groundwater

Elevation Monitoring (CASGEM) program. The data were processed as follows:

- Data from CASGEM were used to identify wells in the Vina Subbasin plus supplemental sites used to extend the contours to the west.
- Water level readings for 2015 and 2019 were then filtered for measurements taken between September 20th and October 30th for the fall contours and between March 20th and April 30th for the spring contours.
- Wells showing depths to first encountered groundwater deeper than 500 feet were eliminated from the data set. The remaining readings were sorted by well depth. Wells having identical state well number site codes were then filtered to select the shallowest well from each nested well cluster.



808
809 Figure 1-10. Water Surface Elevation Contours – Spring 2015



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811 Figure 1-11. Water Surface Elevation Contours – Fall 2015

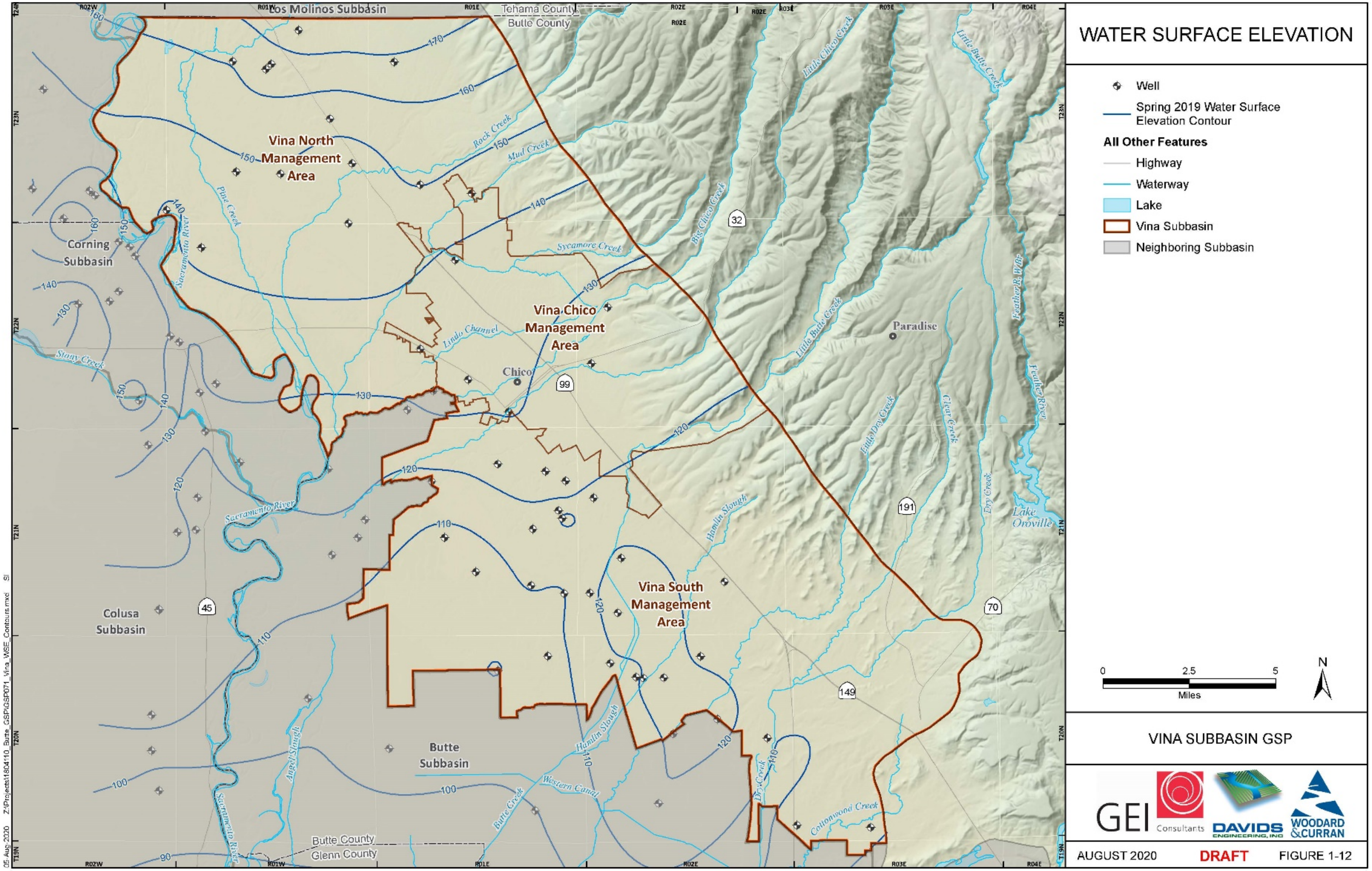
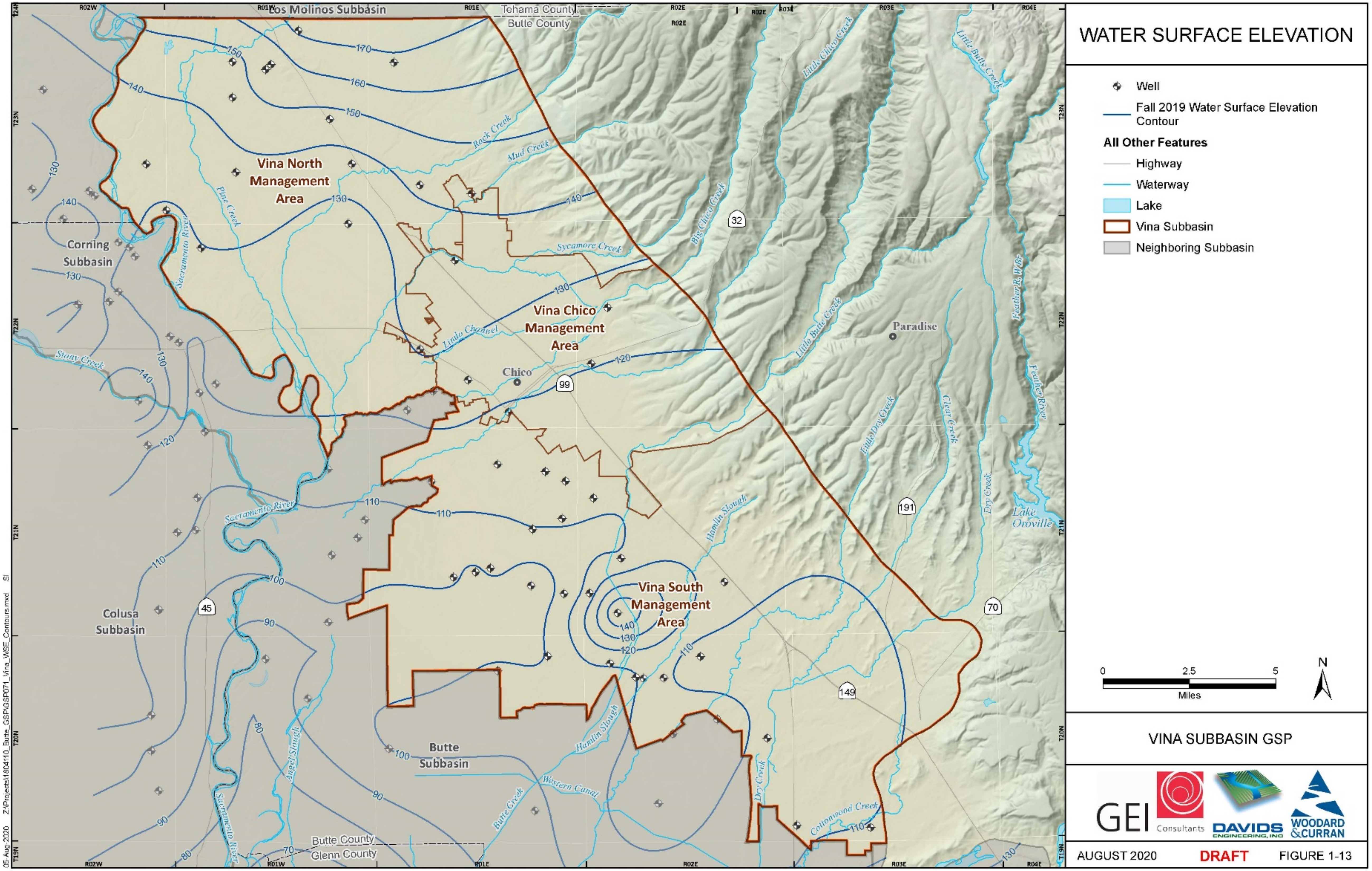


Figure 1-12. Water Surface Elevation Contours – Spring 2019



814
815 **Figure 1-13. Water Surface Elevation Contours – Fall 2019**

Each of the four contour maps displays groundwater elevations that are higher in the north of the Subbasin than in the south indicating a gradient that would cause water to flow from north toward the southwestern corner of the Subbasin. While groundwater elevations are lower in the fall than in the spring, the general direction and gradient of flow are similar during both periods.

When comparing elevations reported in 2015 with those reported in 2019, groundwater elevations reported for the spring of 2015 are generally somewhat higher than those observed in the spring of 2019. However, elevations reported for the fall of 2015 are slightly lower than those observed in 2019. This may be an indication of an increase in the volume of water recharged from upland areas flowing into the Subbasin's principal aquifer during subsequent wet years (2017 and 2019).

1.2.2.2 Lateral/vertical gradients

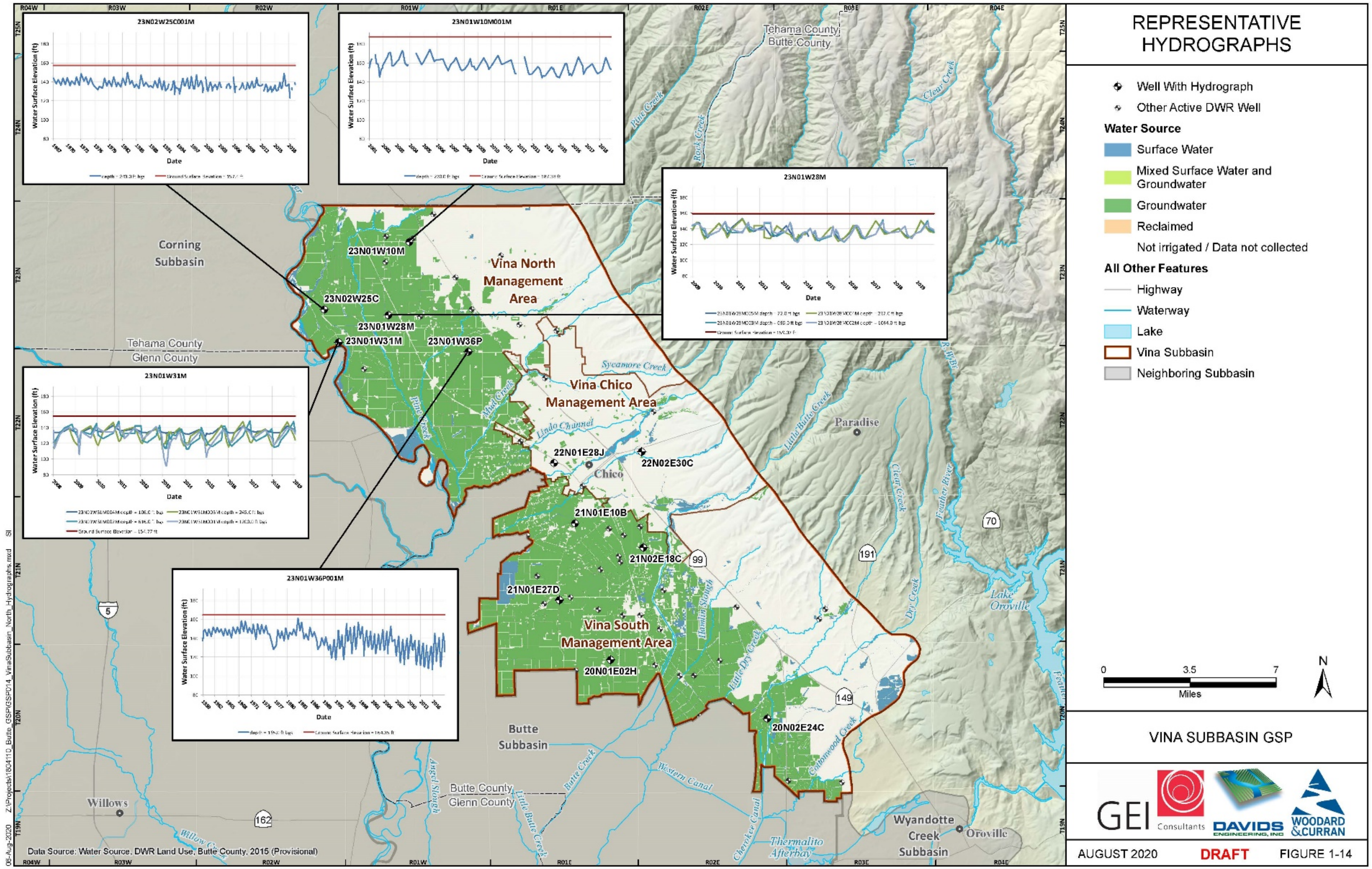
Lateral groundwater gradients generally reflect ground surface topography. In the foothills east of the Sacramento Valley the gradient is steep, as high as 60 feet per mile. However, the gradient in most of the Vina Subbasin is gentle reflecting the area's flat topography and the presence of the Sacramento River. Although the overall gradient is relatively flat, there are locations in the Subbasin where local conditions affect the direction and gradient of flow such as the groundwater depression under the City of Chico, where groundwater flows toward the depression. A second localized condition is a depression in the Durham area.

Regionally, there is a groundwater mound near the Thermalito Afterbay, where groundwater flows outward from the groundwater mound. Another groundwater mound occurs near Hamilton City fed by the Stony Creek Fan.

Figures 1-14, 1-15, and **1-16** are maps of the Vina - North, Vina - Chico and Vina - South Management areas with hydrographs of key monitoring wells displayed on each map. Just as comparison of the spring and fall contours indicated the shift in groundwater elevations that typically occurs between the seasons, the hydrographs display annual oscillations in elevations as well as trends over the monitoring period, snapshots of which are captured in comparison between the 2015 and 2019 contours. Each of the hydrographs displays water surface elevations in feet above mean sea level and also gives the depth of the bottom of the well which indicates the location of the zone being measured.

Most of the hydrographs are taken from single completion wells where only one aquifer zone is screened, however a number of the hydrographs are from clusters of nested monitoring wells which measure groundwater elevations at three or four aquifer zones at a single location.

Hydrographs for the selected wells in the Vina-North Management Area echo the seasonal fluctuations illustrated in the contour maps with depths at all locations being shallower in the winter and spring than in the summer and fall. Most of the hydrographs show annual changes in groundwater levels oscillating around a central axis with the three wells lying in the interior of the Management Area showing declines in annual high and low readings that correspond to the period of the recent drought while the water levels in the well located between the Sacramento River and Harbean Slough show little impact from the drought.



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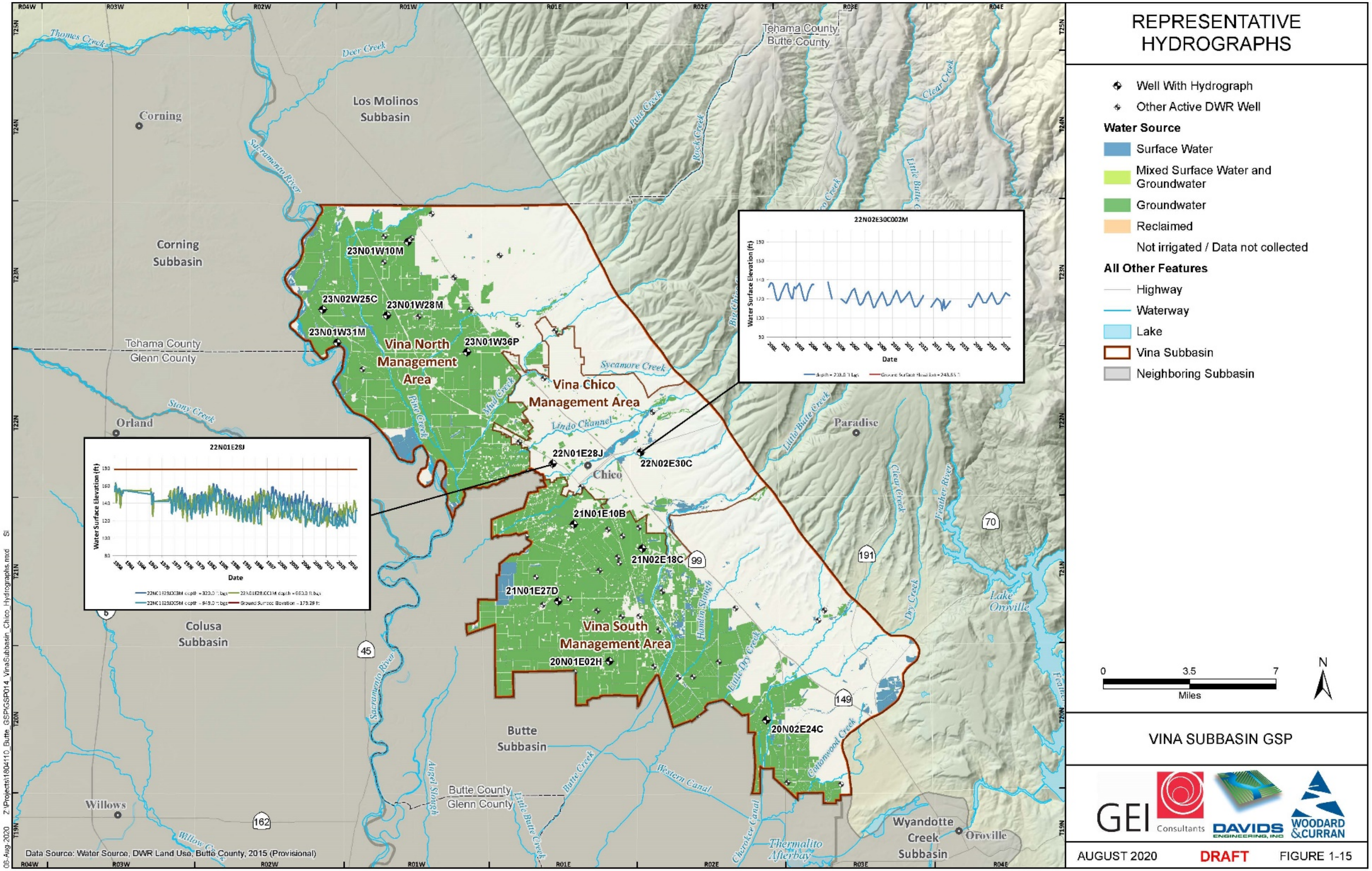
866 **Figure 1-14. Selected Hydrographs (Vina North MA)**



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868 Figure 1-15. Selected Hydrographs (Vina Chico MA)

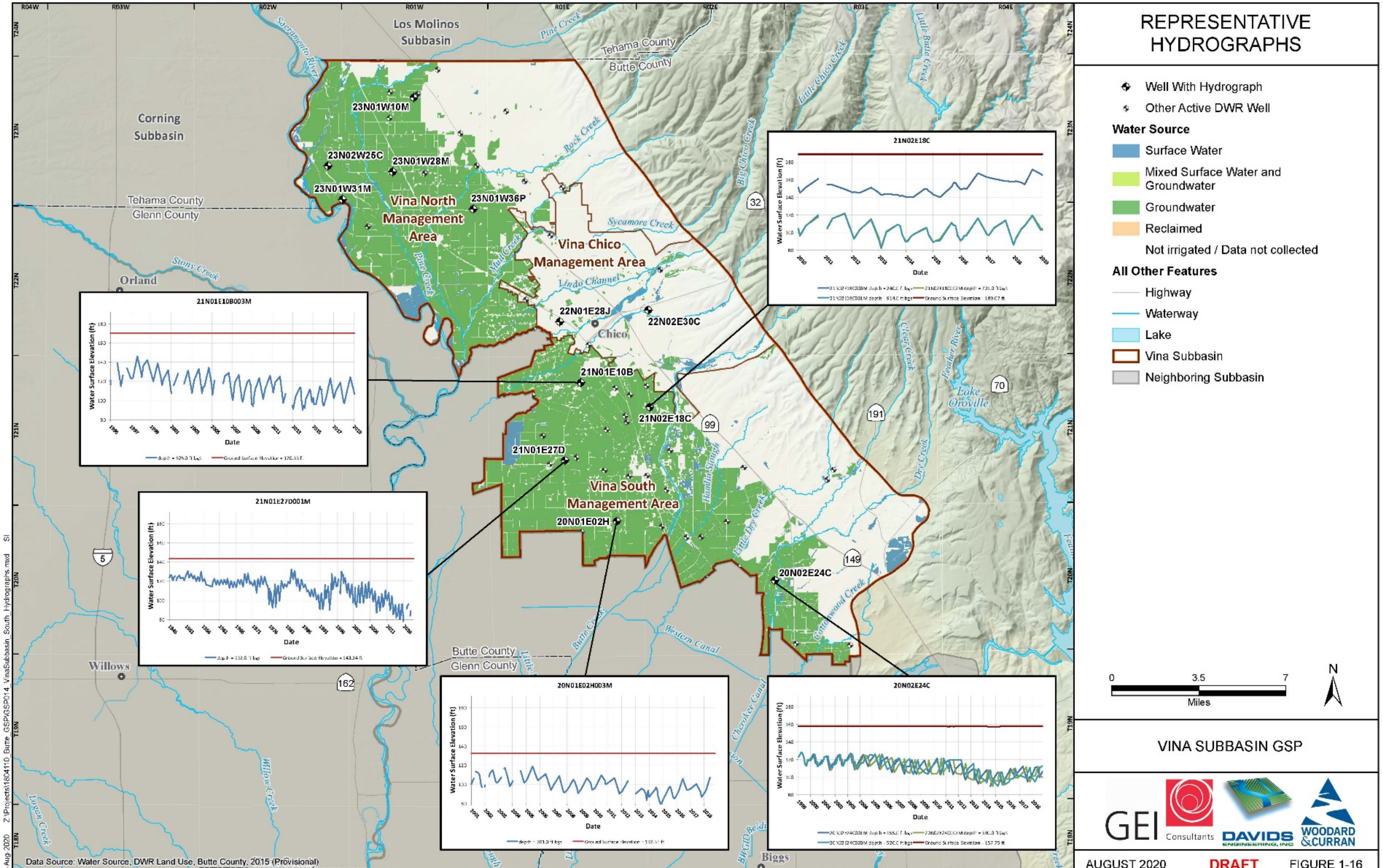


Figure 1-16. Selected Hydrographs (Vina South MA)

Vertical groundwater gradients are typically measured by comparing groundwater elevations using multi-completion or nested wells that are designed to measure elevations from different aquifer zones. If groundwater levels in the shallower wells are higher than in the deeper completions, the gradient allows downward movement of groundwater. In locations where groundwater levels in the shallower wells are lower than in the deeper wells, the gradient encourages upward movement of groundwater. In locations where groundwater levels are similar in elevation and track each other in fluctuations, there is no vertical gradient and no vertical movement of groundwater.

The hydrographs of the nested well located adjacent to the Sacramento River shows water levels in the very shallow well that display relatively little annual fluctuation suggesting a correspondence between groundwater elevations and river levels. The deeper wells display greater fluctuation in seasonal water levels that tend to track each other indicating some connection between the shallow, intermediate and deep zones. The second nested hydrograph is farther from the river and shows a close correspondence in water elevations recorded at all of the four aquifer zones being are monitored. This indicates a clear connection across the aquifer zones.

Hydrographs for selected monitoring wells in the Vina-Chico Management Area resemble those in Vina-North in that they show some decline in water surface elevations during the drought. The single nested monitoring well in this Management Area shows water levels in the intermediate and lower zones closely tracking those in the upper zone indicating strong communication among the three zones.

Hydrographs for selected monitoring wells in the Vina-South Management Area show groundwater elevations lower than those in Management Areas to the north, an indication of the general north-to-south gradient of flow in the Subbasin. Most of the hydrographs in Vina-South also display more pronounced responses to the drought than do wells to the north. The nested monitoring wells in the south of the Management Area (Well ID Nos. 21N02E24C001M-003M) show the close communication among aquifer zones displayed in the nested sites in the Vina-North and Vina Chico Management Areas. However the nested well on the Midway in the vicinity of Butte Creek (Well ID Nos. 21N02E18C001M-003M) shows weak communication between the upper zone and the two lower zones and a strong recovery in water elevations in the upper zone that corresponds with the change in hydrologic conditions between the drought and the period immediately following the drought.

1.2.2.3 Regional patterns

The series of contour maps and hydrographs presented above complement each other in showing how groundwater levels respond to seasonal variations in demand and recharge and are affected by long-term events such as the recent drought. The patterns in groundwater conditions observed in the Vina Subbasin resemble those found throughout the region and are driven by similar forces.

In addition to the impacts of local water use and regional hydrology, groundwater conditions in the Vina Subbasin are also affected by the Subbasin's setting. As the groundwater contour maps show, there is a clear pattern of groundwater recharge that originates in the foothills outside the Subbasin flowing from the north into the Vina Subbasin. Less evident on the contour maps is recharge from the foothills to the east which contributes to the aquifers underlying the Subbasin. These flows of groundwater into the Vina Subbasin are important sources of supply within the Subbasin and are augmented by recharge generated within the Subbasin which supports the continuing movement of groundwater to the southeast into the Butte Subbasin.

1.2.2.4 Change in storage

Hydrographs from monitoring wells in the Vina Subbasin indicate that groundwater elevations, and hence groundwater storage, are relatively stable except for localized cones of depression. The Sacramento River and streams that cross the Subbasin stabilize groundwater elevations and storage volumes by providing recharge to the Subbasin (losing reaches at times) and to the southeast increasing as groundwater levels rise.

The dynamics of the interaction between inflows, outflows, changes in groundwater elevations and changes in storage are captured in the water budget for the Vina Subbasin and by the Butte Basin Groundwater Model (BBGM) (BCDWRC 2020).

A graph depicting estimates the annual and cumulative change in the volume of groundwater in storage between seasonal high groundwater conditions, including the annual groundwater use and water year type based on the Sacramento Valley Water Year Index[1] is provided in **Figure 1-17**. Water year types are identified as wet (W, shaded blue), above normal (AN, shaded green), below normal (BN, shaded yellow), dry (D, shaded orange), or critical (C, shaded red). Annual change in storage was estimated using the BBGM based on March groundwater storage amounts. Groundwater pumping was estimated using the BBGM and is shown on a water year basis[2]. Values are reported in thousands of acre-feet (TAF).

As indicated in the figure, groundwater storage has generally decreased in dry and critical years and increased in wet years. Storage has also tended to decrease in above normal and below normal years, with the exception of 2004 and 2016. For the recent historical period, which was marked by relatively dry conditions from 2007 to 2016, with the exception of the wet year of 2011, there has generally been a decline in groundwater storage within the Subbasin. Historical and projected changes in storage are discussed in greater detail in Section 1.3 Water Budget.

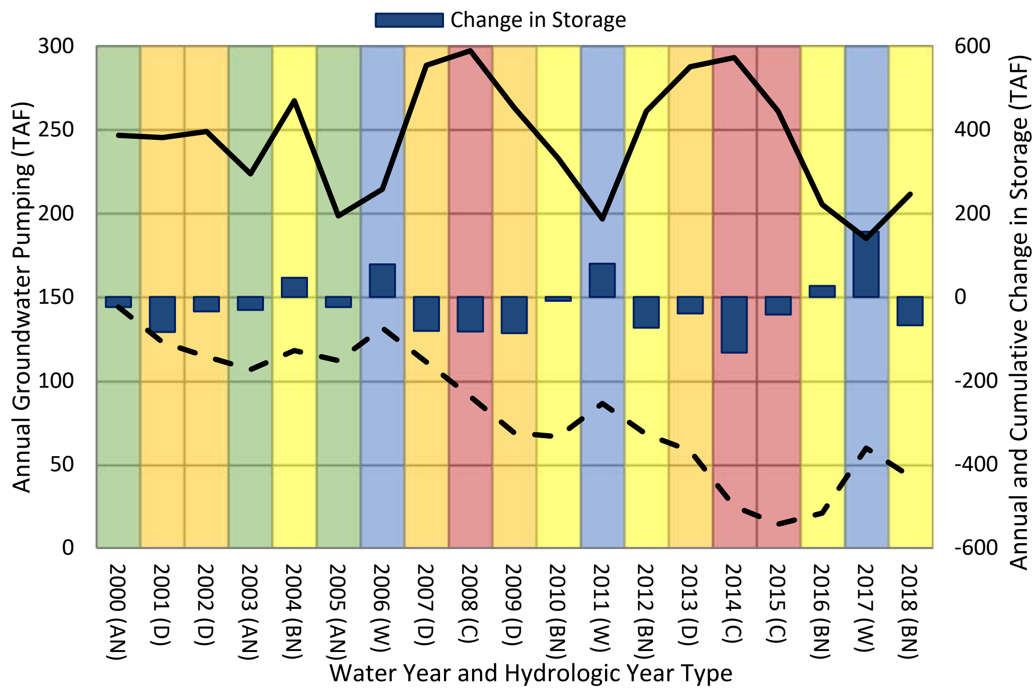


Figure 1-17. Change in Storage and Groundwater Pumping by Water Year Type

1.2.3 Seawater Intrusion

Intrusion of seawater is not a consideration in the Vina Subbasin because of the Subbasin's inland location. For this reason no monitoring of seawater intrusion is required nor is there a need for projects and management actions to mitigate seawater intrusion.

1.2.4 Groundwater Quality

1.2.4.1 General Water Quality of Principal Aquifers

The goal of groundwater quality management under SGMA is to supplement information available from other sources with data targeted to assist GSAs in the Vina Subbasin to comply with the requirements of SGMA. Development of groundwater quality-related Sustainable Management Criteria for the Vina Subbasin is not intended to duplicate or supplant the goals and objectives of ongoing programs including those by Butte County, the Sacramento Valley Water Quality Coalition (SVWQC) and the State Drinking Water Information System (SDWIS).

Because irrigated agriculture is the predominant land use in the Subbasin, monitoring of the groundwater quality data developed through the Groundwater Quality Trend Monitoring Work Plan (GQTMWP) being implemented by the SVWQC for compliance with the Central Valley Regional Board's Irrigated Lands Regulatory Program (ILRP) will be an important source of information to GSAs in the Vina Subbasin.

Among the contaminants that may affect groundwater conditions in the future are chemicals of Emerging Concern (CECs). These are contaminants having toxicities not previously recognized, which may have the potential to cause adverse effects to public health or the environment and are found to be building up in the environment or to be accumulating in humans or wildlife. CECs such as Perfluorooctanesulfonic acid (PFOS) and Per- and polyfluoroalkyl substances (PFAS) will not be monitored under the groundwater quality monitoring program established for SGMA. However, GSAs will have access to data on CECs collected by other agencies and will be attentive to the effect the presence of CECs may have on groundwater management in specific locations.

1.2.4.2 Description and Map of Known Sites and Plumes

The SGMA regulations require that Groundwater Sustainability Plans describe locations, identified by regulatory agencies, where groundwater quality has been degraded due to industrial and commercial activity. Locations of impacted groundwater were identified by reviewing information available on the SWRCB Geotracker/GAMA website, the California Department of Toxic Substances Control (DTSC) EnviroStor website, and the Environmental Protection Agency's (EPA) National Priorities List (NPL). Cases that have been closed by the supervisory agency are not considered.

Figure 1-18 – Sites of Potential Groundwater Impacts from EnviroStor and Geotracker/GAMA databases, presents the locations and details of known impacted groundwater or potentially impacted groundwater in the Vina Subbasin. The sites were divided into the following categories based on regulatory designation:

- Other Sites with Corrective Action (Current);
- Sites Needing Evaluation (Active or Inactive);
- Federal Superfund-Listed Sites, and
- Leaking Underground Storage Tank (LUST) Cleanup Sites

Active DTSC Cleanup Program Sites in the Vina Subbasin include the following

- No. 04880002 - Chico - Skyway Subdivision groundwater plume
    - Past use that caused contamination: Manufacturing – metal
    - Potential contaminants of concern: Halogenated solvents, Tetrachloroethylene (PCE), Trichloroethylene (TCE)
    - Potential media affected: Aquifer used for drinking water supply; well used for drinking water supply.
- No. 04990002 - Chico Groundwater Plume – Southwest
    - Past use that caused contamination: dry cleaning
    - Potential contaminants of concern: Tetrachloroethylene (PCE)
    - Potential media affected: Aquifer used for drinking water supply, other groundwater affected, well used for drinking water supply.
- No. 04990003 - Chico Groundwater Plume – Central
    - Past use that caused contamination: dry cleaning
    - Potential contaminants of concern: Tetrachloroethylene (PCE)
    - Potential media affected: Aquifer used for drinking water supply, other groundwater affected, well used for drinking water supply.
- No. 04450006 - Chico Municipal Airport
    - Past use that caused contamination: manufacturing – metal
    - Potential contaminants of concern: Trichloroethylene (TCE)
    - Potential media affected: Aquifer used for drinking water supply, indoor air, soil, soil vapor
- No. 4720001 - Esplanade Cleaners
    - Past use that caused contamination: Dry cleaning
    - Potential contaminants of concern: Tetrachloroethylene (PCE)

    - Potential media affected: Groundwater uses other than drinking water

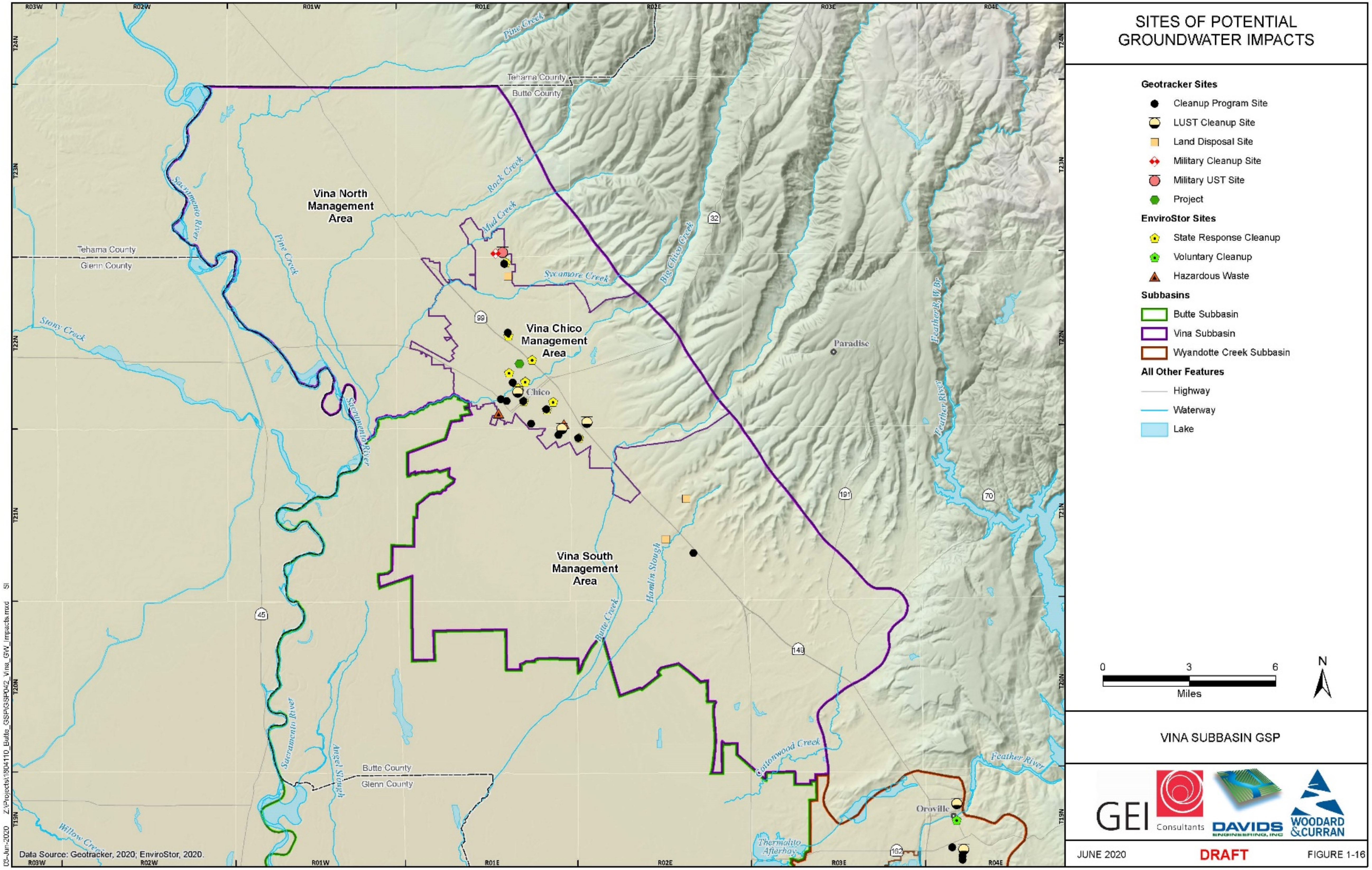
- No. 4720002 - First Avenue Cleaners
    - Past use that caused contamination: Dry cleaning
    - Potential contaminants of concern: Tetrachloroethylene (PCE)
    - Potential media affected: Aquifer used for drinking water supply, well used for drinking water supply

- No. 4720003 - Flair Custom Cleaners
    - Past use that caused contamination: Dry cleaning
    - Potential contaminants of concern: Tetrachloroethylene (PCE)
    - Potential media affected: Groundwater uses other than drinking water, soil, soil vapor

- No. 4720005 - North Valley Plaza Cleaners
    - Past use that caused contamination: Dry cleaning
    - Potential contaminants of concern: 1,2-Dichloroethylene (CIS), 1,2-Dichloroethylene (trans), Tetrachloroethylene (PCE)
    - Potential media affected: Aquifer used for drinking water, well used for drinking water supply, indoor air, soil vapor

- No. 4360003 - Victor Industries
    - Past use that caused contamination: Manufacturing – metal
    - Potential contaminants of concern: Trichloroethylene (TCE)
    - Potential media affected: Aquifer used for drinking water supply, well used for drinking water supply, soil

Of the 9 open cases in the Vina Subbasin, all were identified as having the potential to impact groundwater. Information on these sites is available at www.envirostor.dtsc.ca.gov.



1072
1073 **Figure 1-18. Active Contamination Remediation Sites**

1.2.5 Land subsidence

1.2.5.1 Rates and locations

The SGMA regulations define the minimum threshold for significant and unreasonable land subsidence to be the “rate and the extent of land subsidence”. The harmful effects of subsidence result from the damage it may cause to critical infrastructure and the costs of repairing or mitigating those damages. In the instance of the Vina Subbasin, critical infrastructure that could be affected by subsidence includes federal state and county roads and highways, irrigation district infrastructure, railroad infrastructure, and power transmission lines.

Land subsidence is a gradual settling or sudden sinking of the Earth's surface owing to subsurface movement of earth materials often caused by groundwater or oil extraction. The potential effects of land subsidence include differential changes in elevation and gradients of stream channels, drain and water transport structures, failure of water well casings due to compressive stresses generated by compaction of the aquifer system, and compressional strain in engineering structures and houses. Inelastic land subsidence is a major concern in areas of active groundwater extraction due to infrastructure damage, permanent reduction in the groundwater storage capacity of the aquifer, well casing collapse, and increased flood risk in low lying areas. To date, no inelastic land subsidence has been recorded in Butte County.

Processes that can contribute to land subsidence include aquifer compaction by overdraft, hydrocompaction (shallow or near-surface subsidence) of moisture deficient deposits above the water table that are wetted for the first time since deposition, and subsidence caused by tectonic forces (Ireland et al., 1984). Land subsidence in the Vina Subbasin would most likely occur as a result of aquitard consolidation. An aquitard is a saturated geologic unit that is incapable of transmitting significant quantities of water. As the pressure created by the height of water (i.e., head) declines in response to groundwater withdrawals, aquitards between production zones are exposed to increased vertical loads. These loads can cause materials in aquitards to rearrange and consolidate, leading to land subsidence. Factors that influence the rate and magnitude of consolidation in aquitards include mineral composition, the amount of prior consolidation, cementation, the degree of aquifer confinement and aquitard thickness.

Subsidence has elastic and inelastic deformation components. As the head lowers in the aquifer, the load that was supported by the hydrostatic pressure is transferred to the granular skeletal framework of the formation. As long as the increased load on the formation does not exceed the pre-consolidation pressure, the formation will remain elastic. Under elastic conditions, the formation will rebound to its original volume as hydrostatic pressure is restored. However, when the head of the formation is lowered to a point where the load exceeds pre-consolidation pressure, inelastic deformation may occur. Under inelastic consolidation, the formation will undergo a permanent volumetric reduction as water is expelled from aquitards[4].

To determine whether subsidence is occurring, a subsidence monitoring network has been established throughout the Sacramento Valley, the Sacramento Valley GPS Subsidence Monitoring Network. This system consists of observation stations and extensometers managed jointly by Reclamation and DWR. The observation stations are a result of DWR's efforts to establish a subsidence monitoring network to capture changes in subsidence across the Sacramento Valley. The observation stations are established monuments with precisely surveyed land surface elevations, which are distributed throughout the County such that the entire county is well represented. In 2008, DWR along with numerous partners performed the initial GPS survey of the observation stations to establish a baseline measurement for future comparisons. The network was resurveyed again in 2017 using similar methods and equipment as those used in the 2008 survey and results were analyzed to depict the change in elevation at each station between those two years.

Extensometers are installed in wells or boreholes and are a more site-specific method of measuring land subsidence as they can detect changes in the thickness of the sediment surrounding the well due to compaction or expansion. These instruments are capable of detecting very slight changes in land surface elevation on a continuous basis with an accuracy of +/- 0.01 feet or approximately 3 millimeters (mm). The three extensometers in Butte County, all located in the Butte Subbasin, have a period of record beginning in 2005 and were chosen by DWR based on a high likelihood of seeing subsidence in these areas if it were to occur, due to the presence of known clay and other fine grained deposits in these areas. Data are available through July 2019 and can be found in the DWR Water Data Library[5]. While seasonal displacement of -9.13 mm (+/- 0.3 mm) have been recorded at one of these extensometers during 2006 a *wet* water year and 2015 a *critical* water year, changes in ground surface elevations are slight and remain at or above baseline levels in 2019.

Recent subsidence studies in the Central Valley have utilized satellite- and aircraft-based Interferometric Synthetic Aperture Radar (InSAR). Much of the InSAR work has been led by the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL). However, because JPL InSAR data is limited to a period from 2015 through 2017, TRE

ALTIMIRA InSAR available through DWR was used for this analysis as data from this source is available for a period extending from June 2015 through September 2019.

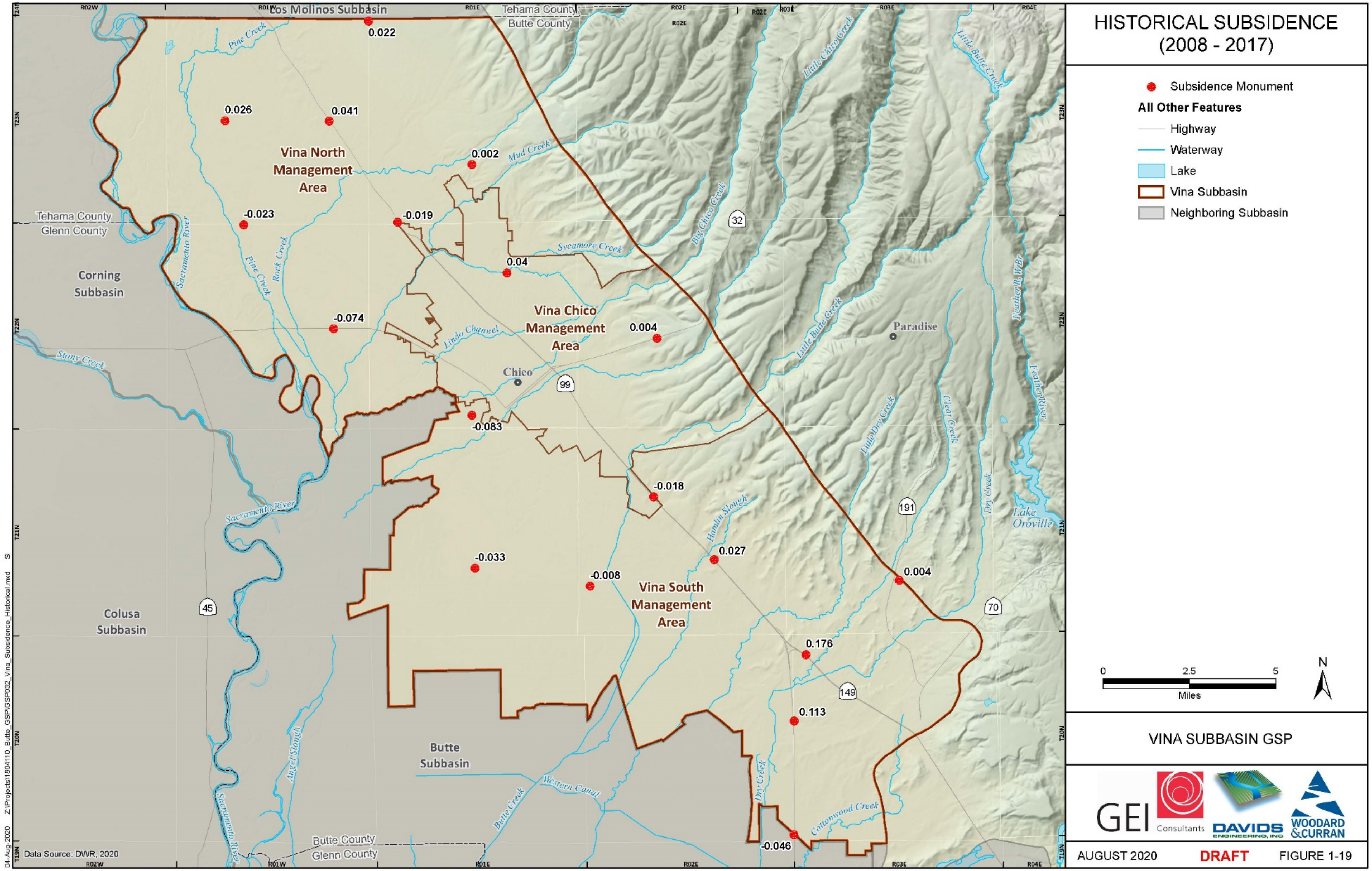
1.2.5.2 Historical and Recent Cumulative Subsidence and Rates of Subsidence

The data shown in **Table 1-4** includes the range of cumulative subsidence observed within the Vina Subbasin over the period between 2008 and 2017 as reported by Sacramento Valley GPS Subsidence Monitoring stations included in the Vina Subbasin Monitoring Network and a range of annual subsidence rates calculated from the cumulative totals. The range of recent cumulative subsidence and rates of subsidence over the period from June 2015 through September 2019 is also presented in the table and are based on InSAR data. As both the Sacramento Valley GPS monuments and InSAR monitor changes in land surface elevations, the data do not distinguish between elastic and inelastic subsidence. However the cumulative subsidence values observed by both sources indicate that inelastic subsidence is not significant in the Vina Subbasin.

Table 1-4. Cumulative Subsidence and Approximate Annual Rate of Subsidence

Subbasin Area (square miles)	Date Range	Cumulative Subsidence (feet)	Calculated Annual Rate of Subsidence (feet/year)	Source
289	2008-2017	0.176 to -0.074	0.020 to -0.008	Sac Valley
289	2015-2019	0.25 to -0.25	0.063 to -0.063	InSAR

Figures 1-19 and **1-20** show historical and recent levels of subsidence within the Vina Subbasin. Historical levels for the period from 2008 to 2017 are shown on **Figure 1-19** – Historical Subsidence as are the locations of subsidence monitoring network monuments used to measure subsidence. Recent levels for the period from 2015 through 2019 are presented on **Figure 1-20** – Recent Subsidence. The values presented in **Table 1-4** and on **Figures 1-19** and **1-20** support the observation that inelastic land subsidence due to groundwater withdrawal is unlikely to result in an Undesirable Result in the Vina Subbasin. Although none of the subsidence data shows substantial changes in ground service elevations, the InSAR mapping presented on **Figure 1-20** shows a clear distinction between changes in elevations observed on the northern and eastern flanks of the Subbasin versus changes observed in the center.



1189
1190 Figure 1-19. Historical Subsidence in the Vina Subbasin (feet)

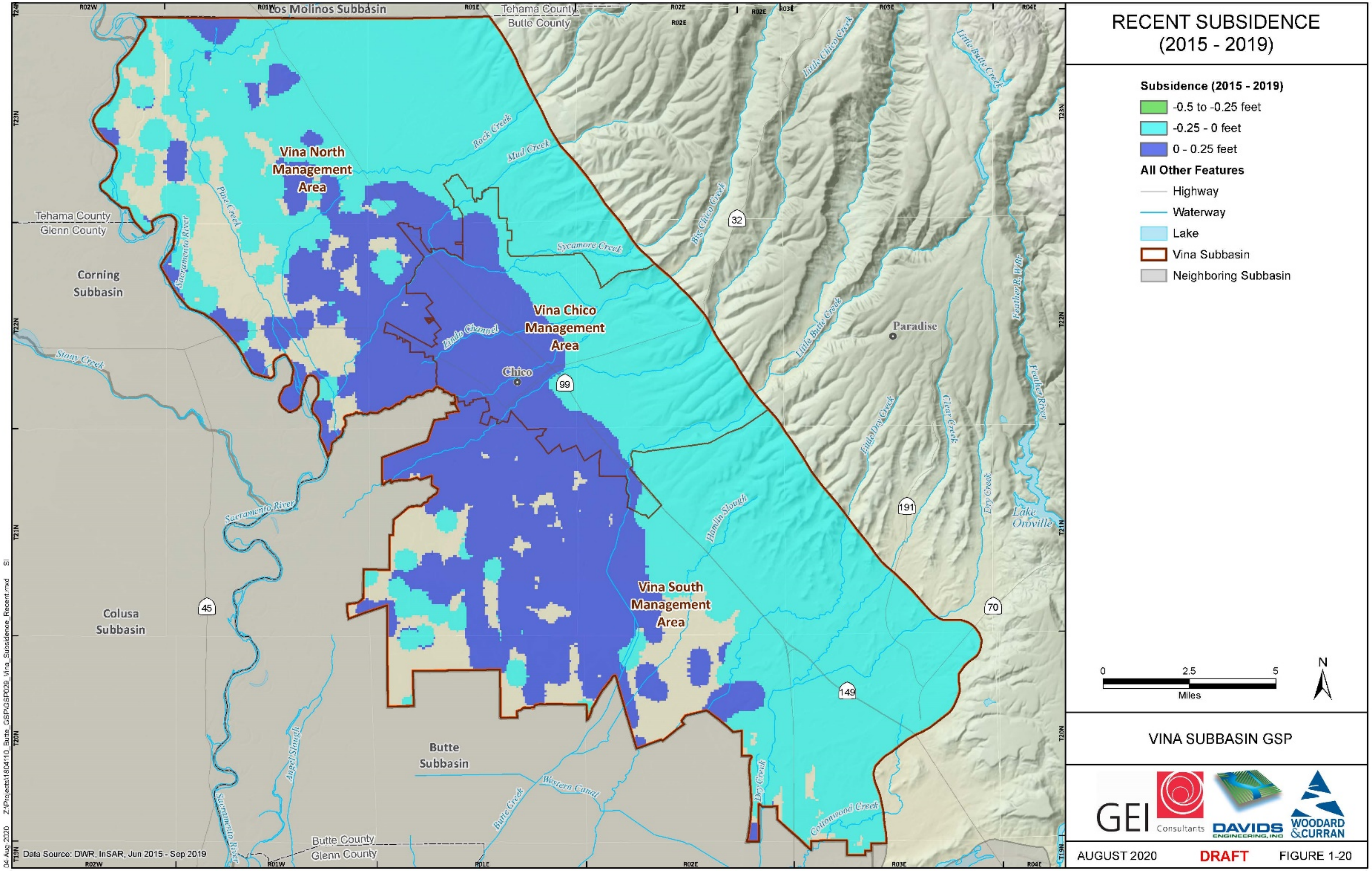


Figure 1-20. Recent Subsidence in the Vina Subbasin (feet)

1.2.6 Interconnected Surface Water Systems

1.2.6.1 Streamflow Depletion and Accretion

The term interconnected surface water systems describes surface water features that are hydraulically connected by a continuous saturated zone to an underlying aquifer such that changes in elevations of either the aquifer or the surface water features propagate throughout the interconnected system.

Interconnected surface waters are classified as either gaining or losing with respect to the condition of the surface water feature with gaining reaches gaining thorough accretion of groundwater and losing reaches losing through depletion to groundwater. It is important to recognize that these interconnections are dynamic and are affected by factors including variations in local geology, hydrology and water use. Thus, at a single point in time, a stream may have both gaining and losing reaches, and reaches that are gaining under certain seasonal, or long-term hydrologic and water use conditions may become losing under others. Moreover, changes in water use or hydrology may cause interconnected surface water features to decouple from the groundwater system.

The difference between gaining and losing reaches is illustrated in **Figure 1-20**. For gaining reaches, the water table adjacent to the stream is above the elevation of water in the stream, resulting in flow of water from the groundwater system to the stream (gains or accretions). For losing reaches, the water table adjacent to the stream is below the elevation of water in the stream, resulting flow of water from the stream to the groundwater systems (losses or seepage). In both cases, flows in the stream are directly connected to the groundwater system, with no unsaturated zone present beneath the streambed.

Direct measurement of interactions between groundwater systems and surface water features is difficult because of the need for a monitoring system that tracks both stream stage and groundwater elevations at nearby locations (see Monitoring Network section for the Vina Subbasin). Therefore, the interactions between groundwater systems and surface water features within the Vina Subbasin are estimated through use of the Butte Basin Groundwater Model (BBGM) which integrates information from groundwater monitoring wells and stream stages to model gradients that control flow between surface water and groundwater.

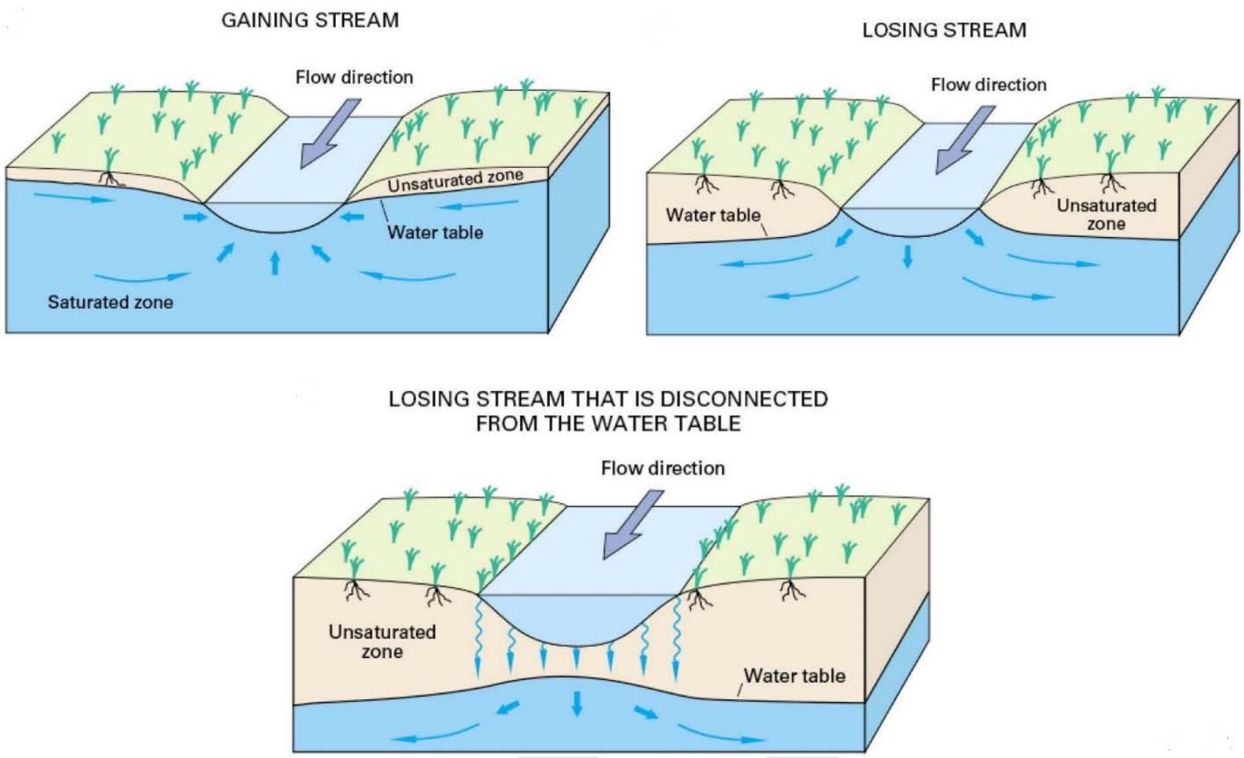


Figure 1-20. Illustration of Gaining and Losing Interconnected and Disconnected Stream Reaches (Source: USGS)

The BBGM was utilized to evaluate stream segments within the subbasin and to classify them as being primarily gaining or losing over the historical period from water year 2000 to 2018. A total of 32 stream segments traversing or bounding the subbasin with a total length of approximately 115 miles were defined. The segments range in length from 1.0 to 9.0 miles with an average length of 3.6 miles and are shown in **Figure 1-21**. The results of this analysis are shown in **Figure 1-22**. The figure shows the percent of months for the period from water year 2000 to 2018 with gaining conditions and classifies streams as primarily gaining (gaining conditions more than 80 percent of the time), primarily losing (losing conditions more than 80 percent of the time), or mixed. As indicated in **Figure 1-22**, segments of streams to the east of Highway 99 tended to not experience gaining conditions between 2000 and 2018, whereas many streams exhibited gaining conditions for at least some months, with the exception of Big Chico Creek, Little Chico Creek, and Butte Creek.

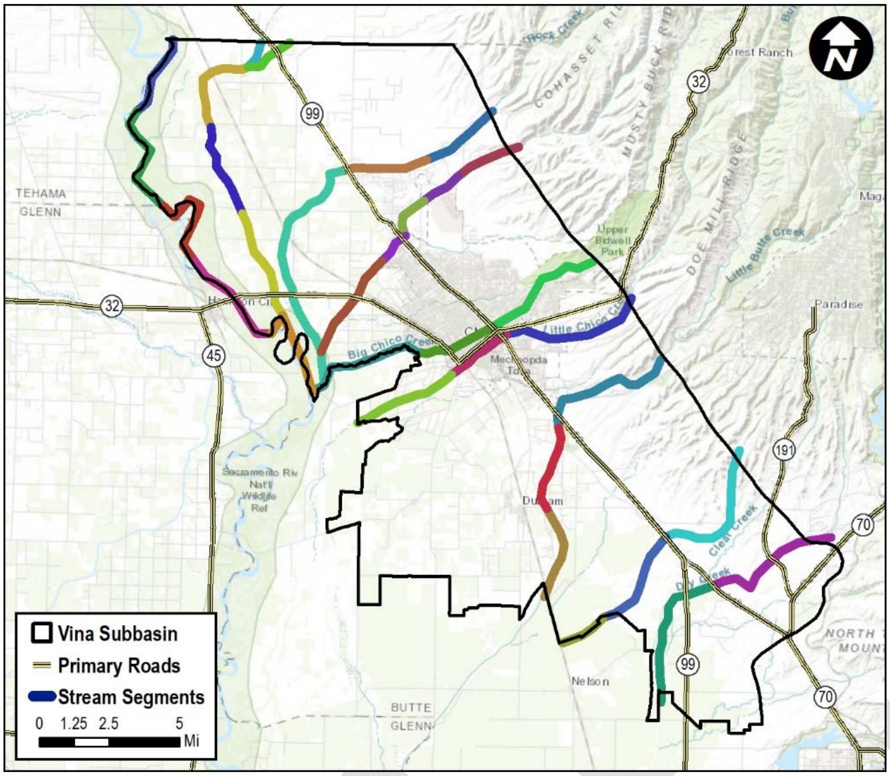


Figure 1-21. Vina Subbasin Stream Segments

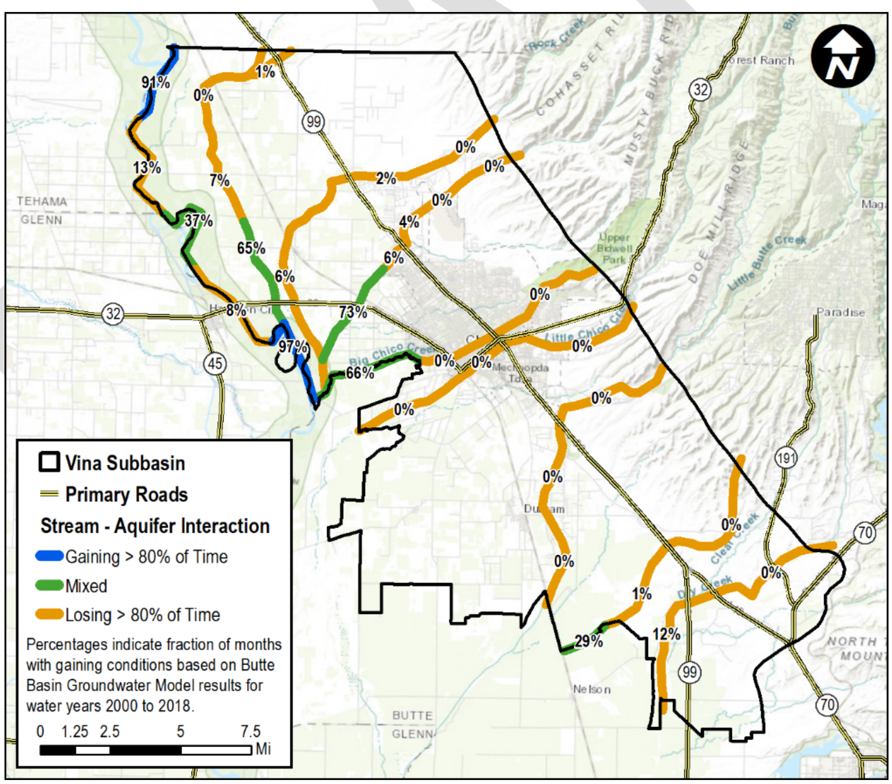


Figure 1-22. Vina Subbasin Gaining and Losing Stream Reaches based on BBGM, Water Year 2000 to 2018

To further evaluate the interconnectedness of streams with the groundwater system in the basin, streambed elevations at individual stream nodes from the BBGM were compared to groundwater elevations from spring groundwater level measurements provided by DWR as part of the SGMA Data Viewer[3]. Spring groundwater levels were available for 2014 to 2018. As indicated in **Figure 1-23**, the estimated average spring depth from the streambed to groundwater over the five-year period tended to be greater than 30 feet for most streams to the east of Highway 99 with the exception of Big Chico Creek, Little Chico Creek, and Butte Creek.

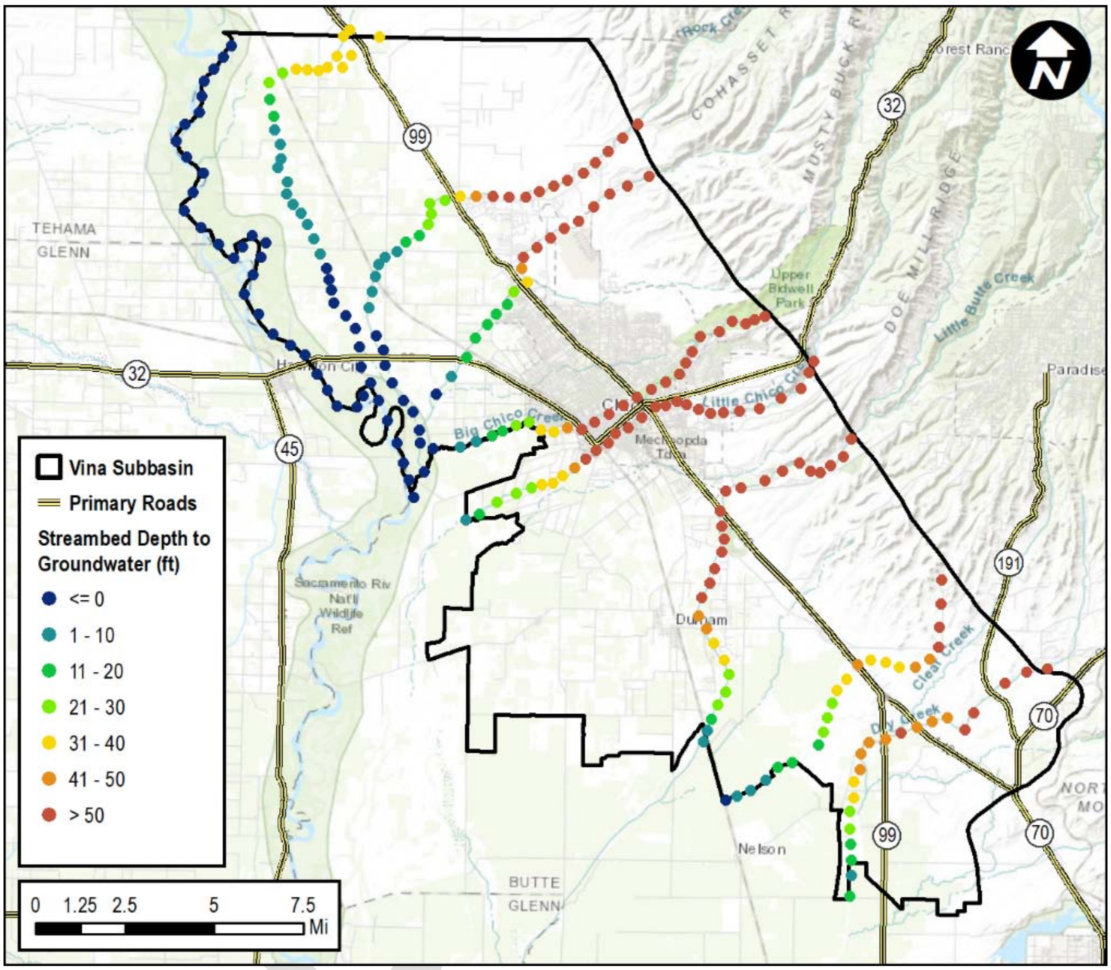


Figure 1-23. Vina Subbasin Average Spring Depth to Groundwater, 2014 to 2018

Based on consideration of the frequency with which stream segments are gaining based on BBGM results and on consideration of the spring depth to groundwater below the estimated streambed depth along each primary stream, it is likely that portions of streams that have not experienced gaining conditions over the recent historical period (2000-2018) and have a depth to groundwater

[3] Accessed at https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#gwlevels.

below the streambed greater than 30 feet are disconnected from the groundwater system.

1.2.6.2 Timing and Amount of Surface Water – Groundwater Interaction

The timing and amount of surface water – groundwater interaction was estimated using the BBGM for the primary streams in the subbasin. Monthly net gains to streamflow from groundwater were estimated on a monthly basis - for the historical period from water year 2000 to 2018 and are summarized in **Table 1-5**. Average monthly gains to streamflow are expressed in cubic feet per second. Negative values denote average losses from streamflow to groundwater (i.e. seepage or leakage).

Table 1-5. Average Monthly Gains to Streamflow from Groundwater, Water Years 2000 to 2018 (cfs)

Stream	Monthly Gains from Groundwater (cfs)												Average (cfs)
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
Angel Slough	0	0	0	0	0	0	0	0	0	0	0	0	0
Big Chico Creek	-2	-3	-6	-7	-7	-8	-5	-3	-2	-2	-2	-1	-4
Butte Creek	-7	-10	-15	-15	-18	-20	-18	-14	-10	-7	-6	-6	-12
Dry Creek	-1	-1	-3	-2	-2	-2	-1	0	0	0	0	0	-1
Little Chico Creek	-1	-1	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1
Little Dry Creek	-2	-3	-6	-6	-6	-5	-4	-2	-2	-1	-1	-1	-3
Mud Creek	0	0	-1	1	1	2	2	1	1	0	0	0	0
Pine Creek	-1	-2	-4	-1	0	2	3	3	2	1	1	0	0
Rock Creek	-3	-3	-4	-3	-3	-2	-2	-2	-2	-2	-2	-2	-2
Sac River	109	151	24	-44	20	50	181	142	91	13	33	57	69
Singer Creek	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	92	129	-17	-79	-18	15	154	123	76	1	22	46	45

Average monthly gains from groundwater are greatest for the Sacramento River, at approximately 70 cfs. Gains are greatest in April and May, potentially due to recovery of groundwater levels from winter recharge along with relatively low river stage. Gains are least in the December to March period and the July to September period, potentially due to relatively high river stage during the winter period and lowered groundwater levels during the summer period.

Butte Creek, Big Chico Creek, and other creeks are estimated to exhibit losses to groundwater throughout the year, on average. These losses appear to be greatest during the winter and spring when stream stage is likely to be relatively high and groundwater levels may not have fully recovered from the fall and winter recharge and recovery period.

On average, streams traversing or bounding the subbasin are currently estimated to gain approximately 45 cfs annually, or approximately 33 thousand acre-feet annually.

1.3 Water Budget

This section describes historical, current, and projected water budgets in accordance with §354.18 of the GSP Emergency Regulations, including quantitative estimates of inflows to and outflows from the basin over time and annual changes in water storage within the basin. Components of the water budgets are depicted in **Figure 1-24**.

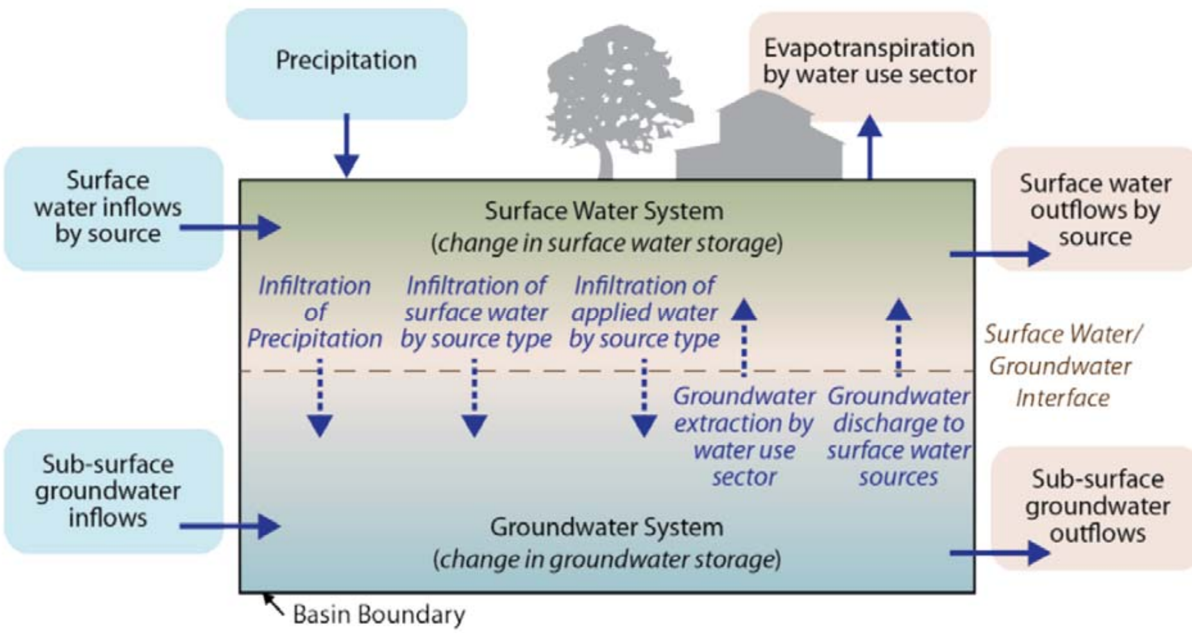


Figure 1-24. Water Budget Components (DWR 2016)

Water budgets were developed considering hydrology, water demand, water supply, land use, population, climate change, surface water – groundwater interaction, and subsurface groundwater inflows and outflows to and from neighboring basins. Water budget results are reported on a water year basis spanning from October 1 of the prior year to September 30 of the current year.

1.3.1 Selection of Hydrologic Periods

The GSP Emergency Regulations require evaluation of water budgets over a minimum of 10 years for the historical water budget, using the most recent hydrology for the current water budget, and 50 years of hydrology for the projected water budget. Hydrologic periods were selected for each water budget category based on consideration of the best available information and science to support water budget development and based on consideration of the ability of the selected periods to provide a representative range of wet and dry conditions.

- Historical – The 19-year period from water years[4] 2000 to 2018 was selected based on the level of confidence in historical information to support water budget development considering land use, surface water availability, hydrology, and other factors.

- Current Conditions – Historical water budget information for 2018 represents the most recent hydrology. To provide a broader basis for understanding current water budget conditions, a water budget scenario combining most recently available land use and urban demands with 50 years of hydrology was selected. The period selected was 1971 to 2018 (48 years) with 2004 – 2005 (two relatively normal years) repeated at the end of the scenario. An advantage of evaluating the current conditions water budget over a representative 50-year period is that the results provide a baseline for evaluation of the projected water budgets.

- Future Conditions – Consistent with the current conditions water budget, the period selected for the projected water budgets was 1971 to 2018 (48 years) with 2004 – 2005 repeated at the end of the scenarios.

Selection of the 50-year hydrologic period for the current and projected water budget scenarios was based primarily on three considerations:

- The Butte Basin Groundwater Model (BBGM), the primary tool used to develop the water budgets, has a simulation period from water years 1971 to 2018.

- The Sacramento Valley Water Year Index[5] over the period from 1971 to 2018 has an average of 8.0, as compared to 8.1 for the 103-year period from 1906 to 2018 (1906 is the first year for which the index is available). (**Figure 1-25**)

- The selected period includes a combination of wet and dry cycles, including relatively wet periods in the early 1970's, mid 1980's, and late 1990's and dry periods in the late 1970's, early 1990's, and from approximately 2007 to 2015.

[4] A water year is defined as the period from October 1 of the prior year to September 30 of the current year. For example, water year 2000 refers to the period from October 1, 1999 to September 30, 2000.
[5] Additional details describing the Sacramento Valley Water Year Index are available from the California Data Exchange Center (https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST).

Additionally, annual precipitation for the 1971 to 2018 period averaged approximately 26.3 inches per year, as compared to 24.8 inches for the 1906 to 2018 period.

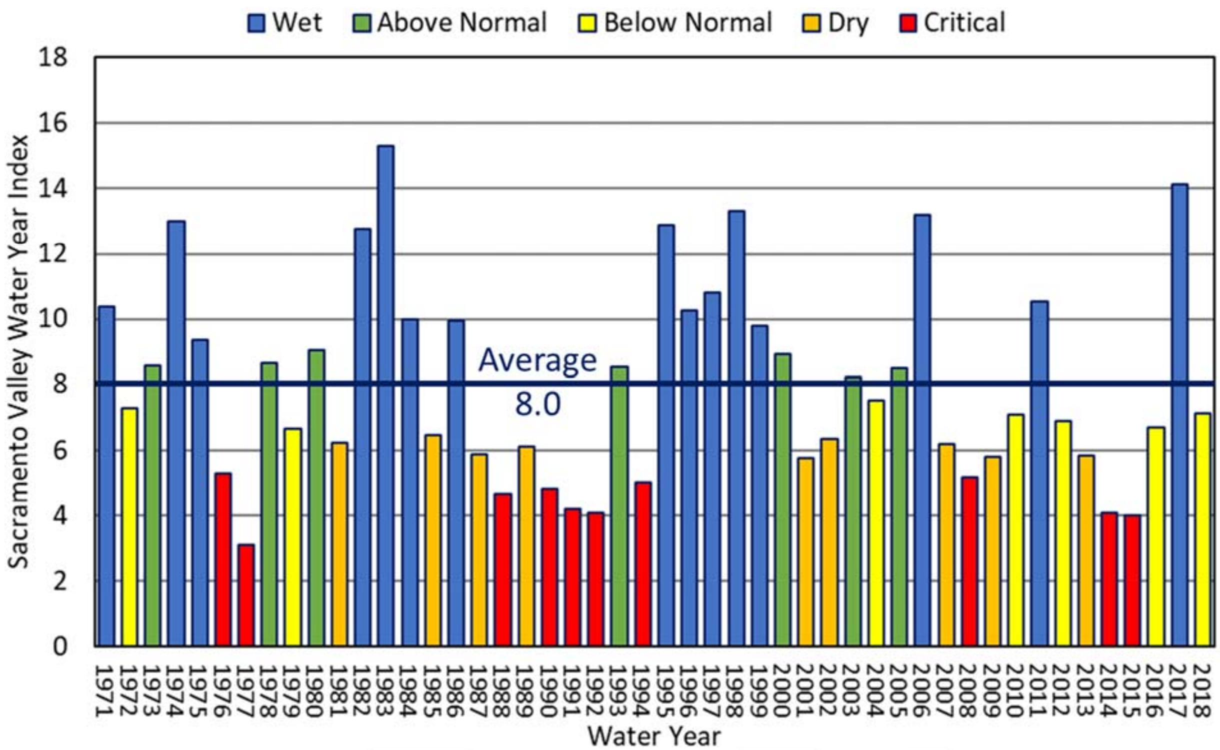


Figure 1-25. 1971 – 2018 Sacramento Valley Water Year Index and Water Year Types

1.3.2 Usage of the Butte Basin Groundwater Model

Development of the original Butte Basin Groundwater Model (BBGM) began in 1992 under the direction and funding of the Butte Basin Water Users Association. The model has been updated over time to simulate historical conditions through water year 2018. The model performs calculations on a daily time step with some daily input (i.e. precipitation, stream inflow), some monthly input data (i.e. surface water diversions) and some annual input data (i.e. land use). Refinements to the model over time include additional crop types to better represent ponded crops (i.e. rice and wetlands), recalibrated soil parameters, and elemental land use. The development of the BBGM are described in more detail in (BCDWRC 2020).

To prepare water budgets for this GSP, historical BBGM results for water years 2000 to 2018 have been relied upon, and four additional baseline scenarios have been developed to represent current and projected conditions utilizing 50 years of hydrology (described previously). Specific assumptions associated with these scenarios are described in the following section.

1.3.3 Water Budget Assumptions

Assumptions utilized to develop the historical, current, and projected water budgets are described below and summarized in **Table 1-6**.

Table 1-6. Summary of Water Budget Assumptions

Water Budget	Analysis Period[1]	Hydrology	Land Use	Water Supplies
Historical Simulation	2000 – 2018	Historical	Historical	Historical
Current Conditions Baseline	1971 – 2018	Historical	Current (2015 and 2016)	Current (2015 and 2016 surface water diversions, 2016-2018 average urban demands)
Future Conditions, No Climate Change Baseline	1971 – 2018	Historical	Current, adjusted based on Butte County 2030 General Plan	Current (2015 and 2016 Surface water diversions and 2050 projected urban demands)
Future Conditions, 2030 Climate Change Baseline	1971 – 2018	Historical, adjusted based on 2030 climate change	Current, adjusted based on General Plan	Current, adjusted based on climate change
Future Conditions, 2070 Climate Change Baseline	1971 – 2018	Historical, adjusted based on 2070 climate change	Current, adjusted based on General Plan	Current, adjusted based on climate change

1.3.3.1 Historical

A historical water budget was developed to support understanding of past aquifer conditions, considering surface water and groundwater supplies utilized to meet demands. The historical water budget was developed using the BBGM and incorporates the best available science and information. Historical water supplies and aquifer response have been characterized by water year type based on DWR's Sacramento Valley Water Year Index, which classifies water years as wet, above normal, below normal, dry, or critical based on Sacramento River unimpaired flows.

As described previously, water years 2000 to 2018 were selected to provide a minimum of ten years across a range of hydrologic conditions. This period includes relatively wet years in 2006, 2011, and 2017 as well as dry conditions between 2007 and 2009 and between 2013 and 2015.

Information utilized to develop the historical water budget includes:

- Analysis Period – Water years 2000 to 2018

- Stream Inflows – Inflows of surface water into the basin were estimated based on stream gage data from USGS and DWR where available (e.g. Butte Creek and Big Chico Creek). For ungauged streams, inflows were estimated using the NRCS rainfall runoff method applied at the watershed scale, considering precipitation timing and amount, soil characteristics, and other factors. Additional detail describing stream inflows is described in the BBGM model report (BCDWRC 2020).
- Land Use – Land use characteristics for agricultural, native, and urban (including rural residential) lands were estimated annually based on a combination of DWR land use surveys and county agricultural commissioner cropping reports. DWR land use data were available for 1994, 1999, 2004, 2011, 2014, 2015, and 2016. Additional detail describing the development of land use estimates can be found in the BBGM model report (BCDWRC 2020).
- Agricultural Water Demand – Agricultural irrigation demands were estimated using the BBGM, which simulates crop growth and water use on a daily basis, considering crop type, evapotranspiration, root depth, soil characteristics, and irrigation practices. For ponded land uses (rice and managed wetlands), pond depths and pond drainage are also considered to simulate demands.
- Urban and Industrial Water Demand[6] – Urban and industrial demands were estimated based on a combination of pumping data provided directly by water suppliers (e.g. CalWater) and estimates of population and per capita water use over time. Additional detail describing the development of urban demand estimates can be found in the BBGM model report (BCDWRC 2020).
- Surface Water Diversions – Surface water diversions were estimated based on a combination of reported diversions by water suppliers and, in some cases, agricultural water demand estimates for areas known to receive surface water but for which reported diversion data were not available.
- Groundwater Pumping – For urban water suppliers, historical pumping was estimated from reported pumping volumes over time. Pumping to meet agricultural and managed wetlands demands was estimated within the BBGM by first estimating the total demand and then subtracting surface water deliveries to calculate estimated groundwater pumping required to meet the remaining demand.

1.3.3.2 Current Conditions

The current conditions water budget was developed as a baseline to evaluate projected water budgets considering future conditions and is based on 50 years of hydrology along with the most recent information describing land use, urban

[6] Current estimates of industrial water use not supplied by urban water suppliers have not been explicitly included at this time and are identified as a data gap that could be filled as part of future GSP updates. These water uses are small relative to other water uses (i.e. agricultural and urban) and tend to be non-consumptive in nature. Additionally, future refinements of the BBGM to incorporate rural residential demands may also be made; these demands were estimated as part of the 2016 Water Inventory & Analysis and are also small relative to other uses.

demands, and surface water supplies. The 50-year hydrologic period was selected rather than the most recent year for which historical water budget information is available to allow for direct comparison of potential future conditions to current conditions. The use of a representative hydrologic period containing wet and dry cycles supports the understanding of uncertainty in groundwater conditions over time, establishment of sustainable management criteria, and development of projects and management actions to avoid undesirable results.

The current water budget estimates current inflows, outflows, and change in storage for the basin using 50 years of representative hydrology and the most recent water supply, water demand, and land use information.

Information utilized to develop the current conditions baseline water budget include:

- Analysis Period – 50 years of historical hydrology were utilized representing the period from 1971 to 2018, with 2004 and 2005 repeated following 2018.
- Stream Inflows – Inflows of surface water into the basin were estimated utilizing the same information as for the historical water budget.
- Land Use – Land use for agricultural, native, and urban (including rural residential) lands was estimated annually using the most recent land use information. Specifically, 2015 and 2016 land use were mapped to the 50-year analysis period, with 2015 land use applied to extreme dry years and 2016 land use applied to all other years. Extreme dry years were identified based on April to July inflows of the Feather River to Lake Oroville, based on settlement agreements between Feather River water users and the State Water Project. April to July runoff to the Feather River is believed to be a reasonable indicator of surface water supplies and associated changes in cropping patterns within the basin. Land use and surface water supplies are relatively consistent in dry and normal years in the Vina Subbasin.
- Agricultural Water Demand – Agricultural irrigation demands were estimated using the BBGM, in the same manner as the historical water budget.
- Urban and Industrial Water Demand – Urban and industrial demands were estimated based on recent demands. Specifically, average demands for the period 2016 to 2018 were assumed.
- Surface Water Diversions – Similar to land use, surface water diversions were estimated based on 2015 and 2016 conditions, with 2015 diversion assumed for extreme dry years and 2016 diversions assumed for other years. For the current conditions scenario, reduced surface water was estimated for four years within the 50-year simulation period.
- Groundwater Pumping – Pumping to meet urban demands was estimated based on average 2016 to 2018 demands, as described above. Pumping to meet agricultural and

managed wetlands demands was estimated using the BBGM as described previously for the historical water budget.

1.3.3.3 Future Conditions

Three projected water budget scenarios were developed considering a range of future conditions in the subbasin that may occur, as documented in the Butte County 2030 General Plan. The scenarios consider future planned land use changes (i.e. development), along with changes in climate, including precipitation, surface water inflows, and evapotranspiration. These scenarios provide information regarding changes in basin conditions (e.g. groundwater storage) that may occur in the future over a series of wet and dry cycles.

The projected water budget estimates potential future inflows, outflows, and change in storage for the basin using 50-years of representative hydrology (including modifications based on climate change projections), the most recent water supply and water demand, and planned future land use information.

Information utilized to develop the future conditions water budgets include:

- Analysis Period – 50-years of hydrology were utilized representing the period from 1971 to 2018, with 2004 and 2005 repeated following 2018.
- Stream Inflows
  - Future Conditions, No Climate Change – Inflows of surface water into the basin were estimated utilizing the same information as for the historical water budget.
  - Future Conditions, 2030 Climate Change – Precipitation, evapotranspiration, and surface water supplies were adjusted to reflect climate change based on the 2030 Central Tendency climate change datasets provided by DWR to support GSP development.
    - For precipitation and evapotranspiration, monthly change factors were applied to historical values to estimate potential future conditions.
    - For streamflows, DWR estimates of stream inflows were utilized where available; for streams without direct estimates of inflows, inflows were estimated using streamflow change factors applied at the watershed scale.
  - Future Conditions, 2070 Climate Change – Precipitation, evapotranspiration, and surface water supplies were adjusted to reflect climate change based on the 2070 Central Tendency climate change datasets provided by DWR to support GSP development.
    - For precipitation and evapotranspiration, monthly change factors were applied to historical values to estimate potential future conditions.
    - For streamflows, DWR estimates of stream inflows were utilized where available; for streams without direct estimates of inflows, inflows were estimated using streamflow change factors applied at the watershed scale.

- Land Use – Land use for agricultural, native, and urban (including rural residential) lands was estimated annually using the most recent land use information and modified based on planned development according to the 2030 General Plan. Specifically, 2015 and 2016 land use were mapped to the 50-year analysis period, with 2015 land use applied to extreme dry years and 2016 land use applied to all other years. 2015 and 2016 land use data were modified to reflect planned development, generally resulting in an increase in urban land through development of previously undeveloped (i.e. native) lands.
    - Future Conditions, No Climate Change – 2015 and 2016 land use data were mapped to the 50-year analysis period in the same manner as the current conditions water budget scenario, with modifications based on planned development based on the General Plan.
    - Future Conditions, 2030 Climate Change – 2015 and 2016 land use data were mapped to the 50-year analysis period considering 2030 central tendency climate change projections, with 2015 land use used for extreme dry years and 2016 land use used for all other years.
    - Future Conditions, 2070 Climate Change – 2015 and 2016 land use data were mapped to the 50-year analysis period considering 2070 central tendency climate change projections, with 2015 land use used for extreme dry years and 2016 land use used for all other years.
- Agricultural Water Demand – Agricultural irrigation demands were estimated using the BBGM, in the same manner as the historical water budget.
- Urban and Industrial Water Demand – Urban and industrial demands were estimated based projected urban demands. Specifically, future urban demands were estimated based on preliminary draft demand estimates provided by urban water suppliers (e.g. CalWater) as part of 2020 Urban Water management Plan (UWMP) development.
- Surface Water Diversions – Similar to land use, surface water diversions were estimated based on 2015 and 2016 conditions, with 2015 diversions assumed for extreme dry years and 2016 diversions assumed for other years.
    - For the 2030 central tendency scenario, extreme dry conditions occurred eleven years within the 50-year simulation period.
    - For the 2070 central tendency scenario, extreme dry conditions occurred thirteen years within the 50-year simulation period.
- Groundwater Pumping – Pumping to meet urban demands was estimated based on draft projections from UWMPs currently under development, as described above. Pumping to meet agricultural and managed wetlands demands was estimated using the BBGM as described previously for the historical water budget.

1.3.4 Water Budget Estimates

As described previously, water budget estimates were developed using the BBGM. Primary components of the land and surface water system water budget include the following:

- Inflows
  - Surface Water Inflows – Inflows at the land surface through streams, canals, or other waterways. These inflows may also include overland flow from upslope areas outside of the basin. Note that although interactions with the Sacramento River along the boundary of the basin (i.e. diversions and stream-aquifer interaction) are accounted for, the flow in the stream is not considered an inflow to the basin. Inflows from streams that traverse the basin are accounted for explicitly.
  - Precipitation – Rainfall intercepting the ground surface within the basin boundary.
  - Groundwater pumping – Extraction of groundwater to meet agricultural, urban, managed wetlands, or other beneficial uses.
  - Stream Accretions – Gains in streamflow from shallow groundwater occurring when the water level in the aquifer adjacent to the stream is greater than the water level in the stream.
- Outflows
  - Surface Water Outflows – Outflows at the land surface through streams, canals, or other waterways. These outflows may also include overland flow to downslope areas outside of the basin.
  - Evapotranspiration – Consumptive use of water including both evaporation and transpiration components.
  - Deep Percolation – Recharge of the groundwater system through the vertical movement of precipitation and applied irrigation water below the root zone.
  - Seepage (Also referred to as Losses or Leakage) – Recharge of the groundwater system from streams, canals, or other water bodies.
- Change in Storage – Changes in soil moisture storage within the upper several feet of soil in the root zone, as well as changes in storage in surface water bodies within the basin. These changes are generally negligible on an annual basis but vary over the course of a year based on precipitation patterns and other factors.

Primary components of the groundwater system water budget include the following:

- Inflows
  - Deep Percolation – Described above.
  - Subsurface Inflows – Groundwater inflows from adjacent basins or from the foothill area.
  - Seepage – Described above.

- Outflows
  - Groundwater Pumping – Described above.
  - Subsurface Outflows – Groundwater outflows to adjacent basins.
  - Accretions – Described above.
- Change in Storage – Changes in water storage in the aquifer system. These changes tend to be large compared to changes in root zone soil moisture storage and can vary substantially from year to year.

Many components of the water budget can be estimated based on measured data (e.g. precipitation, diversions, evapotranspiration, etc.) and are used to develop inputs to the BBGM to support water budget development. Other components are more difficult to measure or do not have measured values readily available (e.g. deep percolation, subsurface flows, groundwater pumping, surface water-groundwater interaction, etc.) and are estimated using the BBGM. Additional detail describing the BBGM is available in (BCDWRC 2020).

Average annual water budget estimates for the historical water budgets and for the current and projected water budget scenarios are summarized in **Table 1-7** for the land and surface water system and in **Table 1-8** for the groundwater system. Additional information and discussion regarding the water budgets is provided in the following subsections. It is anticipated that the water budgets will be refined and updated over time as part of GSP implementation in the basin.

Table 1-7. Water Budget Summary: Land and Surface Water System.

Component	Historical (AFY)	Current (AFY)	Future, No Climate Change (AFY)	Future, 2030 Climate Change (AFY)	Future, 2070 Climate Change (AFY)
Inflows					
Surface Water Inflows	554,800	602,300	601,900	630,600	652,200
Outside Diversions	*400*	*400*	*400*	*400*	*400*
Butte Creek	*298,100*	*324,900*	*324,900*	*339,200*	*348,700*
Big Chico Creek	*111,200*	*114,500*	*113,700*	*118,000*	*120,500*
Pine Creek	*13,400*	*14,200*	*14,200*	*14,800*	*15,000*
Dry Creek	*14,000*	*14,500*	*14,500*	*15,000*	*15,300*
Rock Creek	*16,600*	*17,200*	*17,200*	*17,700*	*17,700*
Little Chico Creek	*17,800*	*20,700*	*20,400*	*21,000*	*21,100*
Mud Creek	*14,400*	*17,400*	*17,300*	*17,800*	*17,900*
Singer Creek	*1,500*	*1,700*	*1,700*	*1,700*	*1,800*
Little Dry Creek	*3,200*	*5,800*	*5,800*	*6,000*	*5,900*
Precipitation Runoff from Upslope Lands	*61,600*	*69,000*	*69,900*	*77,500*	*86,300*
Applied Water Return Flows from Upslope Lands	*2,600*	*1,900*	*1,900*	*1,700*	*1,600*
Precipitation	410,900	421,700	421,700	438,200	453,100
Groundwater Pumping	243,500	209,200	215,800	225,900	238,000
Agricultural	*209,100*	*185,500*	*184,800*	*194,700*	*206,800*
Urban and Industrial	*26,500*	*20,100*	*27,500*	*27,500*	*27,500*
Managed Wetlands	*8,000*	*3,500*	*3,500*	*3,600*	*3,700*
Stream Gains from Groundwater	3,700	1,100	1,000	1,000	1,000
Total Inflow	***1,212,900***	***1,234,300***	***1,240,400***	***1,295,700***	***1,344,300***
Outflows					
Evapotranspiration	362,900	348,300	347,300	358,200	371,400
Agricultural	*253,500*	*243,000*	*242,000*	*250,700*	*262,300*
Urban and Industrial	*21,800*	*20,900*	*27,400*	*27,900*	*28,400*
Managed Wetlands	*6,000*	*3,000*	*3,000*	*3,100*	*3,100*
Native Vegetation	*81,200*	*80,900*	*74,400*	*76,100*	*77,200*
Canal Evaporation	*400*	*500*	*500*	*400*	*400*
Deep Percolation	192,700	191,800	189,300	194,500	196,800
Precipitation	*120,200*	*125,400*	*120,400*	*123,500*	*123,600*
Applied Surface Water	*4,800*	*5,600*	*5,600*	*4,900*	*4,500*
Applied Groundwater	*67,600*	*60,900*	*63,300*	*66,100*	*68,700*
Seepage	24,000	27,700	27,800	27,800	27,400
Streams	*20,800*	*24,100*	*24,200*	*24,600*	*24,400*
Canals and Drains	*3,200*	*3,600*	*3,600*	*3,200*	*3,000*
Surface Water Outflows	633,300	666,300	675,900	715,100	748,700
Precipitation Runoff	*57,900*	*58,300*	*62,100*	*66,700*	*72,800*
Applied Surface Water Return Flows	*2,200*	*2,800*	*2,800*	*2,200*	*1,800*
Applied Groundwater Return Flows	*20,200*	*14,000*	*16,000*	*16,000*	*16,000*
Streams	*525,500*	*563,800*	*567,600*	*605,200*	*633,600*
Butte Creek Diversions to Butte Subbasin	*27,500*	*27,400*	*27,400*	*25,100*	*24,400*
Total Outflow	***1,213,000***	***1,234,200***	***1,240,300***	***1,295,600***	***1,344,300***
Change in Storage (Inflow - Outflow)	***-100***	***100***	***100***	***100***	***0***

Table 1-8. Water Budget Summary: Groundwater System.

Component	Historical (AFY)	Current (AFY)	Future, No Climate Change (AFY)	Future, 2030 Climate Change (AFY)	Future, 2070 Climate Change (AFY)
Inflows					
Subsurface Inflows	137,400	143,200	142,800	144,600	145,500
Foothill Area	*45,700*	*50,100*	*49,700*	*50,600*	*50,600*
Los Molinos Subbasin	*63,000*	*67,000*	*67,300*	*67,900*	*68,100*
Butte Subbasin	*28,600*	*25,900*	*25,500*	*25,800*	*26,600*
Wyandotte Creek Subbasin	*200*	*300*	*200*	*300*	*300*
Deep Percolation	192,700	191,800	189,300	194,500	196,800
Precipitation	*120,200*	*125,400*	*120,400*	*123,500*	*123,600*
Applied Surface Water	*4,800*	*5,600*	*5,600*	*4,900*	*4,500*
Applied Groundwater	*67,600*	*60,900*	*63,300*	*66,100*	*68,700*
Seepage	24,000	27,700	27,800	27,800	27,400
Streams	*20,800*	*24,100*	*24,200*	*24,600*	*24,400*
Canals and Drains	*3,200*	*3,600*	*3,600*	*3,200*	*3,000*
Total Inflow	***838,100***	***844,500***	***842,800***	***852,700***	***857,200***
Outflows					
Subsurface Outflows	70,400	76,200	72,000	70,700	67,800
Foothill Area	*300*	*200*	*200*	*200*	*200*
Los Molinos Subbasin	*4,700*	*900*	*900*	*900*	*900*
Butte Subbasin	*65,400*	*75,100*	*70,800*	*69,500*	*66,600*
Wyandotte Creek Subbasin	*0*	*0*	*0*	*0*	*0*
Groundwater Pumping	243,500	209,200	215,800	225,900	238,000
Agricultural	*209,100*	*185,500*	*184,800*	*194,700*	*206,800*
Urban and Industrial	*26,500*	*20,100*	*27,500*	*27,500*	*27,500*
Managed Wetlands	*8,000*	*3,500*	*3,500*	*3,600*	*3,700*
Stream Gains from Groundwater	3,700	1,100	1,000	1,000	1,000
Western Boundary Net Outflows	56,100	77,400	73,000	71,000	65,600
Total Outflow	***857,700***	***845,600***	***844,600***	***854,400***	***859,800***
Change in Storage (Inflow - Outflow)	***-19,600***	***-1,100***	***-1,700***	***-1,700***	***-2,600***

1.3.4.1 Historical

The historical water budget provides a foundation for how the basin has behaved historically, including insight into historical groundwater conditions (e.g. observed water levels). Also, in accordance with the GSP Regulations, the historical water budget covers a period of at least ten years (19-year period from 2000 to 2018), is used to evaluate the availability and reliability of historical surface water supplies, and provides insight into the ability to operate the basin within the sustainable yield. Note that the historical analysis period experienced somewhat less precipitation than the long-term average and included historic drought conditions from approximately 2007 to 2015[7].

[7] For the 2000 to 2018 period, mean annual precipitation was 26.7 inches, compared to 23.1 inches for the 2007 to 2015 period.

Average annual inflows to and outflows from the basin for the historical land and surface water system water budget were estimated to be 1.21 million acre-feet (MAF) per year. Average annual values were presented previously in **Table 1-7** and are shown graphically in **Figure 1-26**.

Primary inflows to the land and surface water system include surface water inflows (555 TAF/yr[8]), precipitation (411 TAF/yr), and groundwater pumping (243 TAF/yr), with estimated stream gains from groundwater (i.e. accretions) of approximately 4 TAF/yr. Surface water inflows include Butte Creek, Big Chico Creek, and several other streams, as well as overland runoff of precipitation and applied water from upslope lands.

Primary outflows from the land and surface water system include surface water outflows (633 TAF/yr), evapotranspiration (363 TAF/yr), deep percolation (193 TAF/yr), and stream losses (also referred to as seepage) (24 TAF/yr). Surface water outflows include outflows through Butte Creek, Big Chico Creek, and other streams, as well as overland runoff of precipitation and applied water to downslope lands. Additionally, water is diverted from Butte Creek for use in the Butte Subbasin. Evapotranspiration is primarily from agricultural lands but also from native vegetation, urban and industrial lands, managed wetlands, and canal evaporation. Deep percolation is primarily from precipitation, but also from applied water.

The average annual change in storage in the land and surface water system is negligible due to similar soil moisture content in the root zone, on average, across water years, and limited storage capacity exists in surface water bodies within the basin.

Additional details describing the historical land and surface water system water budget are provided in Appendix A.

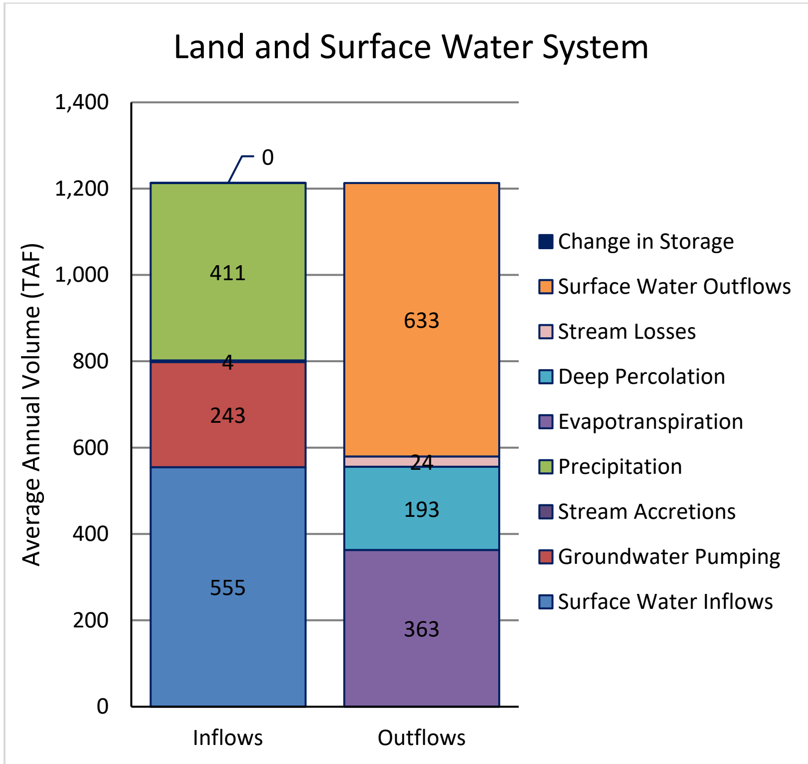


Figure 1-26. Average Annual Historical Land and Surface Water System Water Budget

Average annual inflows to and outflows from the groundwater system were estimated to be 838 TAF and 858 TAF, respectively, with an average decrease in groundwater storage of 20 TAF per year during the historical simulation period. Average annual values were presented previously in **Table 1-8** and are shown graphically in **Figure 1-27**.

Inflows to the groundwater system include deep percolation (193 TAF/yr[9]); subsurface inflows from the Los Molinos, Butte, and Wyandotte Creek subbasins and from the foothill area (137 TAF/yr); and stream losses (24 TAF/yr). Outflows from the groundwater system include groundwater pumping (243 TAF/yr); subsurface outflows to the Butte, Los Molinos, and Wyandotte Creek subbasins and to the foothill area (70 TAF/yr); western boundary net outflows (56 TAF/yr); and stream gains from groundwater (4 TAF/yr).

Western boundary net outflows represent Sacramento River gains from groundwater and subsurface outflows to the Corning Subbasin. The split between these outflows is uncertain at this time and identified as a data gap. It is anticipated that this data gap will be addressed through future refinements to the BBGM and through coordination and collaboration with neighboring subbasins as part of GSP implementation.

Additional details describing the historical groundwater system water budget are provided in Appendix A.

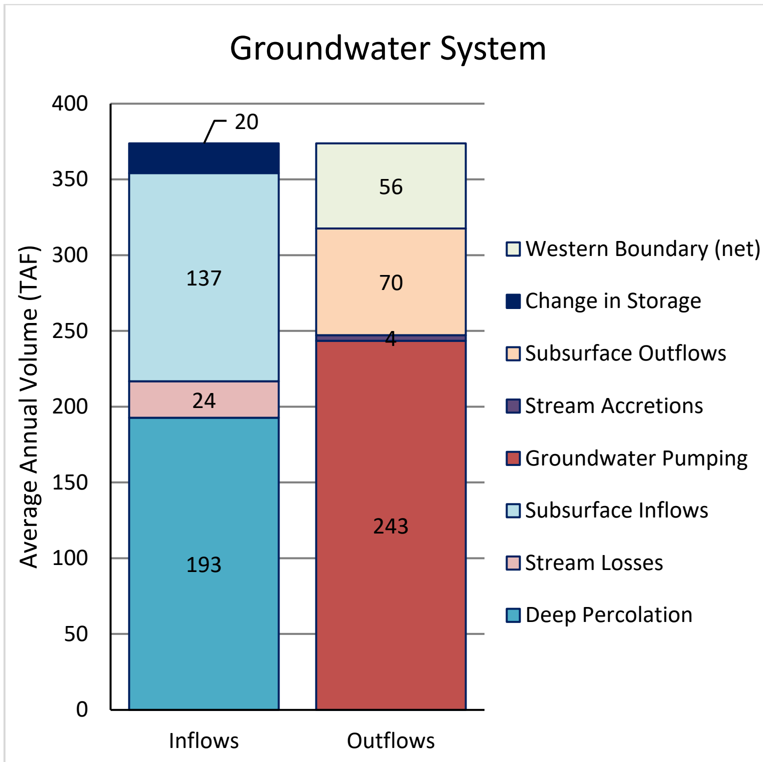


Figure 1-27. Average Annual Historical Groundwater System Water Budget

Historical water supplies and change in groundwater storage are summarized by water year type in **Table 1-9** based on the Sacramento Valley Water Year Index[10], which classifies water years as wet, above normal, below normal, dry, or critical based on Sacramento River unimpaired runoff. Between 2000 and 2018, there were three wet years, three above normal years, five below normal years, five dry years, and three critical years. Historical surface water deliveries were greatest in wet years and least in critical years. Conversely, groundwater pumping has been least in wet years and greatest in critical years. Historically, groundwater storage in the basin has tended to increase in wet and above normal years and to decrease in below normal, dry, and critical years.

Table 1-9. Historical Water Supplies and Change in Groundwater Storage by Hydrologic Water Year Type

Water Year Type	Surface Water Deliveries (AFY)	Groundwater Pumping (AFY)	Total Supply (AFY)	Change in Groundwater Storage (AFY)
Wet	24,000	198,600	222,700	117,900
Above Normal	21,100	222,800	243,900	10,700
Below Normal	20,600	235,500	256,200	-19,200
Dry	17,300	266,600	284,000	-82,000
Critical	12,200	283,700	295,800	-84,500

Availability or Reliability of Historical Surface Water Supplies

As indicated in **Table 1-9**, historical surface water supplies for delivery to agricultural land vary based on water year type, with less availability in drier years. The primary source of surface water in the basin is Butte Creek, which is an undammed stream. Historically, water has been diverted to the Toadtown Canal from the West Branch of the Feather River for power generation and cold water for fish by PG&E. The Butte Canal carries Toadtown Canal and Butte Creek water to the De Sabla power plant forebay. Hydropower is also generated at several other locations. Operations at all of these sites affect the timing of water releases. At Oroville-Thermalito, Toadtown, and De Sabla-Centerville, water for power generation is transferred from the Feather River watershed to the Butte Creek watershed.

Despite the ability to convey water from the Feather River watershed to Butte Creek, flows during summer months are limited and perform important environmental functions, reducing the reliability of surface water to support other beneficial uses. Diversions claimed after 1914 including both riparian and appropriative surface water rights require permits from the State Water Resources Control Board. Surface water rights are subject to curtailment by the State Board during drought conditions. Water rights holders are required to report surface water diversions to the State Board. Based on the Board's electronic Water Rights Information Management System (eWRIMs), there are an estimated 60 points of diversion in the Vina Subbasin representing 53 water rights applications and statements of use.

Suitability of Tools and Methods for Planning

The water budgets presented herein have been developed using the best available information and best available science and structured in a manner consistent with the hydrogeologic conceptual model of the basin. The BBGM, which is used to organize information for the water budgets, develop water budget scenarios, and perform water budget calculations, is currently the best available tool and is suitable for GSP development for the subbasin. The BBGM has been developed over the past several decades and updated over time to use updated model code, updated datasets, and updated input parameters through a series of efforts. Refinements to the BBGM have been made through extensive engagement with local stakeholders through a series of past efforts.

The water budgets developed using the BBGM support the development of sustainable management criteria, evaluation of the monitoring network, and development of projects and management actions as part of GSP development. It is anticipated that the BBGM will be updated and refined in the future as part of GSP implementation. Additional information describing the BBGM is available in BCDWRC (2020).

Ability to Operate the Basin within the Sustainable Yield

Sustainable yield refers to the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin, and including any temporary surplus that can be withdrawn annually from a groundwater supply without causing an undesirable result. As a result, determination of sustainable yield requires consideration of SGMA's six sustainability indicators. Historical water budget estimates indicate an average annual decrease in storage of 20 thousand acre-feet per year for the period from water year 2000 to 2018. In general, decreased precipitation and increased groundwater pumping in dry years leads to decreases in groundwater levels and storage and may pose challenges to operating within the sustainable yield over multiple dry years. Operation of the basin within the sustainable yield will likely require incorporation of projects and management actions into the GSP and implementation over the 50-year SGMA planning and implementation horizon. The estimated sustainable yield of the basin is described in greater detail in Section 1.3.6.

1.3.4.2 Current Conditions

The current conditions baseline water budget provides a foundation to understand the behavior of the basin considering current land use and urban demands over a broad range of hydrologic conditions as well as a basis for evaluating how groundwater conditions may change in the future based on comparison of water budget results to projected water budgets presented in the following section. A 50-year hydrologic period was selected, rather than a single, recent year to improve the basis for estimation of sustainable yield under current conditions.

Average annual inflows to and outflows from the basin for the current conditions land and surface water system baseline water budget were estimated to be 1.23 million acre-feet (MAF) per year. Average annual values were presented previously in **Table 1-7** and are shown graphically in **Figure 1-28**.

Primary inflows to the land and surface water system include surface water inflows (602 TAF/yr), precipitation (422 TAF/yr), and groundwater pumping (209 TAF/yr), with estimated stream gains from groundwater (i.e. accretions) of approximately 1 TAF/yr. Surface water inflows include Butte Creek, Big Chico Creek, and several other streams, as well as overland runoff of precipitation and applied water from upslope lands. A minor inflow includes diversions of surface water that occur outside of the basin and are conveyed into the basin for use.

Primary outflows from the land and surface water system include surface water outflows (666 TAF/yr), evapotranspiration (348 TAF/yr), deep percolation (192 TAF/yr), and stream losses (also referred to as seepage) (28 TAF/yr). Surface water outflows include outflows through Butte Creek, Big Chico Creek, and other streams, as well as overland runoff of precipitation and applied water to downslope lands. Additionally, water is diverted from Butte Creek for use in the Butte Subbasin. Evapotranspiration is primarily from agricultural lands but also from native vegetation, urban and industrial lands, managed wetlands, and canal evaporation. Deep percolation is primarily from precipitation, but also from applied water.

The average annual change in storage in the land and surface water system is negligible due to similar soil moisture content in the root zone, on average, across water years, and limited storage capacity exists in surface water bodies within the basin.

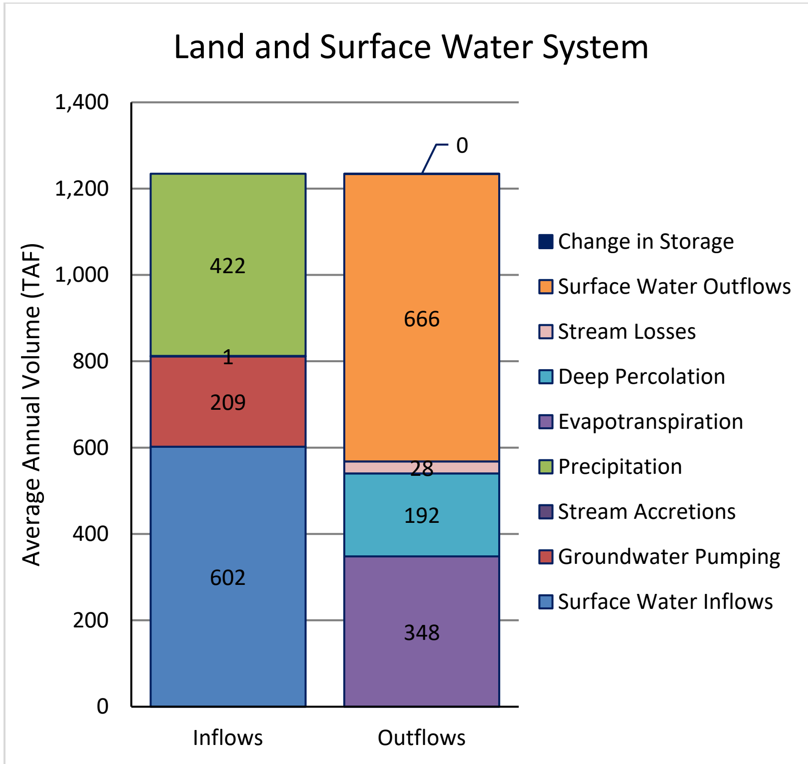


Figure 1-28. Average Annual Current Conditions Land and Surface Water System Water Budget

Average annual inflows to and outflows from the groundwater system were estimated to be 845 TAF and 846 TAF, respectively, with an average decrease in groundwater storage of 1 TAF per year during the 50-year simulation period. Average annual values were presented previously in **Table 1-8** and are shown graphically in **Figure 1-29**.

Inflows to the groundwater system include deep percolation (192 TAF/yr); subsurface inflows from the Los Molinos, Butte, and Wyandotte Creek subbasins and from the foothill area (143 TAF/yr); and stream losses (28 TAF/yr). Outflows from the groundwater system include groundwater pumping (209 TAF/yr); subsurface outflows to the Butte, Los Molinos, and Wyandotte Creek subbasins and to the foothill area (76 TAF/yr); western boundary net outflows (77 TAF/yr); and stream gains from groundwater (1 TAF/yr).

Western boundary net outflows represent Sacramento River gains from groundwater and subsurface outflows to the Corning Subbasin. The split between these outflows is uncertain at this time and identified as a data gap. It is anticipated that this data gap will be addressed through future refinements to the BBGM and through coordination and collaboration with neighboring subbasins as part of GSP implementation.

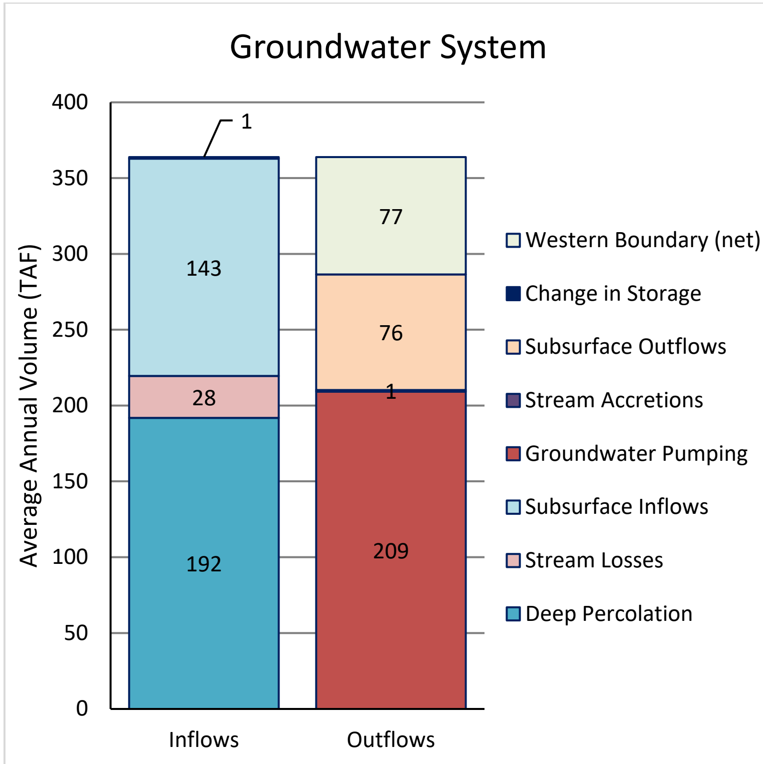


Figure 1-29. Average Annual Current Conditions Groundwater System Water Budget

1.3.4.3 Future Conditions

Three projected water budgets were developed for the basin to provide baseline scenarios representing potential future conditions considering planned development under the 2030 General Plan and climate change centered around 2030 and 2070 based on central tendency climate change datasets provided by DWR. The projected water budget scenarios provide a foundation to understand the behavior of the basin considering potential land use and urban demands over a broad range of hydrologic conditions, modified based on climate change projections). Use of a 50-year hydrologic period provides a basis for estimation of sustainable yield under potential future conditions.

Future Conditions, No Climate Change

Average annual inflows to and outflows from the basin for the future conditions without climate change projected land and surface water system baseline water budget were estimated to be 1.24 million acre-feet (MAF) per year. Average annual values were presented previously in **Table 1-7** and are shown graphically in **Figure 1-30**.

Primary inflows to the land and surface water system include surface water inflows (602 TAF/yr), precipitation (422 TAF/yr), and groundwater pumping (216 TAF/yr), with estimated stream gains from groundwater (i.e. accretions) of approximately 1 TAF/yr. Surface water inflows include Butte Creek, Big Chico Creek, and several other streams, as well as overland runoff of precipitation and applied water from upslope lands. A minor inflow includes diversions of surface water that occur outside of the basin and are conveyed into the basin for use.

Primary outflows from the land and surface water system include surface water outflows (676 TAF/yr), evapotranspiration (347 TAFyr), deep percolation (189 TAF/yr), and stream losses (also referred to as seepage) (28 TAF/yr). Surface water outflows include outflows through Butte Creek, Big Chico Creek, and other streams, as well as overland runoff of precipitation and applied water to downslope lands. Additionally, water is diverted from Butte Creek for use in the Butte Subbasin. Evapotranspiration is primarily from agricultural lands but also from native vegetation, urban and industrial lands, managed wetlands, and canal evaporation. Deep percolation is primarily from precipitation, but also from applied water.

The average annual change in storage in the land and surface water system is negligible due to similar soil moisture content in the root zone, on average, across water years, and limited storage capacity exists in surface water bodies within the basin.

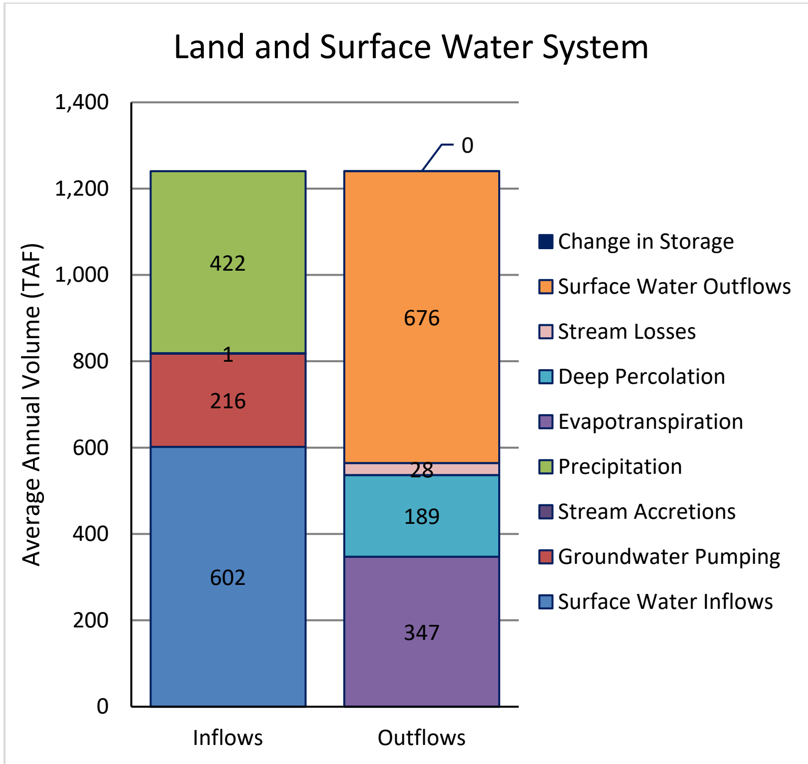


Figure 1-30. Average Annual Future Conditions without Climate Change Land and Surface Water System Water Budget

Average annual inflows to and outflows from the groundwater system were estimated to be 843 TAF and 845 TAF, respectively, with an average decrease in groundwater storage of 2 TAF per year during the 50-year simulation period. Average annual values were presented previously in **Table 1-8** and are shown graphically in **Figure 1-31**.

Inflows to the groundwater system include deep percolation (189 TAF/yr); subsurface inflows from the Los Molinos, Butte, and Wyandotte Creek subbasins and from the foothill area (143 TAF/yr); and stream losses (28 TAF/yr). Outflows from the groundwater system include groundwater pumping (216 TAF/yr); subsurface outflows to the Butte, Los Molinos, and Wyandotte Creek subbasins and to the foothill area (72 TAF/yr); western boundary net outflows (73 TAF/yr); and stream gains from groundwater (1 TAF/yr).

Western boundary net outflows represent Sacramento River gains from groundwater and subsurface outflows to the Corning Subbasin. The split between these outflows is uncertain at this time and identified as a data gap. It is anticipated that this data gap will be addressed through future refinements to the BBGM and through coordination and collaboration with neighboring subbasins as part of GSP implementation.

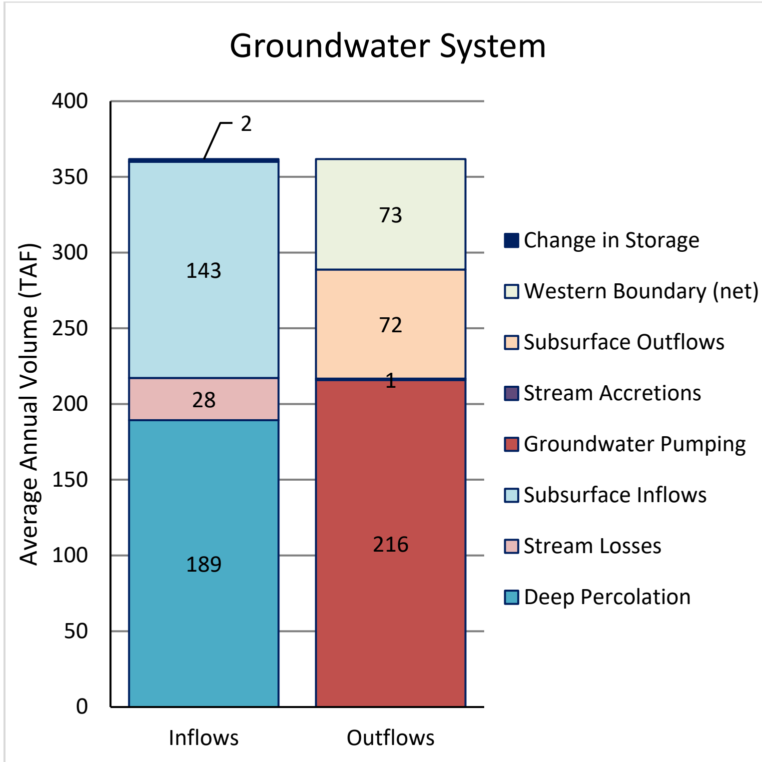


Figure 1-31. Average Annual Future Conditions without Climate Change Groundwater System Water Budget

Future Conditions, 2030 Climate Change

Average annual inflows to and outflows from the basin for the future conditions with 2030 climate change projected land and surface water system baseline water budget were estimated to be 1.30 million acre-feet (MAF) per year. Average annual values were presented previously in **Table 1-7** and are shown graphically in **Figure 1-32**.

Primary inflows to the land and surface water system include surface water inflows (631 TAF/yr), precipitation (438 TAF/yr), and groundwater pumping (226 TAF/yr), with estimated stream gains from groundwater (i.e. accretions) of approximately 1 TAF/yr. Surface water inflows include Butte Creek, Big Chico Creek, and several other streams, as well as overland runoff of precipitation and applied water from upslope lands. A minor inflow includes diversions of surface water that occur outside of the basin and are conveyed into the basin for use.

Primary outflows from the land and surface water system include surface water outflows (715 TAF/yr), evapotranspiration (358 TAF/yr), deep percolation (194 TAF/yr), and stream losses (also referred to as seepage) (28 TAF/yr). Surface water outflows include outflows through Butte Creek, Big Chico Creek, and other streams, as well as overland runoff of precipitation and applied water to downslope lands. Additionally, water is diverted from Butte Creek for use in the Butte Subbasin. Evapotranspiration is primarily from agricultural lands but also from native vegetation, urban and industrial lands, managed wetlands, and canal evaporation. Deep percolation is primarily from precipitation, but also from applied water.

The average annual change in storage in the land and surface water system is negligible due to similar soil moisture content in the root zone, on average, across water years, and limited storage capacity exists in surface water bodies within the basin.

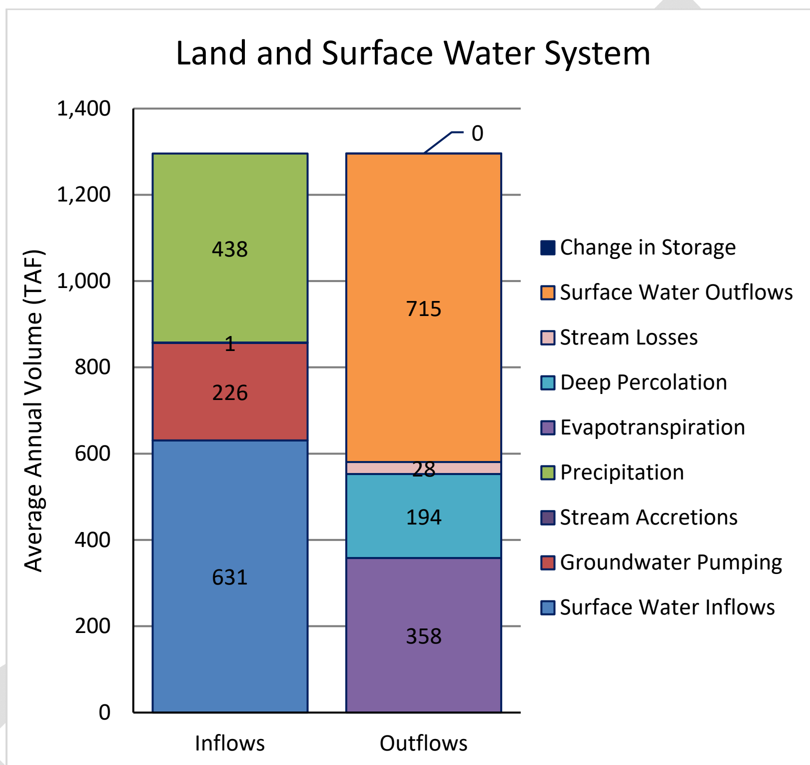


Figure 1-32. Average Annual Future Conditions with 2030 Climate Change Land and Surface Water System Water Budget

Average annual inflows to and outflows from the groundwater system were estimated to be 853 TAF and 854 TAF, respectively, with an average decrease in groundwater storage of 2 TAF per year during the 50-year simulation period. Average annual values were presented previously in **Table 1-8** and are shown graphically in **Figure 1-33**.

Inflows to the groundwater system include deep percolation (193 TAF/yr); subsurface inflows from the Los Molinos, Butte, and Wyandotte Creek subbasins and from the foothill area (145 TAF/yr); and stream losses (28 TAF/yr). Outflows from the groundwater system include groundwater pumping (226 TAF/yr); subsurface outflows to the Butte, Los Molinos, and Wyandotte Creek subbasins and to the foothill area (71 TAF/yr); western boundary net outflows (71 TAF/yr); and stream gains from groundwater (1 TAF/yr).

Western boundary net outflows represent Sacramento River gains from groundwater and subsurface outflows to the Corning Subbasin. The split between these outflows is uncertain at this time and identified as a data gap. It is anticipated that this data gap will be addressed through future refinements to the BBGM and through coordination and collaboration with neighboring subbasins as part of GSP implementation.

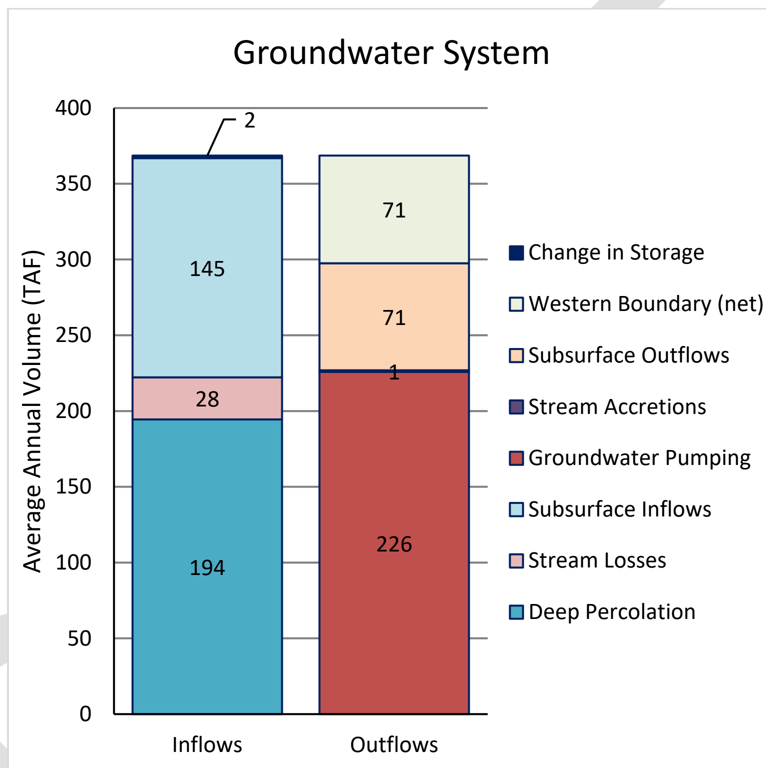


Figure 1-33. Average Annual Future Conditions with 2030 Climate Change Groundwater System Water Budget

Future Conditions, 2070 Climate Change

Average annual inflows to and outflows from the basin for the future conditions with 2070 climate change projected land and surface water system baseline water budget were estimated to be 1.34 million acre-feet (MAF) per year. Average annual values were presented previously in **Table 1-7** and are shown graphically in **Figure 1-34**.

Primary inflows to the land and surface water system include surface water inflows (652 TAF/yr), precipitation (453 TAF/yr), and groundwater pumping (238 TAF/yr), with estimated stream gains from groundwater (i.e. accretions) of approximately 1 TAF/yr. Surface water inflows include Butte Creek, Big Chico Creek, and several other streams, as well as overland runoff of precipitation and applied water from upslope lands. A minor inflow includes diversions of surface water that occur outside of the basin and are conveyed into the basin for use.

Primary outflows from the land and surface water system include surface water outflows (749 TAF/yr), evapotranspiration (371 TAF/yr), deep percolation (197 TAF/yr), and stream losses (also referred to as seepage) (27 TAF/yr). Surface water outflows include outflows through Butte Creek, Big Chico Creek, and other streams, as well as overland runoff of precipitation and applied water to downslope lands. Additionally, water is diverted from Butte Creek for use in the Butte Subbasin. Evapotranspiration is primarily from agricultural lands but also from native vegetation, urban and industrial lands, managed wetlands, and canal evaporation. Deep percolation is primarily from precipitation, but also from applied water.

The average annual change in storage in the land and surface water system is negligible due to similar soil moisture content in the root zone, on average, across water years, and limited storage capacity exists in surface water bodies within the basin.

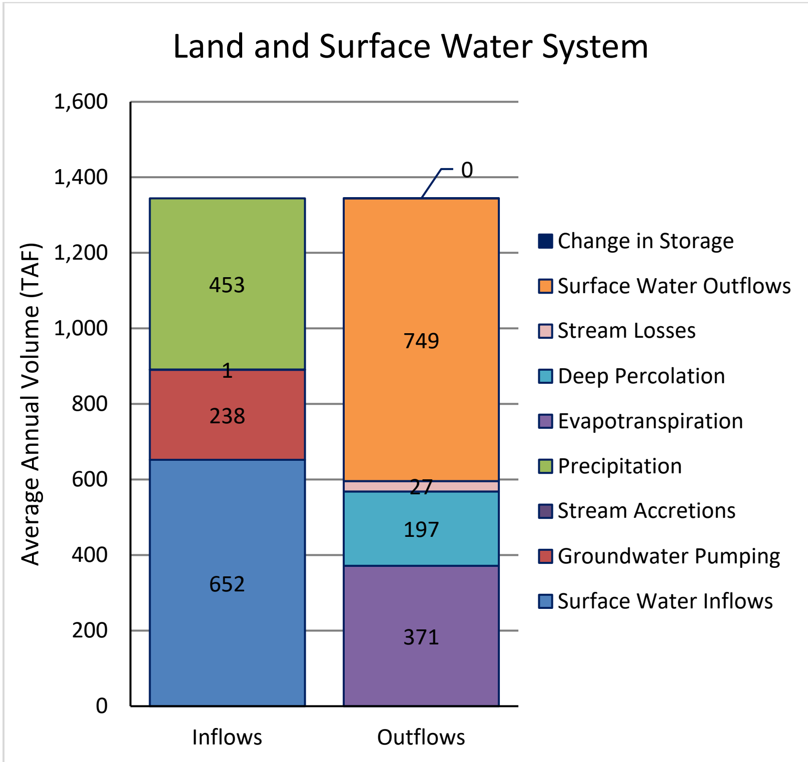


Figure 1-34. Average Annual Future Conditions with 2070 Climate Change Land and Surface Water System Water Budget

Average annual inflows to and outflows from the groundwater system were estimated to be 857 TAF and 860 TAF, respectively, with an average decrease in groundwater storage of 3 TAF per year during the 50-year simulation period. Average annual values were presented previously in **Table 1-8** and are shown graphically in **Figure 1-35**.

Inflows to the groundwater system include deep percolation (197 TAF/yr); subsurface inflows from the Los Molinos, Butte, and Wyandotte Creek subbasins and from the foothill area (145 TAF/yr); and stream losses (27 TAF/yr). Outflows from the groundwater system include groundwater pumping (238 TAF/yr); subsurface outflows to the Butte, Los Molinos, and Wyandotte Creek subbasins and to the foothill area (68 TAF/yr); western boundary net outflows (66 TAF/yr); and stream gains from groundwater (1 TAF/yr).

Western boundary net outflows represent Sacramento River gains from groundwater and subsurface outflows to the Corning Subbasin. The split between these outflows is uncertain at this time and identified as a data gap. It is anticipated that this data gap will be addressed through future refinements to the BBGM and through coordination and collaboration with neighboring subbasins as part of GSP implementation.

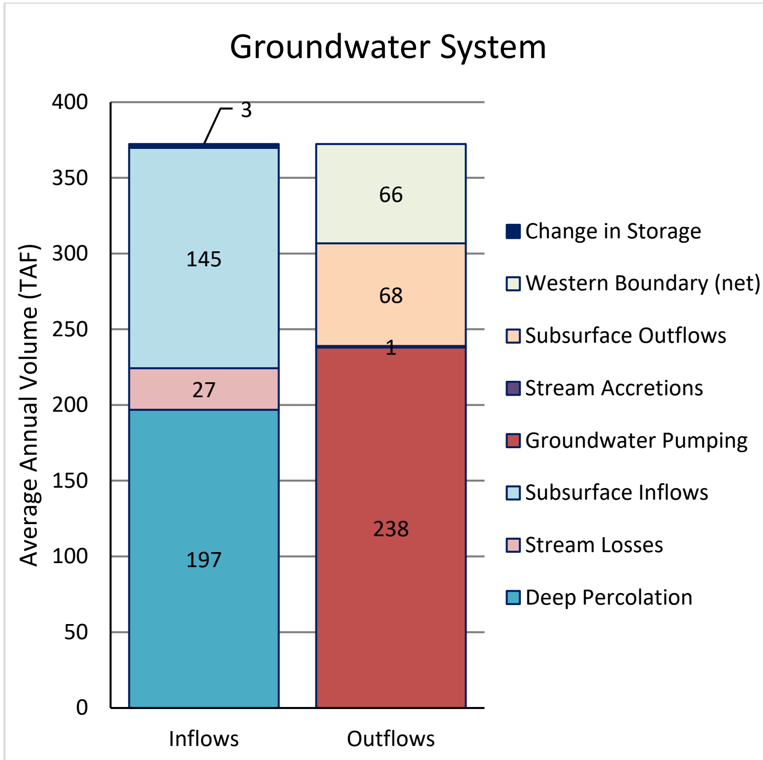


Figure 1-35. Average Annual Future Conditions with 2070 Climate Change Groundwater System Water Budget

Comparison of Water Budget Scenarios

A figure depicting cumulative change in storage for the current conditions and three future conditions baseline scenarios is provided on the following page (**Figure 1-36**). In the figure, the cumulative change in groundwater storage is shown for the 50-year hydrologic period. The x-axis (horizontal axis) is labeled with the historical reference year along with the corresponding water year type based on the Sacramento Valley Water Year Index. Years are identified as wet (W), above normal (AN), below normal (BN), dry (D), or critical (C).

Estimated changes in storage are similar for each of the scenarios, with increased cumulative reduction in storage for the future conditions scenarios relative to the current conditions scenario. The 2070 climate change scenario suggests somewhat greater cumulative decrease in storage than the future conditions without climate change and 2030 climate change scenarios likely due to projected increases in temperature and associated irrigation demands within the subbasin.

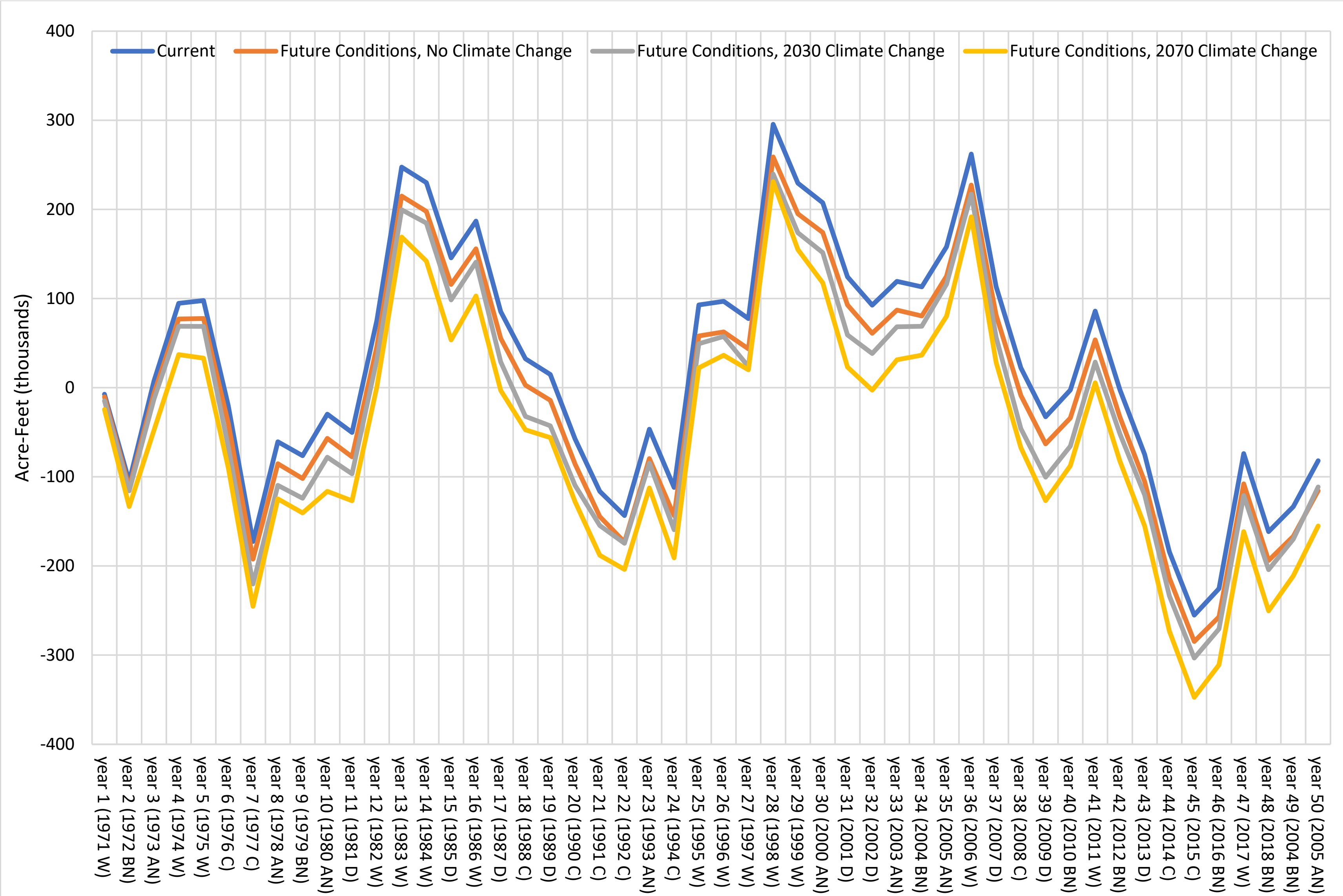


Figure 1-36. Cumulative Change in Groundwater Storage for Current and Future Conditions Baseline Scenarios

1.3.5 Water Budget Uncertainty

Uncertainty refers to a lack of understanding of the basin setting that significantly affects an Agency's ability to develop sustainable management criteria and appropriate projects and management actions in a GSP, or to evaluate the efficacy of plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed. Uncertainty exists in all components of each water budget and in the assumptions used to project potential future conditions related to planned development and associated urban demands as well as projections of climate change. These uncertainties are not expected to substantially limit the ability to develop and implement a GSP for the basin including the ability develop sustainable management criteria and appropriate projects and management actions, nor the ability to assess whether the basin is being sustainably managed over time. It is anticipated that these uncertainties will be reduced over time through monitoring and additional data collection, refinements to the BBGM and other tools, and coordination with neighboring basins.

1.3.6 Overdraft Conditions

Based on the current conditions and future conditions baseline scenarios, which approximate long-term average conditions in the subbasin considering climate change and other factors, there is the potential for overdraft conditions to occur. Overdraft estimates range from approximately 1,100 to 2,600 acre-feet per year based on average annual estimated decrease in storage presented previously in **Table 1-8** and in **Table 1-10** in the following section.

1.3.7 Sustainable Yield Estimate

As described previously, sustainable yield refers to the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin, and including any temporary surplus that can be withdrawn annually from a groundwater supply without causing an undesirable result. Draft estimates have been developed for the basin for each scenario as the long-term annual groundwater pumping, minus the average annual decrease in groundwater storage, as summarized in **Table 1-10**.

Table 1-10. Estimated Groundwater Pumping, Decrease in Storage, and Sustainable Yield

Baseline Scenario	Groundwater Pumping (AFY)	Decrease in Groundwater Storage (AFY)	Difference (AFY)
Current	209,200	1,100	208,100
Future, No Climate Change	215,800	1,700	214,100
Future, 2030 Climate Change	225,900	1,700	224,200
Future, 2070 Climate Change	238,000	2,600	235,400

1.3.8 Recommended Next Steps

1.3.8.1 Refine Surface Water Diversion Estimates

While many of the large diversions are continuously monitored and recorded, limited information is available for others. It is recommended that GSAs in the basin work with local stakeholders to better document surface water diversions, including investigation of riparian diversions in some area and additional information describing water supplies for managed wetlands. Diversion estimates developed as part of the water budgets provide a good basis to support discussion with diverters.

1.3.8.2 Refine Groundwater Pumping Estimates

Groundwater pumping for irrigation has generally been estimated based on estimates of crop irrigation requirements in areas known to rely on groundwater. It is recommended that GSAs look for opportunities to verify and refine groundwater pumping estimates to improve water budget estimates by obtaining pumping data from cooperative landowners.

1.3.8.3 Refine Deep Percolation Estimates

Deep percolation in some areas may return to the surface layer through accretion in drains and natural waterways or may be consumed by phreatophytic vegetation. It is recommended that GSAs look for opportunities to further understand and investigate the ultimate fate of deep percolation from agricultural lands. Through modeling of specific waterways and shallow groundwater, the BBGM can help support these investigations.

1.3.8.4 Refine Urban Lands Water Budgets

The relative proportion of non-consumed water returning as deep percolation or surface runoff does not explicitly account for percolation from stormwater retention ponds or releases from wastewater treatment plants to local waterways. There is an opportunity to refine water budgets for developed lands to verify and refine estimates of non-consumed water. Additionally, there is an opportunity to evaluate and develop refined water use estimates for industrial uses.

1.3.8.5 Refine Characterization of Interbasin Flows and Net Outflows along Western Boundary

Interbasin flows are dependent on conditions in adjacent basins. It is recommended that GSAs refine estimates of subsurface groundwater flows from and to neighboring basins through coordination with GSAs in neighboring basins during or following GSP development and through review of modeling tools that cover the Sacramento Valley region, including the C2VSim and SVSim integrated hydrologic model applications developed by DWR.

1.3.8.6 Land Use Changes Due to the Camp Fire

In 2018, the Camp Fire destroyed 18,000 structures in Butte County displacing over 27,000 residents. While the Town of Paradise, Concow and other areas destroyed by the Camp Fire rebuild, many residents have relocated to the City of Chico and other portions of the Vina subbasin. The existing General Plans may not fully account for the relocation of Camp Fire survivors. A focused accounting of changes to residential land use and associated water demands as a result of the Camp Fire should be conducted.

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