2. BASIN SETTING

2.1 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. The HCM serves as an important component of the basin setting, 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 include the Geology of the Northern Sacramento Valley (DWR, 2014) and the Butte County Groundwater Inventory Analysis, 2005 (DWR, 2005). Local studies include the Butte County Lower Tuscan Aquifer Monitoring, Recharge, and Data Management Project Final Report (Brown and Caldwell, 2013), the Stable Isotope Recharge Study (Brown and Caldwell, 2017), Butte County Water Inventory and Analysis Report (Davids Engineering, 2016), and the Hydrostratigraphy and Pump-Test Analysis of the Lower Tuscan/Tehama Aquifer, Northern Sacramento Valley (Greene and Hoover, 2015). 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.

2.1.1 Basin Boundaries

2.1.1.1 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 Subbasin to the north; Corning Subbasin to the west; Butte Subbasin to the south; and a small portion of the Wyandotte Creek Subbasin on the southeast border (Figure 1-3).

The lateral boundaries of the Vina 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 DWR Bulletin 118 Update 2003 (DWR, 2003).

2.1.1.2 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 have been 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 2-1 shows the base of fresh groundwater in the Vina Subbasin ranging from 800 to 1,200 feet below ground surface (bgs) (Berkstresser, 1973).

2.1.2 Topography, Surface Water and Recharge

2.1.2.1 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 Vina 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 Vina Subbasin. Figure 2-2 shows the topography of the Vina Subbasin.

2.1.2.2 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 Vina Subbasin are well suited for growing rice. Figure 2-3 shows the distribution of hydrologic soil groups for the Vina Subbasin. Soils designated as C/D are lands having soils 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 (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 Vina Subbasin include 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 2-1. The distribution of dominant soils (e.g., “map units”) in the Vina Subbasin is shown in Figure 2-4.

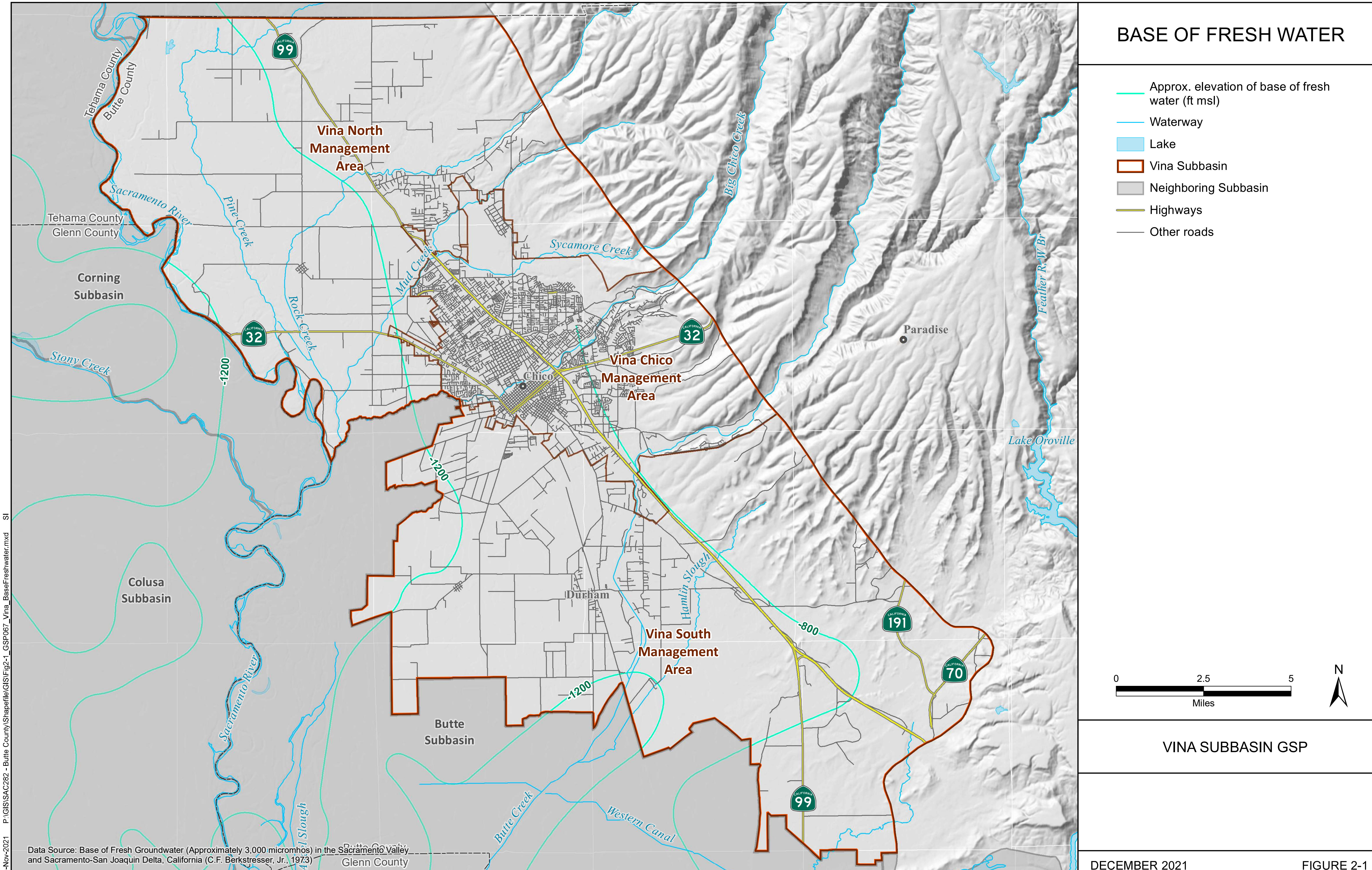
BASE OF FRESH WATER
Approx. elevation of base of fresh water (ft msl)
Waterway
Lake
Vina Subbasin
Neighboring Subbasin
Highways
Other roads
0
2.5
5
Miles
N
VINA SUBBASIN GSP
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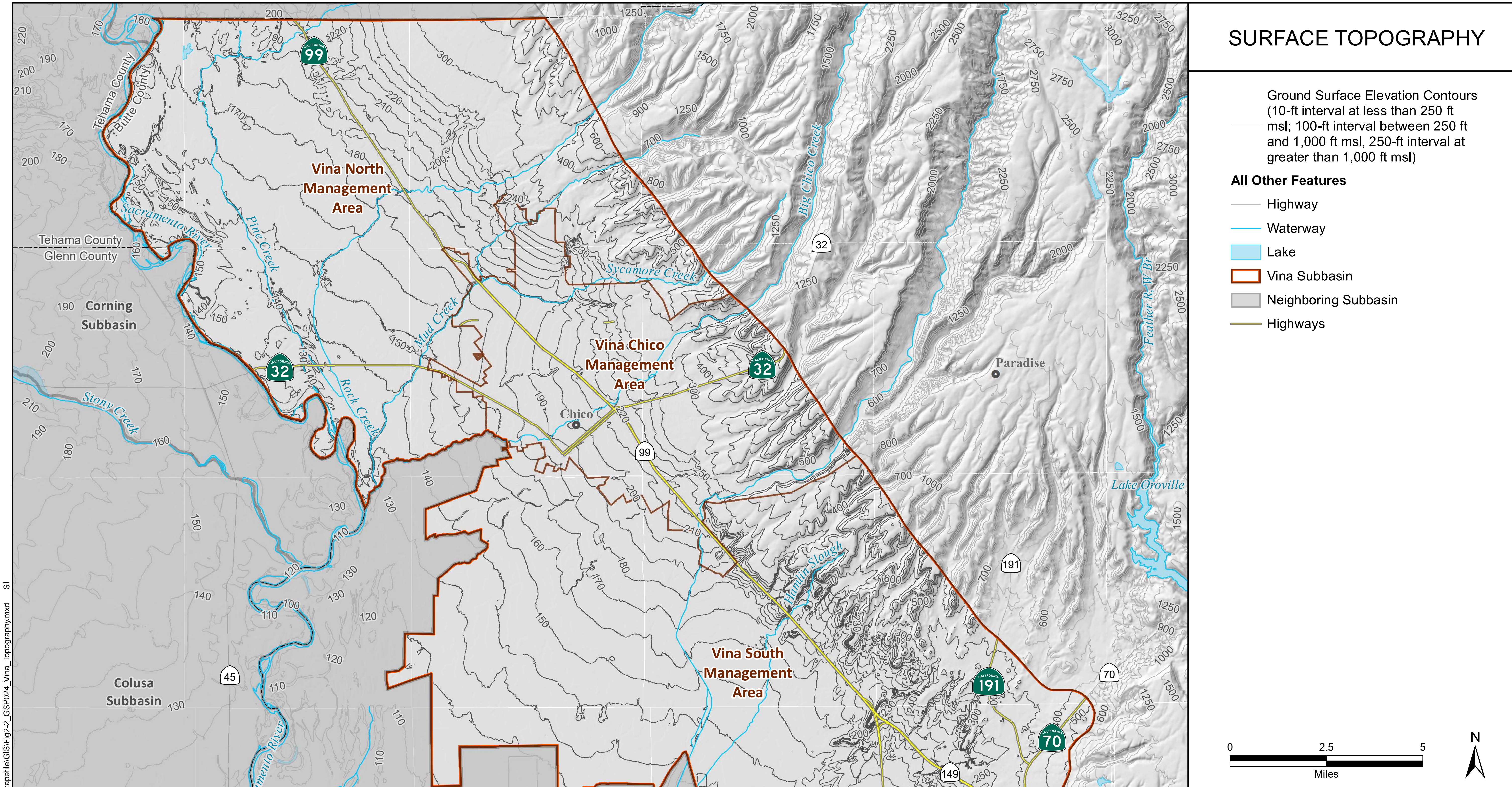
FIGURE 2-1
Vina North Management Area
Vina Chico Management Area
Vina South Management Area
Corning Subbasin
Colusa Subbasin
Butte Subbasin
Tehama County
Butte County
Glenn County
Sacramento River
Pine Creek
Rock Creek
Mud Creek
Sycamore Creek
Big Chico Creek
Stony Creek
Hamlin Slough
Butte Creek
Western Canal
Feather R. W Br
Lake Oroville
Paradise
Chico
Durham
-1200
-800
99
32
191
70
Data Source: Base of Fresh Groundwater (Approximately 3,000 micromhos) in the Sacramento Valley and Sacramento-San Joaquin Delta, California (C.F. Berkstresser, Jr., 1973)
P:\GIS\SAC282 - Butte County\Shapefile\GIS\Fig2-1_GSP067_Vina_BaseFreshwater.mxd SI
30-Nov-2021



SURFACE TOPOGRAPHY

VINA SUBBASIN GSP

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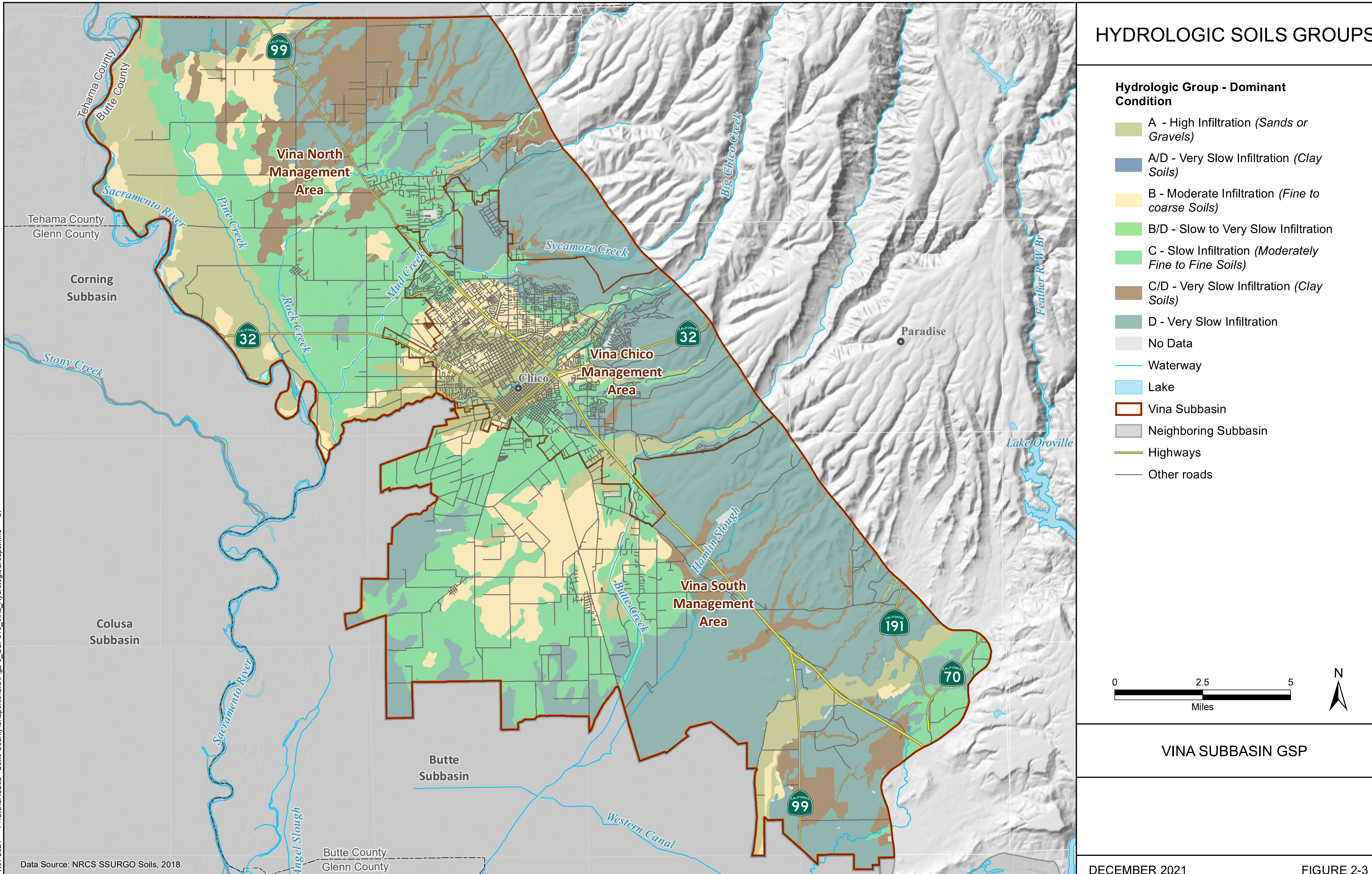
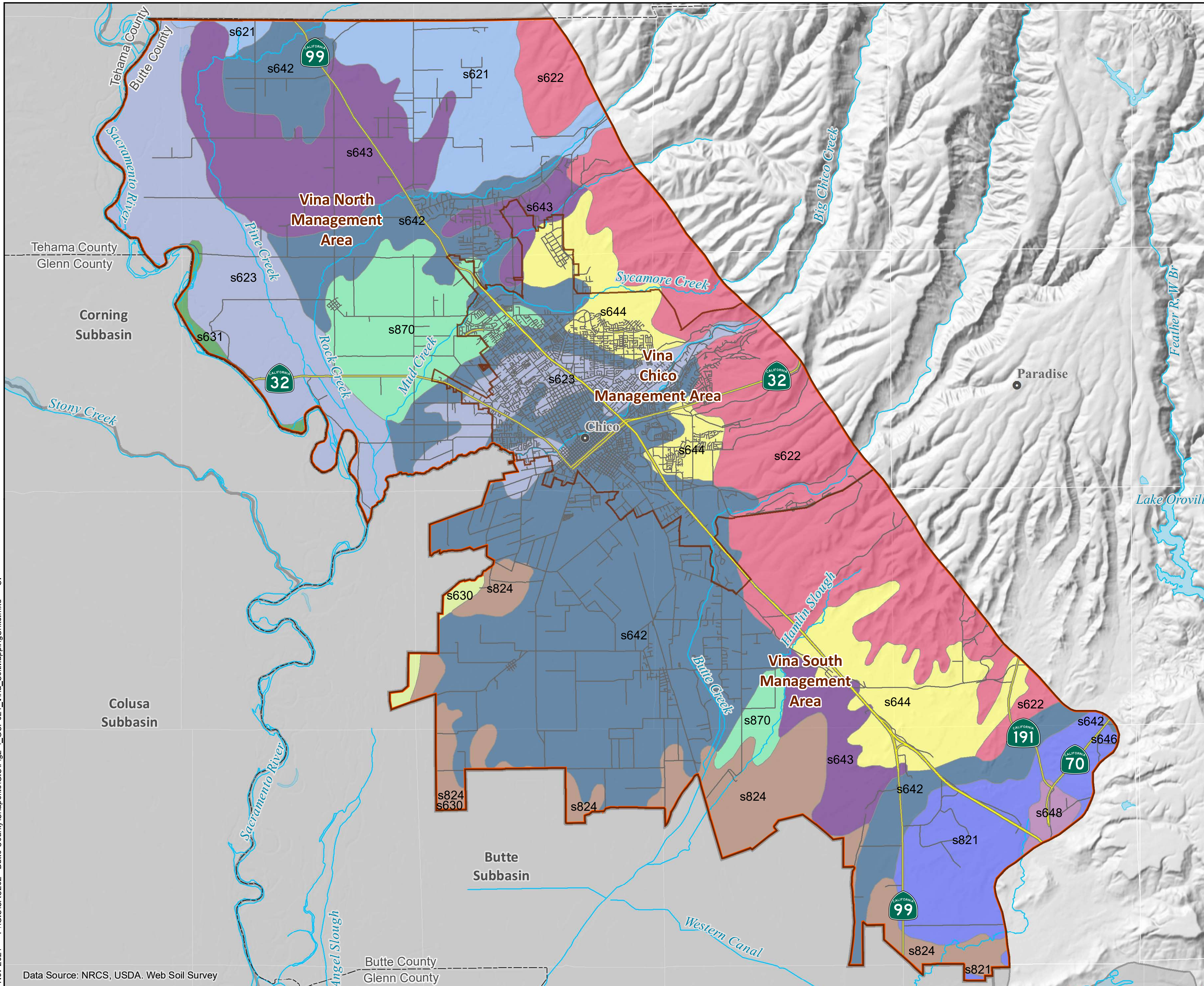
FIGURE 2-2

19-Nov-2021 P:\GIS\SAC282 - Butte County\Shapefile\GIS\Fig2-2_GSP024_Vina_Topography.mxd SI



VINA SUBBASIN GSP

DECEMBER 2021 FIGURE 2-3



SOIL MAPPING UNITS

Mapunit Name (Mapunit Symbol)

- Corning-Anita (s643)
- Goulding-Auburn (s646)
- Landlow-Clear Lake (s630)
- Redding-Corning (s821)
- Riverwash-Dumps-Cortina (s648)
- Riverwash-Orland-Los Robles-Cortina (s631)
- Stockton-Clear Lake-Capay (s824)
- Tisdale-Kilaga-Conejo (s870)
- Toomes-Supan (s622)
- Tuscan-Anita (s644)
- Tuscan-Keefers-Inks (s621)
- Vina-Brentwood (s642)
- Vina-Riverwash-Reiff-Columbia (s623)
- Waterway
- Lake
- Vina Subbasin
- Neighboring Subbasin
- Highways
- Other roads

0 2.5 5
Miles

N

VINA SUBBASIN GSP

DECEMBER 2021 FIGURE 2-4

19-Nov-2021 P:\GIS\SAC282 - Butte County\Shapefile\GIS\Fig2-4_GSP021_Vina_SoilMappingUnits.mxd SI

Table 2-1: STATSGO2 Soils Table for Vina Subbasin

Soil Map Unit	Percent of Area	Sum of Acres	Slope Range	Drainage
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
Vina Subbasin	100%	184,918		

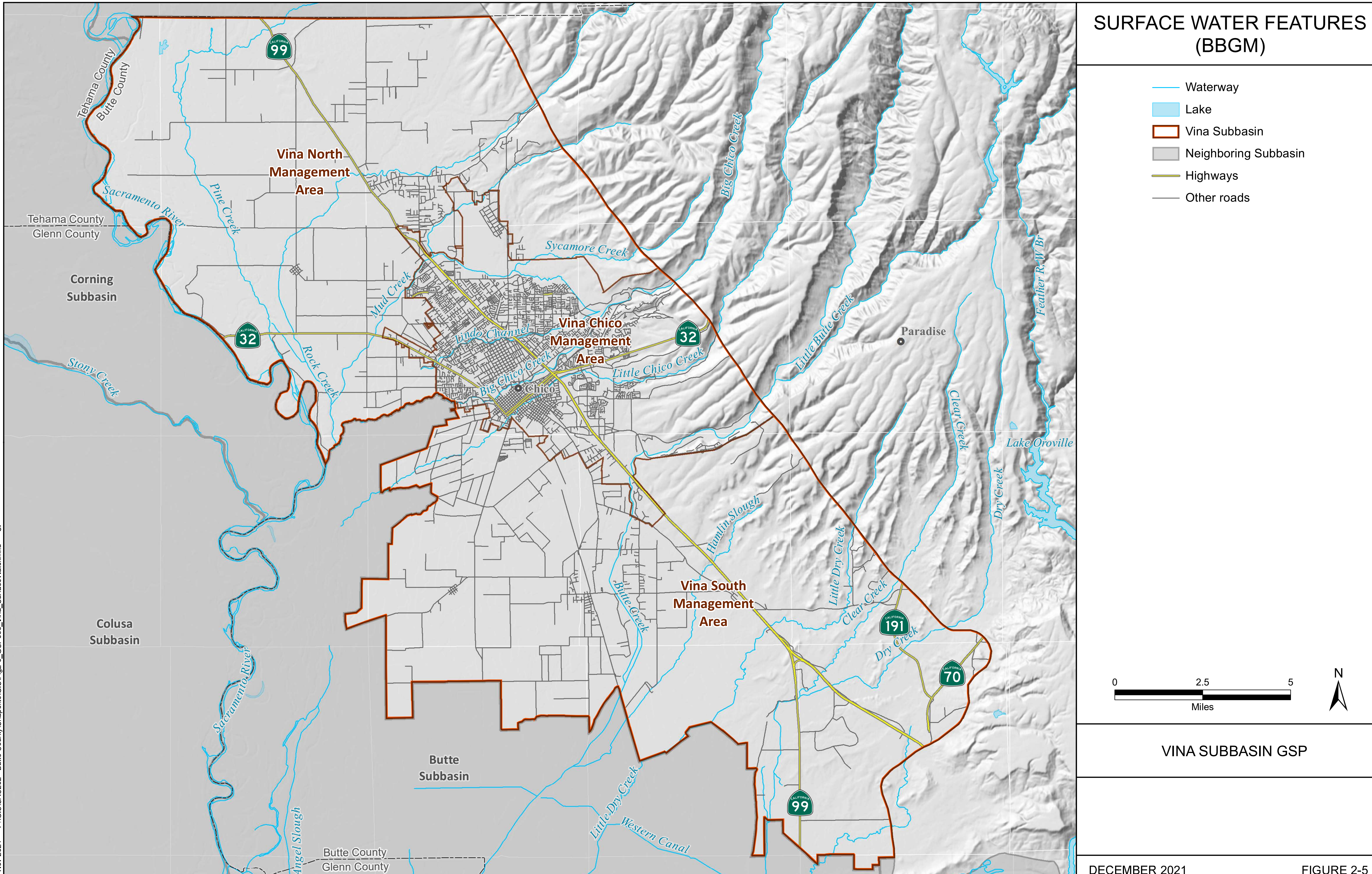
2.1.2.3 Surface Water

Surface Water Sources and Channels

The Sacramento River borders the Vina Subbasin on its western side. Other larger surface water bodies traversing the Vina Subbasin include Big Chico Creek and Butte Creek. Smaller local or ephemeral streams entering and traversing the Vina Subbasin include Pine Creek, Rock Creek, Mud Creek, Sycamore Creek, Little Chico Creek, Hamlin Slough, Little Dry Creek, and Clear Creek. Lindo Channel (Sandy Gulch) and the Sycamore Bypass Channel are flood control channels for the City of Chico. Figure 2-5 shows the locations of rivers, streams, and major water supply, and drainage features.

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 the Pacific Gas and Electric Company (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. Diversions from Butte Creek supplies water for irrigation in portions of the Vina Subbasin.

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.


Vina North Management Area
Vina Chico Management Area
Vina South Management Area
Corning Subbasin
Colusa Subbasin
Butte Subbasin
Tehama County
Butte County
Glenn County
Sacramento River
Pine Creek
Sycamore Creek
Big Chico Creek
Mud Creek
Lindo Channel
Rock Creek
Stony Creek
Little Chico Creek
Little Butte Creek
Feather R. W Br
Paradise
Chico
Clear Creek
Lake Oroville
Dry Creek
Hamlin Slough
Little Dry Creek
Butte Creek
Western Canal
Angel Slough
99
32
191
70
SURFACE WATER FEATURES (BBGM)
Waterway
Lake
Vina Subbasin
Neighboring Subbasin
Highways
Other roads
0
2.5
5
Miles
N
VINA SUBBASIN GSP
DECEMBER 2021
FIGURE 2-5
19-Nov-2021 P:\GIS\SAC282 - Butte County\Shapefile\GIS\Fig2-5_GSP068_Vina_SurfaceWater.mxd SI

2.1.2.4 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.

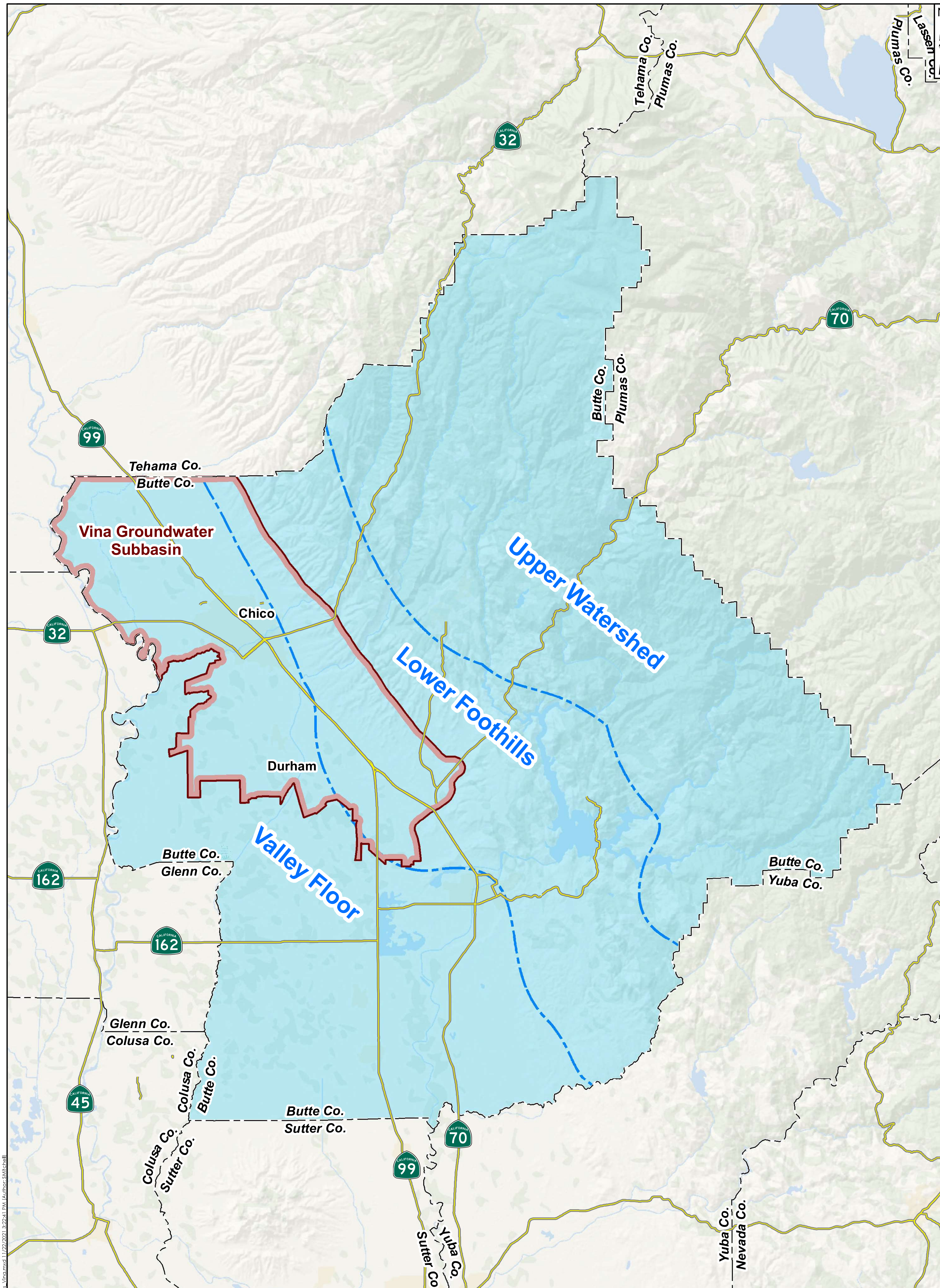
The Stable Isotope Recharge Study (Brown and Caldwell, 2017) delineated three areas based on land surface elevation that are general sources of precipitation and serve as water sources to the surface water and groundwater systems in Butte County. Figure 2-6, reproduced from Brown and Caldwell (2017), shows these areas labeled as Upper Watershed, Lower Foothills, and Valley Floor. 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.

The Vina Subbasin is located primarily within the Valley Floor area, as shown in Figure 2-6. The Upper Watershed receives rain and snow, primarily during the winter and spring months. Rainfall runoff and snowmelt from the Upper Watershed 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 run off 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 Vina Subbasin. Results from stable isotope data indicated that the only route by which the Upper Watershed provides recharge to the groundwater system in the vicinity of Butte Creek in the Vina South MA 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 Vina 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 bgs 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.



Legend

Groundwater Subbasin[1]

Vina Groundwater Subbasin

Roads[2]

Highways

Precipitation Source Areas

Precipitation Source Area Boundaries

Boundaries[2]

County boundaries

Notes:
1) California Department of Water Resources (CA DWR).
2) TIGER/Line, U.S. Census Bureau.

8 4 0 8 Miles

Precipitaion Source Areas
(Brown and Caldwell, 2017)
Vina Groundwater Subbasin GSP

Geosyntec
consultants

Figure **2-6**

Project No.: SAC282

December 2021

Aquifer testing conducted as part of the Lower Tuscan Aquifer study (Brown and Caldwell, 2013) indicated that 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 MA.

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.

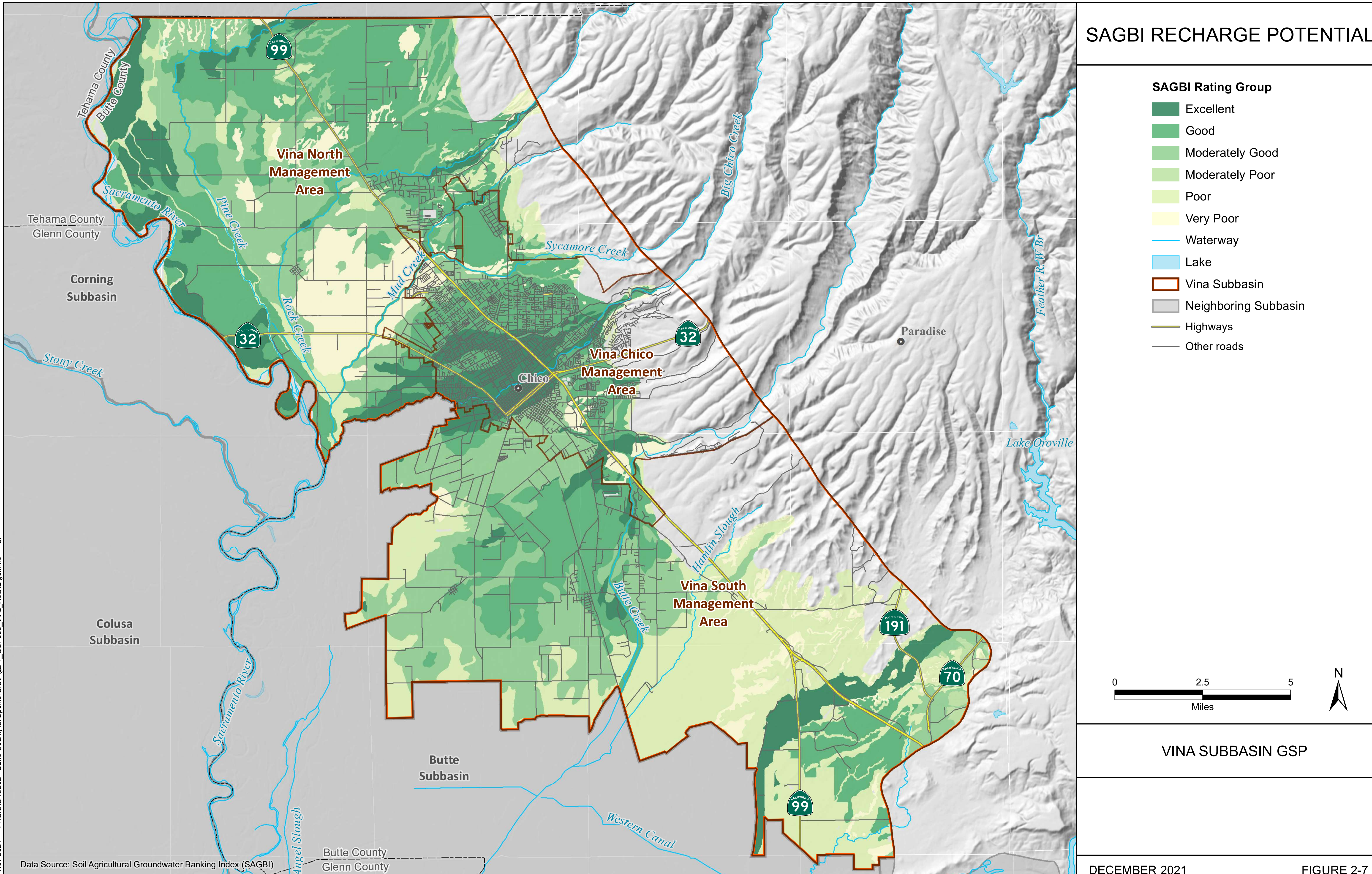
Additional recharge through management activities of flood flows or irrigation practices has potential in the Vina Subbasin. The Soil Agricultural Groundwater Banking Index (SAGBI) is a suitability index for groundwater recharge on agricultural land based on five major factors: deep percolation, root 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 Vina Subbasin generally received a moderately good to good rating (Figure 2-7), except for in the southeastern area of the Vina Subbasin. Additional considerations will be important for specific evaluation of any proposed recharge project.

2.1.3 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 bgs. 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).

2.1.4 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 Vina Subbasin is the Tuscan Formation. Other units that are less predominant are the Tehama, Riverbank, and Modesto formations (DWR, 2005).



VINA SUBBASIN GSP

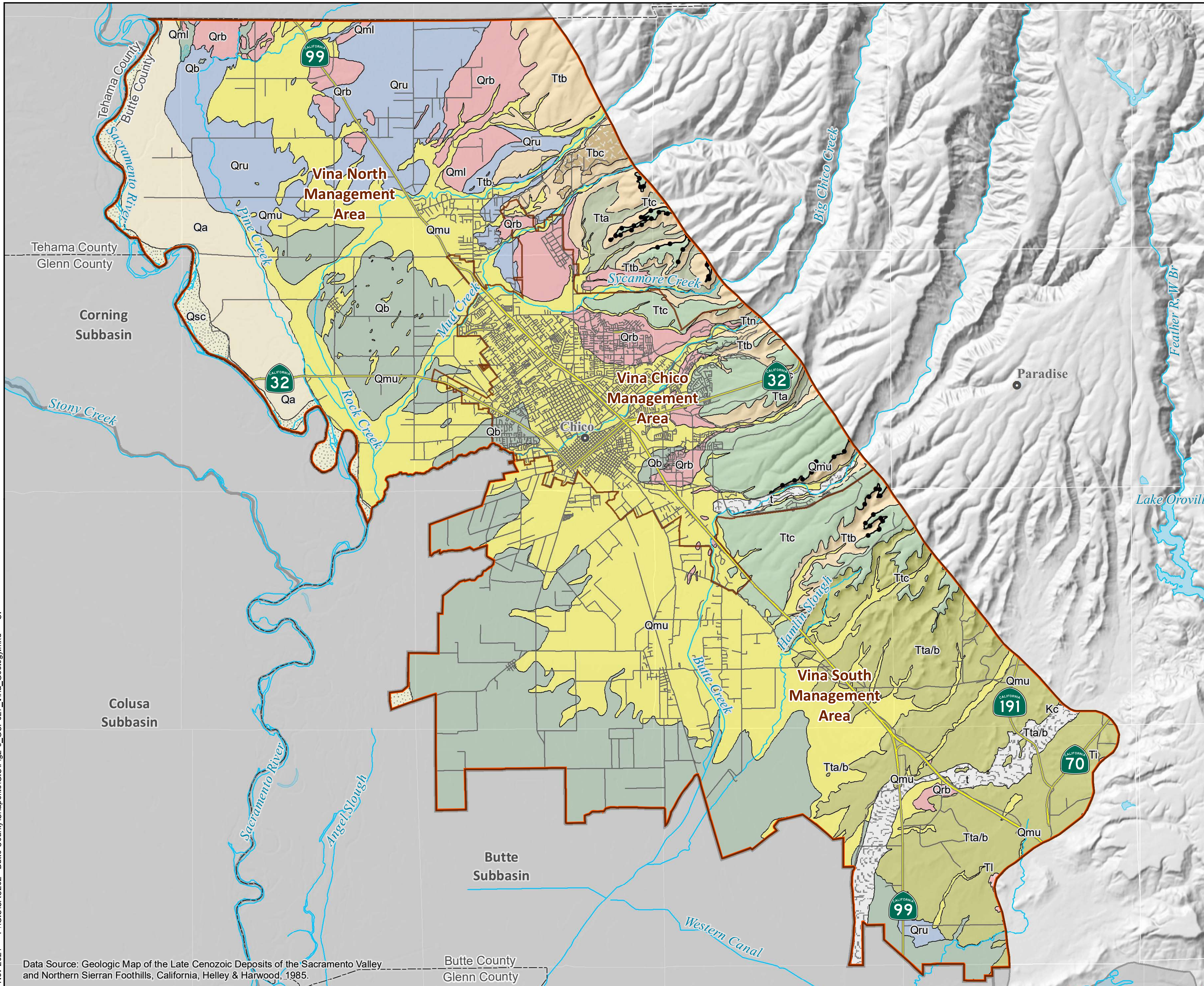
DECEMBER 2021

FIGURE 2-7

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 Vina Subbasin.

Figure 2-8 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 Vina Subbasin as the source material of the aquifer system. Table 2-2 provides brief descriptions of the significant geologic units that are found in the Vina Subbasin.

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



SURFICIAL GEOLOGY

Geology Lines

- Contact, approx. located
- Contact, certain
- Contact, certain, tuffbed

Geology Polygons

- Stream Channel Deposits (Qsc)
- Alluvium (Qa)
- Basin Deposits, Undivided (Qb)
- Marsh Deposits (Qm)
- Upper Member, Modesto Formation (Qmu)
- Lower Member, Modesto Formation (Qml)
- Upper Member, Riverbank Formation (Qru)
- Red Bluff Formation (Qrb)
- Olivine Basalt of Cohasset Ridge (Tbc)
- Nomlaki Tuff Member (Ttn)
- Unit C, Tuscan Formation (Ttc)
- Unit B, Tuscan Formation (Ttb)
- Unit A, Tuscan Formation (Tta)
- Tuscan Formation, Undifferentiated Unit A & B (Tta/b)
- Laguna Formation (Tla)
- Lovejoy Basalt (Tl)
- Ione Formation (Ti)
- Chico Formation (Kc)
- Tailings (t)
- Waterway
- Lake
- Vina Subbasin
- Neighboring Subbasin
- Highways
- Other roads

0 2.5 5
Miles
N

VINA SUBBASIN GSP

DECEMBER 2021 FIGURE 2-8

30-Nov-2021 P:\GIS\SAC282 - Butte County\Shapefile\GIS\Fig2-8_GSP027_Vina_Geology.mxd SI

Table 2-2: Geologic Units

System and Series		Geologic Unit	Lithologic Character		Maximum Thickness, [a] feet	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 Big Chico Creek are important recharge areas[b], extensive water-bearing capacity is restricted by thickness and areal extent[a].
		Basin Deposits, Qb	Unconsolidated[d] 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].
	Pleistocene	Modesto Formation, Qm	Poorly sorted unconsolidated weathered and unweathered gravel, sand, silt, and clay[c].	Upper Member Modesto Formation, Qmu: Unconsolidated, unweathered gravel, sand, silt and clay.	200	Moderately to highly permeable[a].
				Lower Member Modesto Formation, Qml: Unconsolidated, slightly weathered gravel, sand, silt and clay.		
		Riverbank Deposits, Qr	Poorly sorted unconsolidated to semi-consolidated(c) pebble and small cobble gravels interlensed with reddish clay, sand, and silt[a].	Upper Member Riverbank Formation, Qru: Unconsolidated but compact, dark brown to red alluvium composed of gravel, sand, silt and with minor clay.	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].
				Lower Member Riverbank Formation, Qrl: Red semiconsolidated gravel, sand, and silt.		

System and Series		Geologic Unit	Lithologic Character	Maximum Thickness, [a] feet	Water-bearing Character
		Red Bluff Formation, Qrb	A thin veneer of distinctive, highly weathered bright-red gravels beveling and overlying the Tehama, Tuscan, and Laguna Formations.	-	Cemented, does not transmit water well.
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[d].	500	Generally has low to moderate permeability, except in scattered gravels in the upper portion. Yields moderate quantities of water to wells along the south eastern margin of the valley[d].
		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] feet	Water-bearing Character
Neogene	Pliocene	Tuscan Formation, Tt	This series of volcaniclastic flows (lahars), 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 into four lithologically similar units A-D[a].	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.	1,500	Within this formation, moderately to highly permeable volcanic sediments are hydraulically confined by layers of volcaniclastic 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 volcaniclastic breccias. Stratigraphically higher, the massive breccia deposits of unit C confine groundwater in the permeable beds of units A and B1.
				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.		
				Unit A, Tuscan Formation (Tta): Interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone all containing scattered fragments of metamorphic rocks.		
	Miocene	Upper Princeton Valley Fill, Tupg	Non-marine sandstone containing mudstone, conglomerate, and sandstone conglomerate interbeds[c]		1,400	Largely non-water bearing or contains interstitial confined fresh to brackish water

System and Series		Geologic Unit	Lithologic Character	Maximum Thickness, (a) feet	Water-bearing Character
	Miocene	Lovejoy Basalt (Tl)	Black, dense, hard, microcrystalline to extremely grained, equigranular to sparsely porphyritic basalt.	-	-
	Miocene	Lower Princeton Submarine Valley Fill, Tlpg	Marine conglomerate and sandstone interbedded with silty shale	2,400	Largely non-water bearing or contains saline water.
	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.	-	-
	Creta ceous	Chico Formation (Kc)	Tan, yellowish-brown to light-gray, fossiliferous marine sandstone with lenticular beds of pebble to fine cobble conglomerate and minor siltstone.	-	-

Source: This table was originally included as part of the HCM for Colusa Subbasin Hydrogeologic Conceptual Model Report (Davids Engineering et al., 2018). This table has been revised and expanded to include the HCM units for the study area represented in this report.

Notes:

(a) WR, web page (www.wq.water.ca.gov).

(b) DWR, 1978. Bulletin 118-6.

(c) DWR, Bulletin 118-7 (Draft, not published).

(d) DWR, Geology of the Northern Sacramento Valley, 2014.

2.1.5 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.

2.1.5.1 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 (debris flows) that includes volcanic breccia, sandstone, and siltstone, and pumiceous tuff layers that were deposited over a period of about one 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) based on outcrop photo geology. It is difficult to apply this nomenclature to the subsurface. 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 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 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).

2.1.5.2 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 supported 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 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).

2.1.5.3 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 Coast Ranges, 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).

2.1.6 Cross Sections

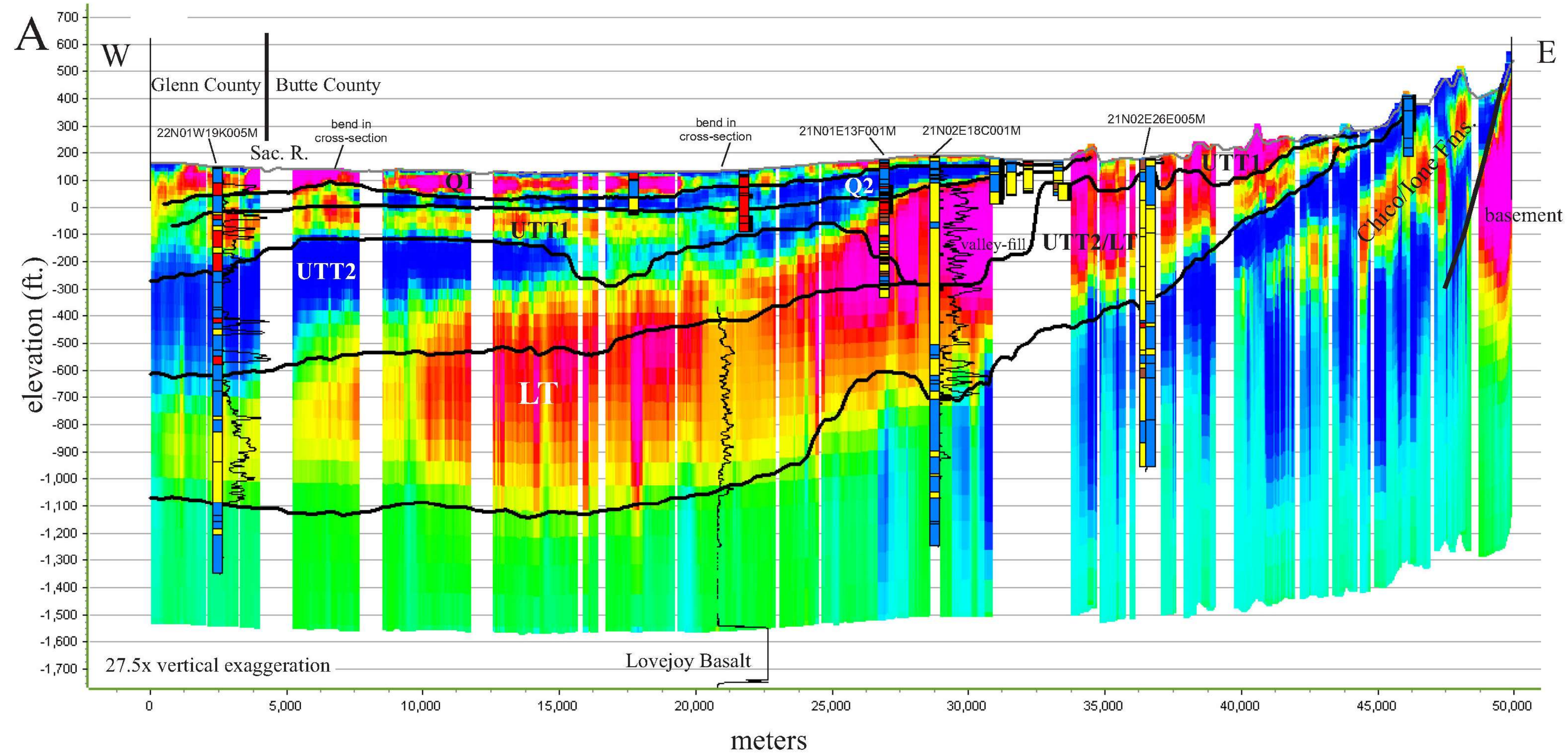
2.1.6.1 Airborne Electromagnetic (AEM) Survey

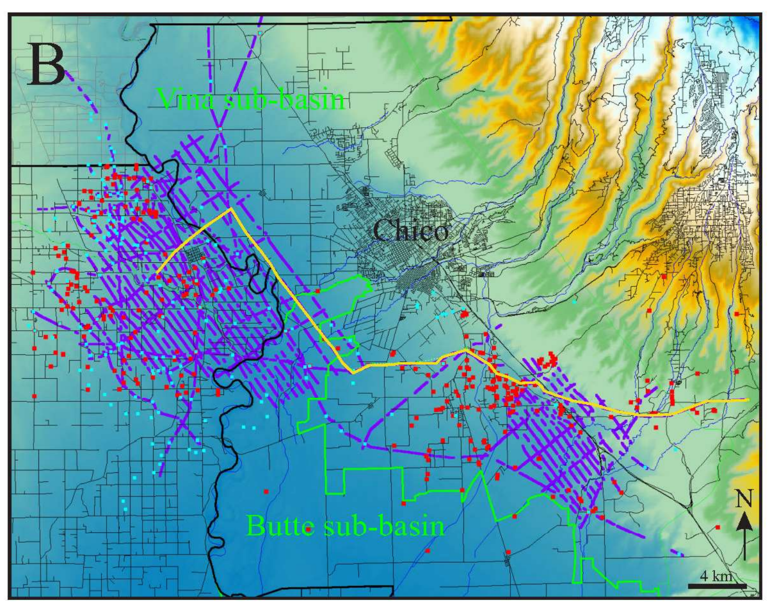
Figure 2-9A was developed using data from a 2018 study (The Stanford Groundwater Architecture Project, which used the AEM method calibrated to existing well data added considerable detail to the known aquifer-bearing units in portions of the Vina Subbasin [Kang et al., 2021]). Therefore, preliminary 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 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 2-9A is a general east-west cross section spanning two main AEM acquisition areas. Superimposed with lithology and electric-logs from WCRs and monitoring wells is the AEM interpretation showing the relative probability of encountering coarse-dominated material (i.e., sand/gravel) along the cross section (Kang et al., 2021, 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-kilometers of the AEM study, but greater detail is available for certain individual areas.

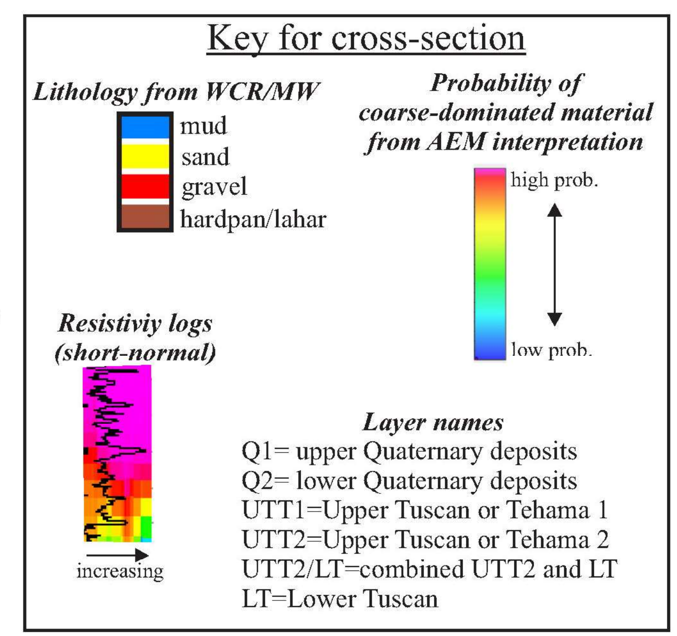
The AEM cross section depicts three main units previously described: 1) Tuscan Formation; 2) Tehama Formation; and 3) Quaternary Deposits. It is important to realize the Tuscan and Tehama Formations interfinger within individual layers toward the western side of the cross section.





A) AEM and well-based hydrogeologic layering through AEM-acquired data areas. AEM interpretation shows probability (cold colors=low; warm colors=high) of encountering coarse-dominated material along the cross-section (from Kang et al., in prep.). Monitoring wells (MW) are denoted by the State's well number ID; B) Location map of cross-section, AEM data, and well data. Background colors are relative elevation.

Key for map
- cross-section
- AEM data
- e-log well
- WCR well



Vina Subbasin East-West AEM Cross-Section
Vina Groundwater Subbasin GSP

Project No.: SAC282 | December 2021

Figure **2-9A**

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 Upper Tuscan/Tehama (UTT1 and UTT2). However, the lower portion of the Tuscan Formation is readily noticeable with no lower Tehama represented in the cross section. Overlying all of these units is the Quaternary Deposits (Q1 and Q2) which includes the Riverbank and Modesto Formations.

The Lower Tuscan layer is mostly coarse-grained material that thickens to the west to 500 to 600 feet thick. The overlying UTT2 layer only exists in the western portion (200 to 500 feet thick) and is fine dominated with intermittent coarse-dominated channels. UTT1 is mostly a coarse-dominated unit 100 to 200 feet thick that combines with the Lower Tuscan in the eastern portion of the cross section. Q2 is mostly fine dominated (~50 feet thick) that has rare occurrences of coarse-dominated material. Q1 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 UTT1, Q2, and Q1 sediments.

2.1.6.2 Additional Cross Sections

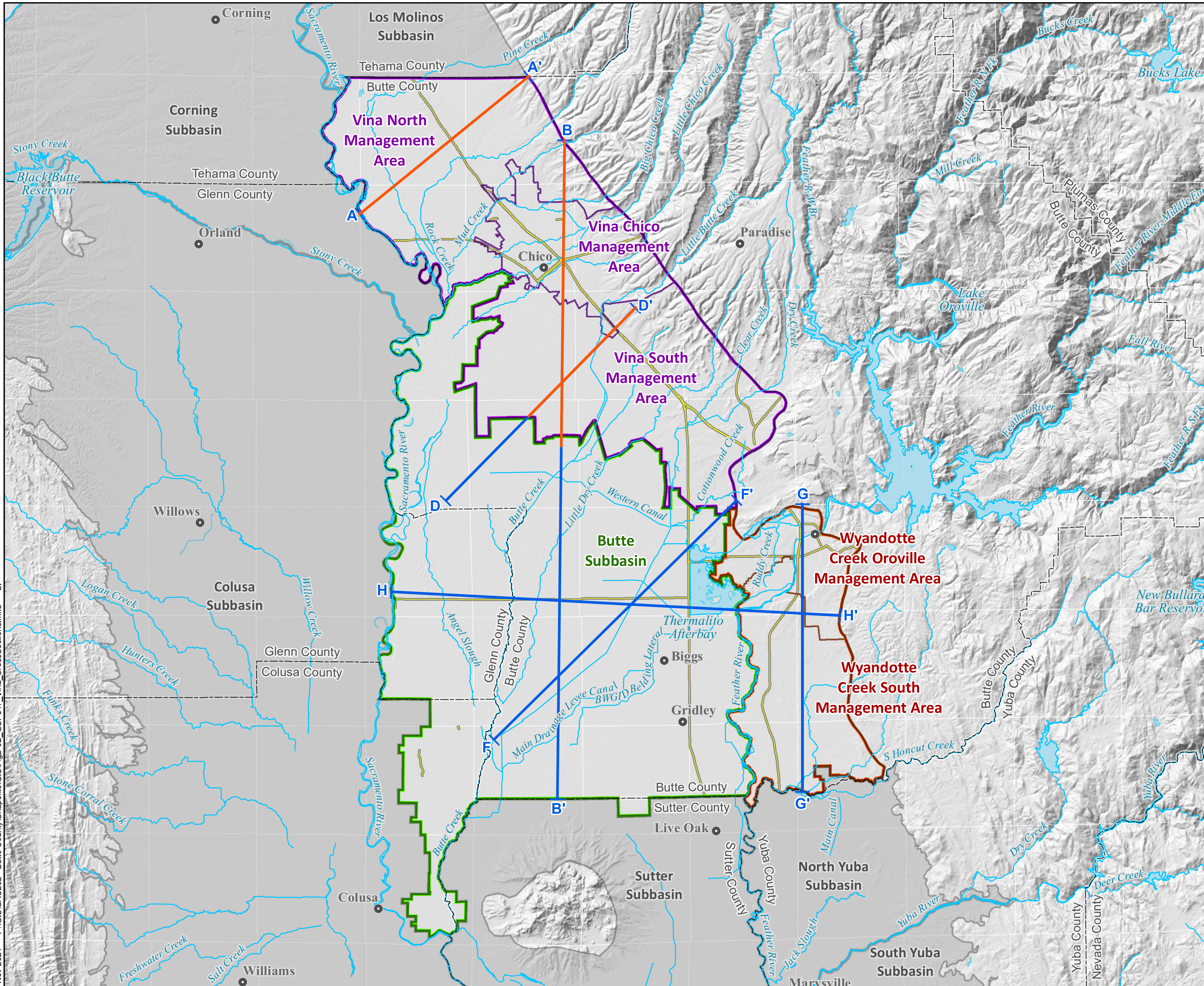
Figure 2-9B is a cross section key that shows the location of Vina cross sections developed from studies performed by DWR (DWR, 2014) and GEI Consultants (GEI, 2018) and the extensions of these sections into the adjacent Wyandotte Creek and Butte subbasins. Figure 2-9C shows a southwest to northeast cross section in the northern portion of the Vina Subbasin, and Figure 2-9D shows a southwest to northeast cross section in the southern portion of the Vina Subbasin.

2.1.7 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).

2.1.7.1 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 (DWR, 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).



CROSS SECTION ALIGNMENTS

- Cross Section Alignment
- Relevant Cross Section Extent

Subbasins

- Butte Subbasin
- Vina Subbasin
- Wyandotte Creek Subbasin
- Neighboring Subbasin
- Waterway
- Lake
- Highways

VINA SUBBASIN GSP

DECEMBER 2021 FIGURE 2-9B

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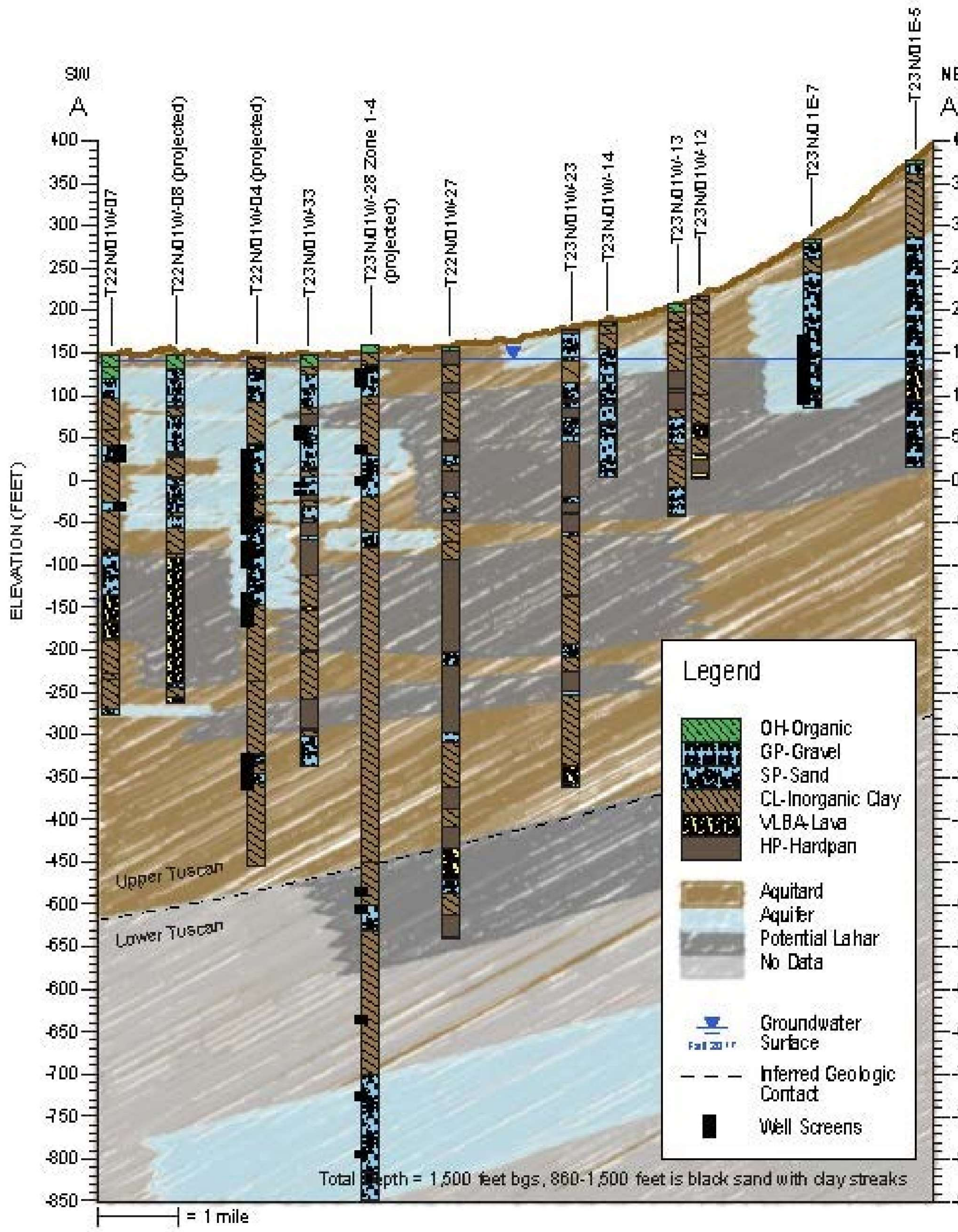
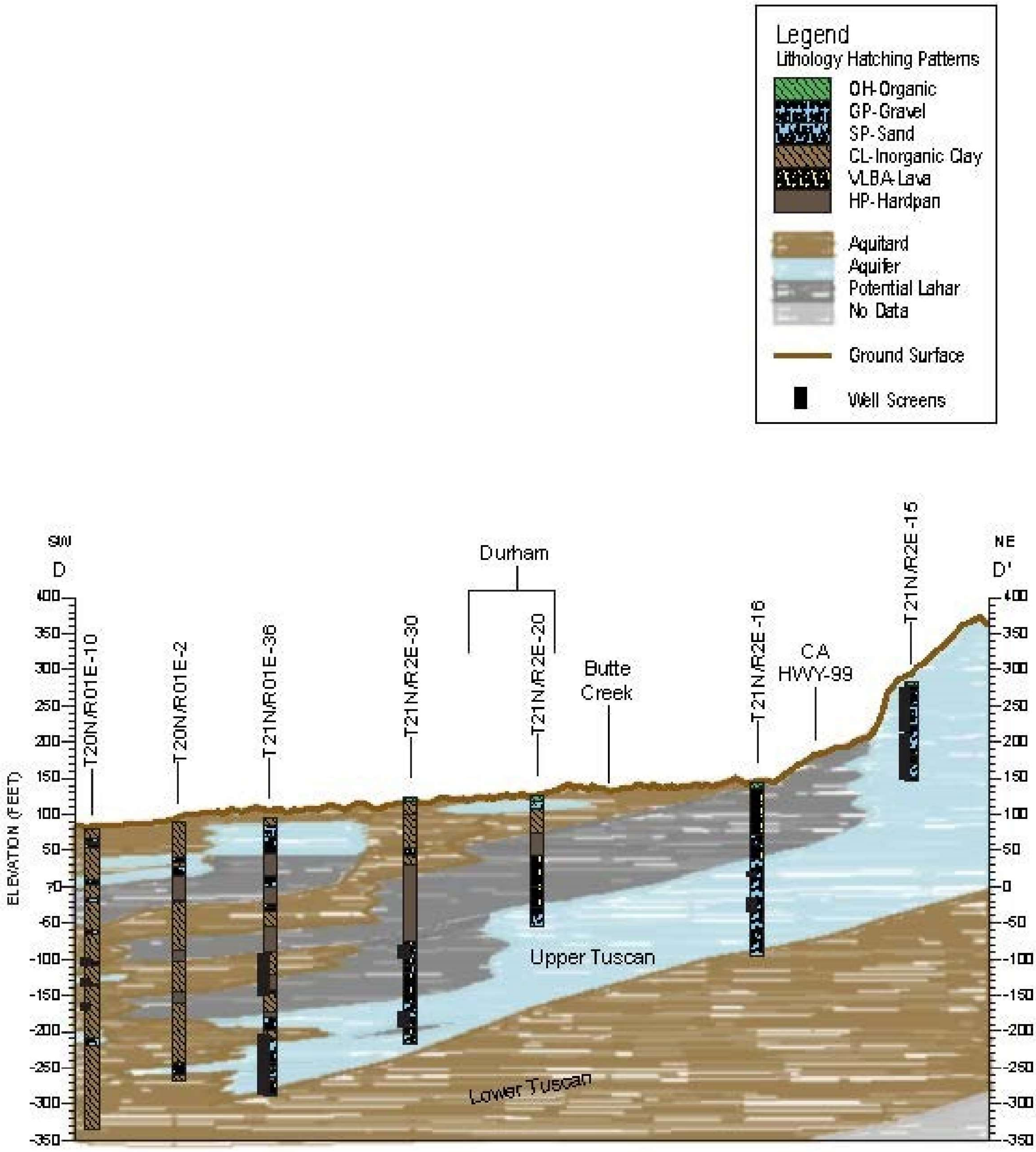


Geologic Cross-Section A-A'
Vina North Management Area
Vina Groundwater Subbasin GSP

Project No.: SAC282	December 2021	Figure 2-9C



Geologic Cross-Section D-D'
Vina South Management Area
Vina Groundwater Subbasin GSP

Figure
2-9D

Project No.: SAC282 | December 2021

2.1.8 Principal Aquifers and Aquitards

2.1.8.1 Overview

The Vina Subbasin groundwater system is comprised of a single principal aquifer composed of the Quaternary Deposits (Q1, Q2), Upper Tuscan/Tehama (UTT1 and UTT2) and Lower Tuscan units creating various aquifer 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 Vina 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 characteristics of the aquifer system also vary 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.

The degree of connectivity between various zones in the aquifer system are evident in some areas based on hydrographs, pumping tests, and water level measurements. Hydrographs from nested wells show slight vertical gradients in the subsurface (Section 1.2.2.2). A pump test in the northeastern area of the Vina 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 (Appendix E of Brown and Caldwell, 2013).

In the central area of the valley near the Sacramento River, thick fine-dominated layers of the UTT2 separate coarser-dominated materials of the UTT1 from the coarse-dominated zone of the Lower Tuscan (Figure 2-9A). 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 UTT2 separating them (Appendix E of Brown and Caldwell, 2013). A pump test in the vicinity of Rancho Esquon demonstrated hydraulic connectivity between an intermediate and deeper aquifer zone of the Lower Tuscan 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 UTT1 (80 to 150 feet bgs) and the Lower Tuscan unit’s intermediate zones where 100 feet of low-permeability fines separated them (Appendix E of Brown and Caldwell, 2013).

Due to the variance in hydraulic connectivity between zones in different areas of the Vina 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 Vina Subbasin within the portion of the aquifer that stores, transmits, and yields significant quantities of water.

2.1.8.2 Beneficial Uses

In 1972, the CRWQCB adopted a uniform list and description of beneficial uses to be applied throughout all basins of the State. In the revised Basin Plan for the Sacramento River and San Joaquin River Basins prepared by the CRWQCB, Central Valley Region (Water Board, 2018) it is stated that unless otherwise designated by the Water Board, all ground waters in the Region are considered as suitable or potentially suitable, at a minimum, for municipal and domestic water supply, agricultural supply, industrial service supply, and industrial process supply.

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 Vina Subbasin primarily rely upon wells for applied water. Relatively shallow groundwater in some areas of the Vina Subbasin support Groundwater Dependent Ecosystems (GDEs) and stream flows.

2.1.8.3 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 2-3) 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.

Values for specific yield (unconfined) and storativity (confined) used in the calibrated BBGM throughout the Vina Subbasin are 10 percent and 0.00001, respectively (BCDWRC, 2021). The groundwater system is a mix of confined and unconfined conditions so the average storage coefficient in the Vina Subbasin in the BBGM is 0.04 (unitless).

Table 2-3: Summary of Calculated Aquifer Parameters
Table taken from Lower Tuscan Aquifer Study Final Report (Brown and Caldwell, 2013)

Summary of aquifer parameters calculated using Moench (1985) solutions			
	T (square feet/day)	S (unitless)	K (feet/day)
Hackett Property	2,322 to 3,078	0.00004 to 0.00009	66 to 881
M&T Ranch	11,550 to 20,540	0.0003 to 0.0005	321 to 5712
Esquon Ranch	12,230 to 23,650	0.00004 to 0.001	41 to 793

Note:

Source: Lower Tuscan Aquifer Study Final Report (Brown and Caldwell, 2013).

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

2.1.8.4 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 (Brown and Caldwell,2013) estimated values for hydraulic conductivity (K) and transmissivity (T) (Table 2-3) for three locations within or adjacent to the Vina Subbasin.

Estimates for transmissivity can vary widely in different areas of the Vina 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 gallons per day (gpd) per foot (10,026 square feet per 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 118-2003 West Butte Subbasin (DWR, 1995, as cited in DWR, 2005).

In the Lime Saddle area east of the Vina Subbasin, transmissivity values in the confined portion of the Tuscan Formation were estimated to be low: 1,100 gpd per foot (147 square feet per day) (Slade, 2000 as cited in DWR, 2005).

2.1.9 Opportunities for Improvement to the HCM

The following lists activities or projects that can be used to improve the HCM.

2.1.9.1 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.

2.1.9.2 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.

2.1.9.3 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 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 feet or less) are preferred to minimize mixing between aquifer zones or between aquifer zones and residual water retained within the aquitard zones between aquifers. Although not quantified, the Lower Tuscan Aquifer study (Brown and

Caldwell, 2013) suggested that the aquitards could release a significant volume of water to the aquifer in areas where large volumes of groundwater are extracted.

2.1.9.4 Characterize Recharge Source with General Water Quality Analysis

Conduct general mineral analysis on groundwater samples to evaluate whether elevated electrical conductivity 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).

2.1.9.5 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 2-6). 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.

2.1.9.6 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.

2.1.9.7 Field Testing and Monitoring Equipment Installation to Understand the Recharge Rates and Stream Losses in the Recharge Zone

Expansion of stream gaging locations should occur to document and better understand changes in stream-aquifer interactions. In addition to the stream gaging, 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.

2.1.9.8 Additional AEM Data Collection

Expanding the extent of AEM surveys is recommended to help address uncertainty in the structure of the Vina 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.

2.2 Groundwater Conditions

2.2.1 Description of Current and Historical Conditions

Groundwater conditions in the Vina Subbasin are regularly monitored and are described in the 2001 and 2016 Water Resource Inventory and Analysis Reports produced by Butte County. These documents and other reports indicate that the Vina Subbasin 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 show a declining trend over the past 20 years, 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. The water budget analysis presented in Section 2.3 provides a quantitative assessment of how conditions have changed in the Vina Subbasin and an indication of how conditions may change in the future.

2.2.2 Groundwater Trends

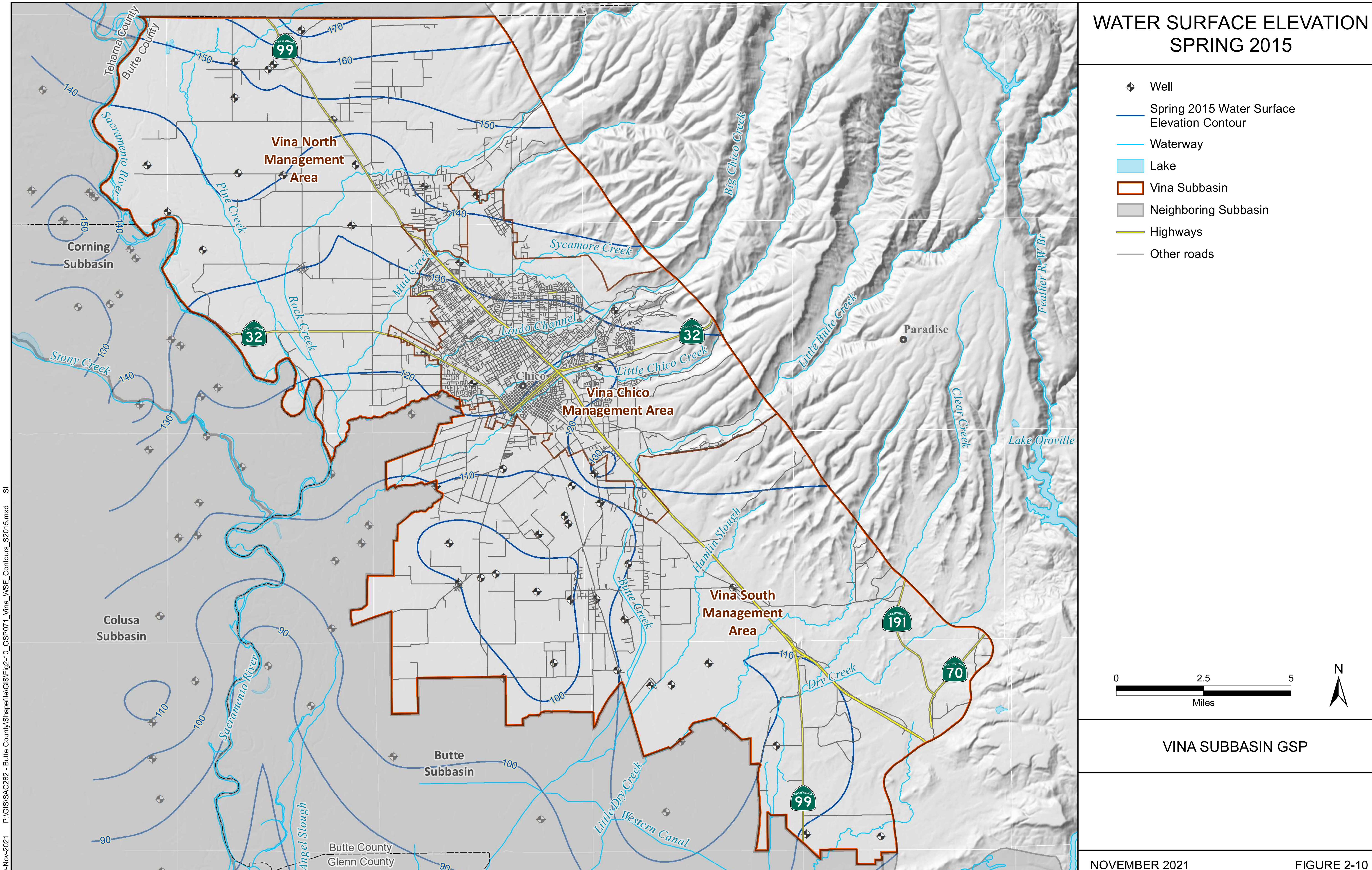
2.2.2.1 Elevation and Flow Directions

Figures 2-10 and 2-11 show groundwater elevation contours in the Vina Subbasin for the spring and fall of 2015 and Figures 2-12 and 2-13 show elevation contours for the spring and fall of 2019. These contours show groundwater levels as reported by the 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 20 and October 30 for the fall contours and between March 20 and April 30 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.

The maps shown in Figures 2-10 to 2-13 do not distinguish between completion intervals of the wells. So, the contours represent an aggregate of groundwater elevations across all zones of the principal aquifer system. The equipotential maps illustrate several general features of the groundwater flow system in the Vina Subbasin, including:

- Overall west-southwest flow consistent with recharge along Quaternary alluvial fans along the eastern foothills.
- Convergence of flow toward Sacramento River in the Vina North MA.
- Flow from the Vina Chico MA converging toward pumping in the Vina South MA and sub-parallel to Sacramento River floodplain. Groundwater generally flows west-southwest in the Vina Chico MA towards the Sacramento River. There is evidence of convergence toward Chico and Little Chico Creek. Contours in this area are based on shallow groundwater levels, which are below the elevation of Big Chico Creek. The convergence of flow in this area may be associated with wells supplying potable water for the City of Chico and/or higher permeability channelized features in this portion of the Quaternary alluvial fans along the eastern foothills.
- Flow from the Vina South MA converging toward pumping and convergence toward Sacramento River in the Vina Subbasin. Groundwater generally flows west-southwest in the Vina South MA towards the Sacramento River. There is evidence of convergence toward areas with higher groundwater pumping, likely associated with agricultural pumping west of Butte Creek.


WATER SURFACE ELEVATION
SPRING 2015
Well
Spring 2015 Water Surface Elevation Contour
Waterway
Lake
Vina Subbasin
Neighboring Subbasin
Highways
Other roads
0
2.5
5
Miles
N
VINA SUBBASIN GSP
NOVEMBER 2021
FIGURE 2-10
Vina North Management Area
Vina Chico Management Area
Vina South Management Area
Corning Subbasin
Colusa Subbasin
Butte Subbasin
Tehama County
Butte County
Glenn County
Chico
Paradise
Sacramento River
Pine Creek
Rock Creek
Mud Creek
Lindo Channel
Sycamore Creek
Big Chico Creek
Little Chico Creek
Little Butte Creek
Stony Creek
Clear Creek
Lake Oroville
Feather R W Br
Hamlin Slough
Butte Creek
Dry Creek
Little Dry Creek
Western Canal
Angel Slough
99
32
191
70
170
160
150
140
130
120
110
100
90
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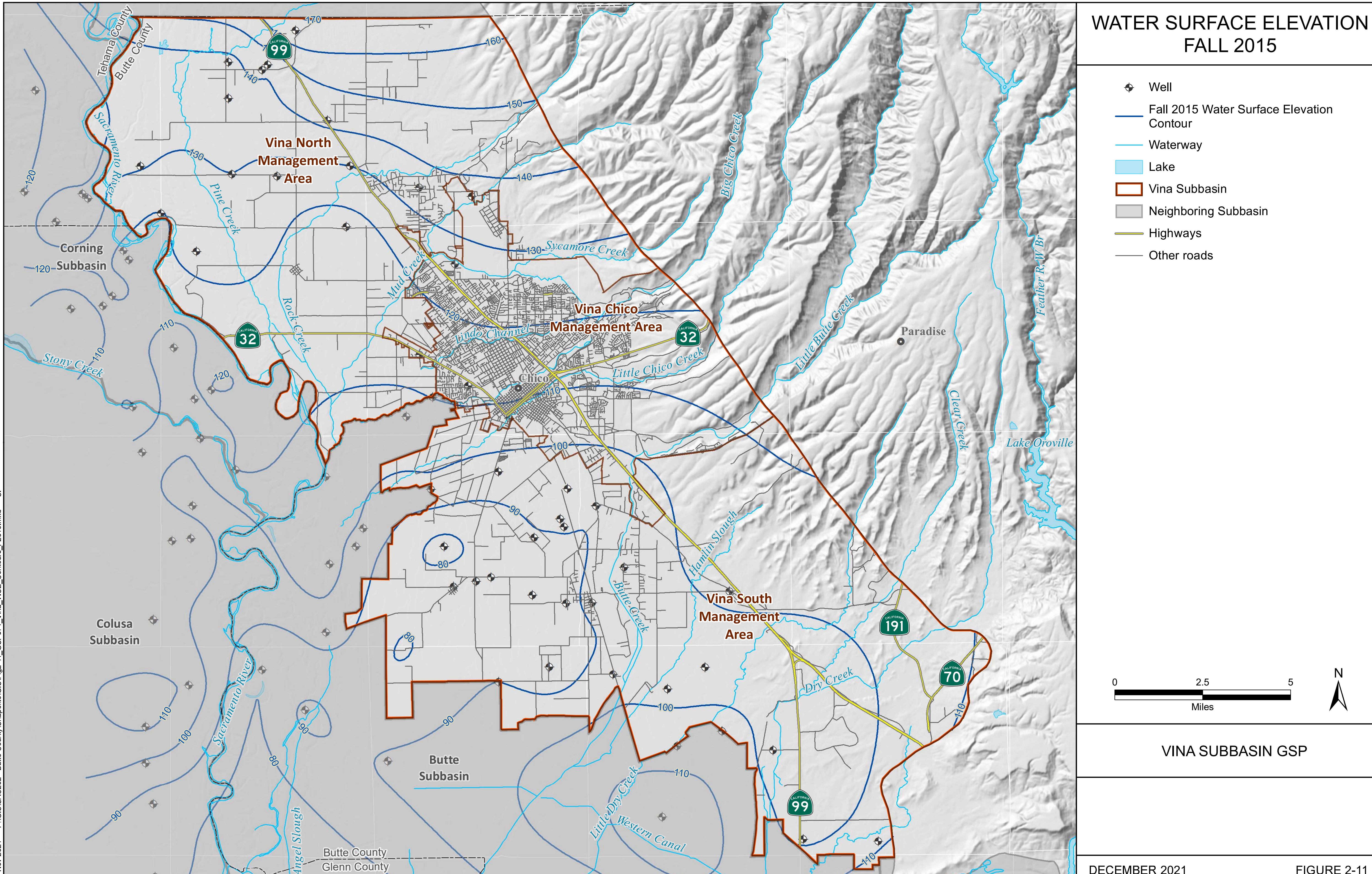

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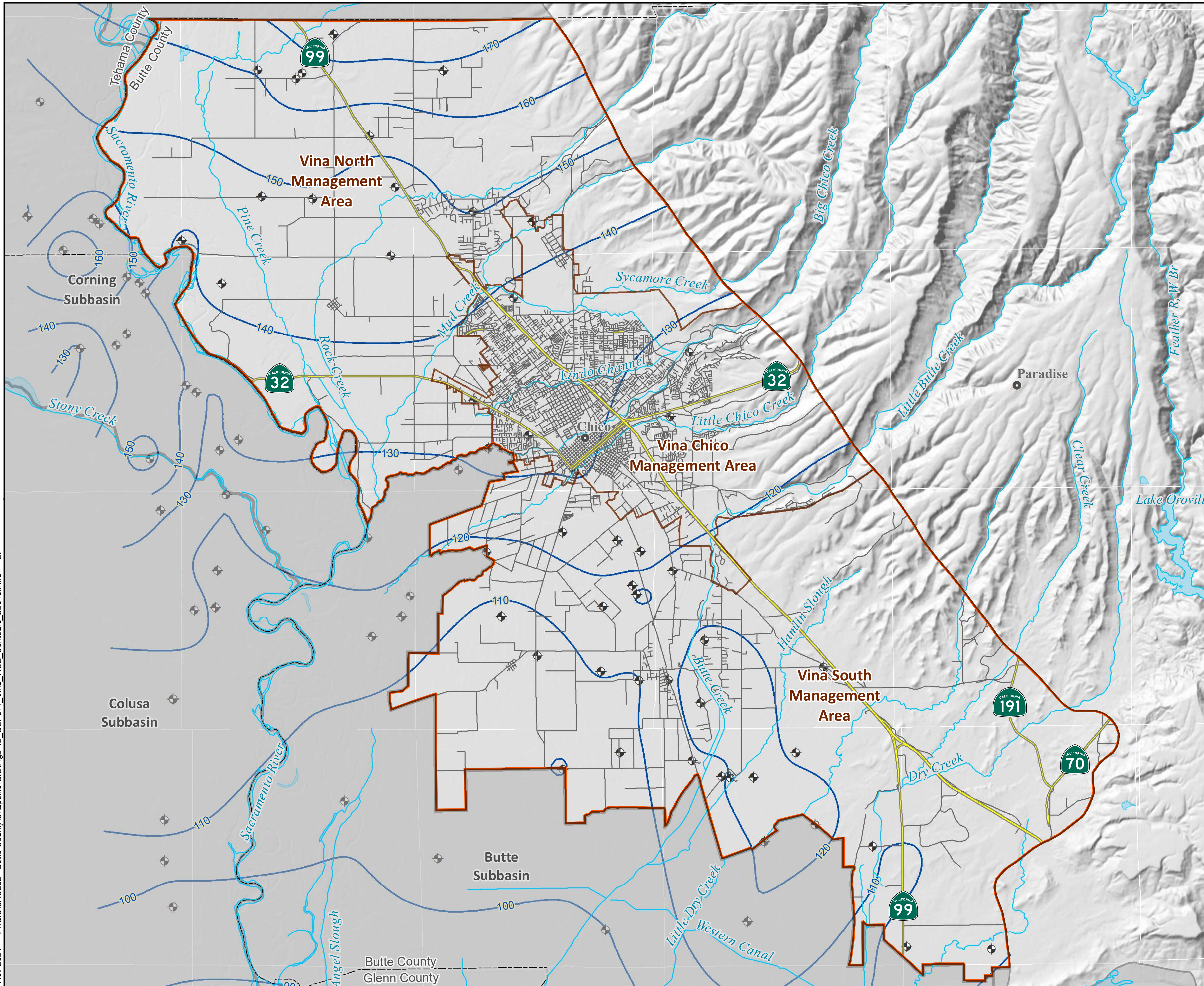

WATER SURFACE ELEVATION SPRING 2019

VINA SUBBASIN GSP

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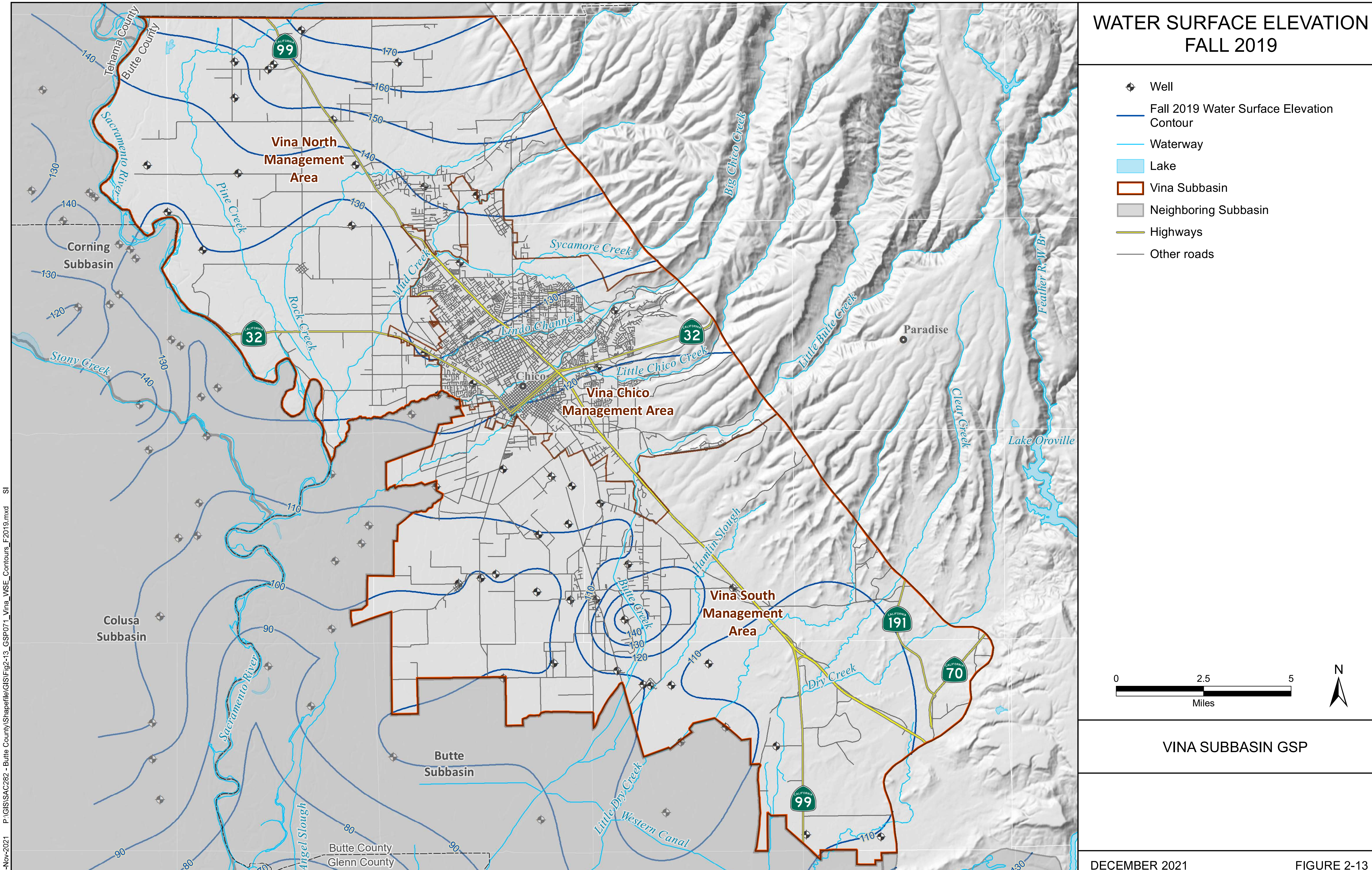
FIGURE 2-12



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Each of the four contour maps displays groundwater elevations that are higher in the north of the Vina Subbasin than in the south, indicating a gradient that would cause water to flow from north toward the southwestern corner of the Vina 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 Vina Subbasin's principal aquifer during subsequent wet years (2017 and 2019).

2.2.2.2 Hydraulic Gradients

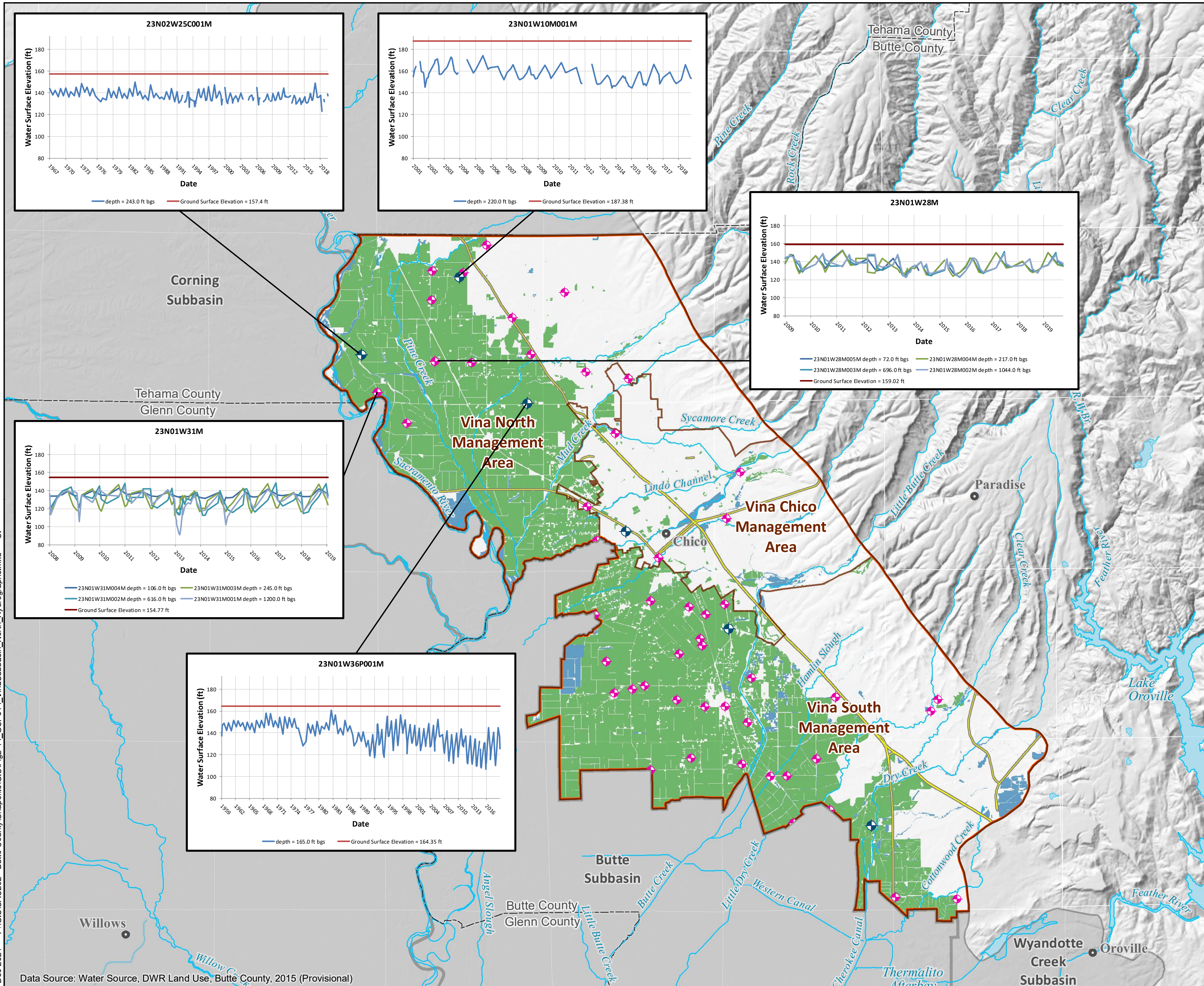
Horizontal or lateral hydraulic gradients generally reflect ground surface topography. In the foothills east of the Sacramento Valley the gradient is steep, as high as 60 feet per mile. In the floodplain of the Sacramento River, lateral gradients are relatively flat, even in the deeper zones of the aquifer. There is a transitional gradient zone between the floodplain and upland areas, which generally reflects the gradient of the main tributary creeks that flow into the Sacramento River, such as Big Chico and Little Chico creeks.

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 Vina 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 in the neighboring subbasin to the west near Hamilton City fed by the Stony Creek Fan.

Figures 2-14, 2-15, and 2-16 are maps of the Vina North, Vina Chico, and Vina South MAs 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 hydrograph displays water surface elevations in feet above msl 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.



REPRESENTATIVE HYDROGRAPHS - VINA NORTH

- RMS Well
- Other Well in Monitoring Network

Water Source

- Surface Water
- Groundwater
- Not Irrigated / Data Not Collected
- Waterway
- Lake
- Vina Subbasin
- Neighboring Subbasin
- Highways

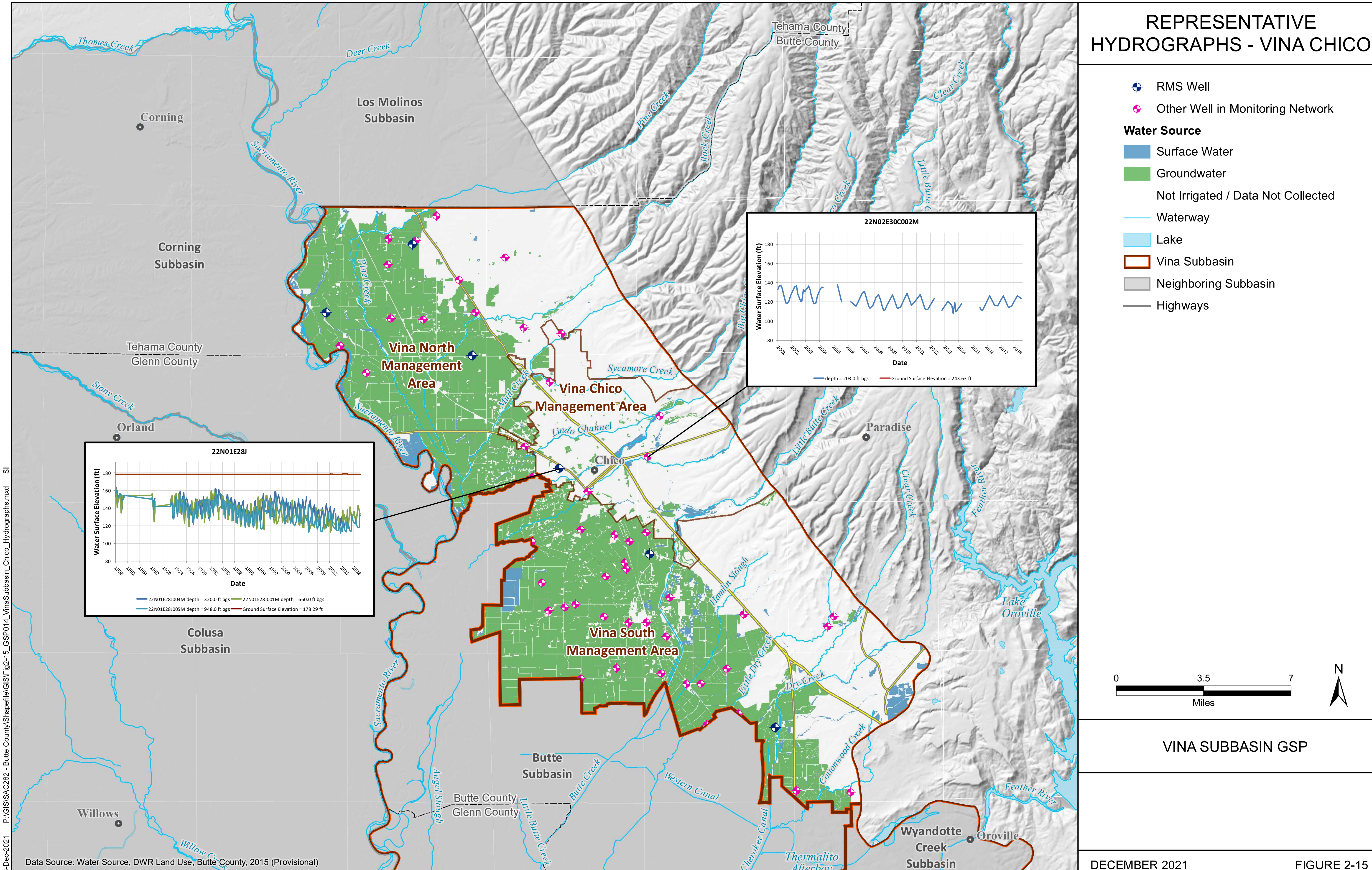
0 3.5 7
Miles

N

VINA SUBBASIN GSP

DECEMBER 2021 FIGURE 2-14

REPRESENTATIVE HYDROGRAPHS - VINA CHICO



VINA SUBBASIN GSP

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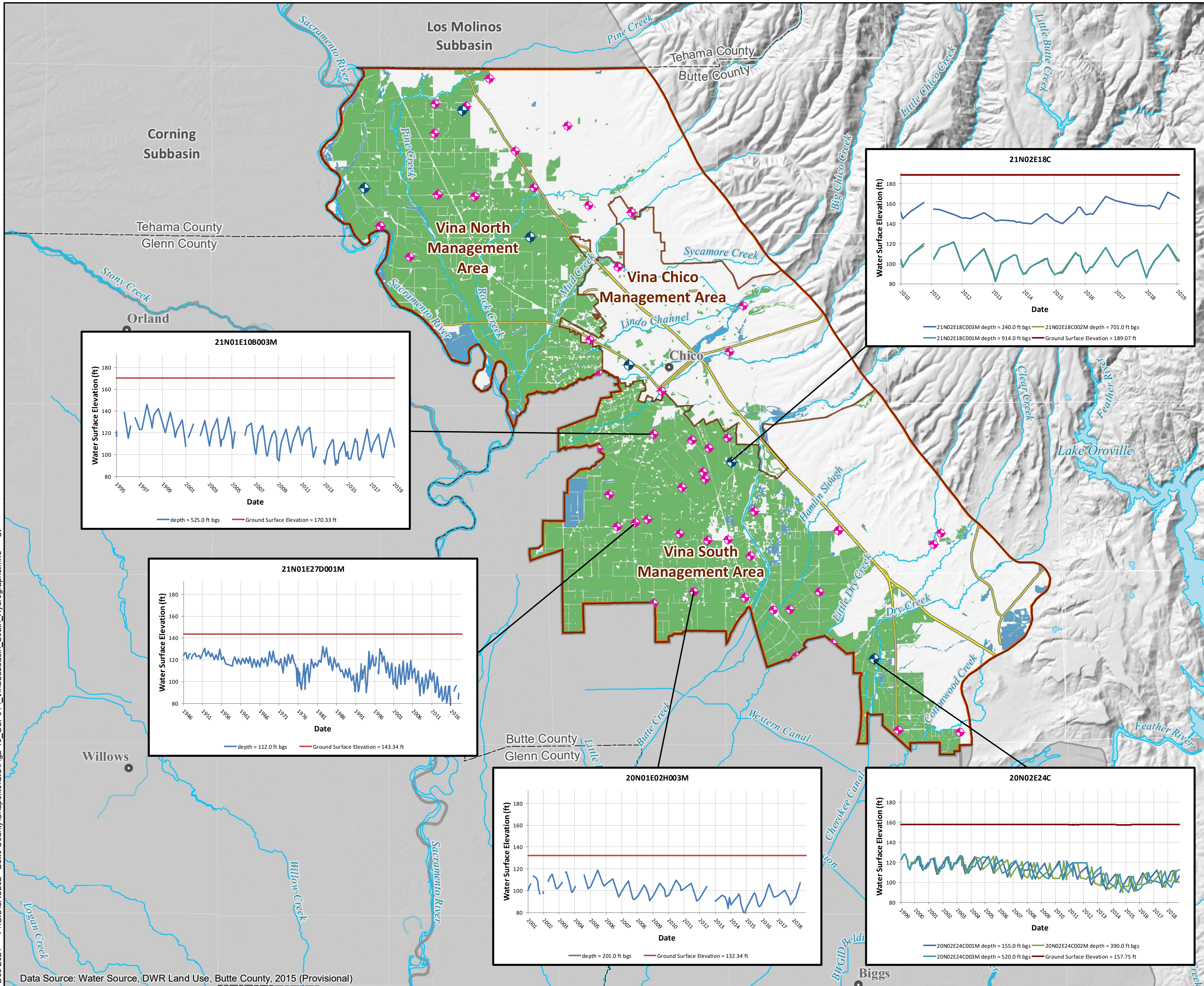
FIGURE 2-15

REPRESENTATIVE HYDROGRAPHS - VINA SOUTH



VINA SUBBASIN GSP

DECEMBER 2021 FIGURE 2-16

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Hydrographs for the selected wells in the Vina North MA echo the seasonal fluctuations illustrated in the contour maps, with groundwater level 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 (23N01W10M001M, 23N01W28M, 23N01W36P001M)) lying in the interior of the MA showing declines in annual high and low readings that correspond to the period of the recent drought while the water levels in the wells (23N02W25C001M and 23N01W31M) located near the Sacramento River show little impact from the drought.

Vertical groundwater gradients are indicative of the hydraulic connectivity of shallow and deep zones of the aquifer system. They are measured by comparing groundwater elevations from multi-completion or nested wells that are completed across different depth zones. A “true” vertical hydraulic gradient is measured in a nested well at the same map location, but vertical gradients can sometimes be estimated using wells completed at different depths in different locations. When groundwater levels in the shallower wells are higher than in the deeper completions, the gradient indicates downward movement of groundwater. The volume of downward flow is proportional to the gradient and the hydraulic conductivity between the shallow and deep measurement points. In locations where groundwater levels in the shallower wells are lower than in the deeper wells, the gradient indicates upward movement of groundwater, with a similar relationship defining the volume of upward flow. Groundwater levels that are similar in elevation, even with distinctly different completion depths, indicate a uniform flow field with limited vertical gradient and vertical exchange of groundwater.

Hydrographs for two nested wells in the Vina North MA are presented in Figure 2-14 and illustrate the heterogeneity of the primary aquifer laterally and vertically within different aquifer zones. The first nested well (well 23N01W31M) is located adjacent to the Sacramento River and consists of four individual wells screened from 65 to 75 feet bgs, 140 to 201 feet bgs, 590 to 600 feet bgs, and 1,020 to 1,030 feet bgs. This hydrograph shows that water levels in the shallowest well display little annual fluctuation, which indicates that this shallowest zone is in direct continuity with river levels and the adjacent floodplain. The deeper wells display greater fluctuation in seasonal water levels that generally tend to track each other, indicating less direct continuity with river levels and the adjacent floodplain. The second nested hydrograph (23N01W28M, Figure 2-14) is farther from the river and consists of four individual wells screened from 30 to 50 feet bgs, 120 to 165 feet bgs, 690 to 670 feet bgs, and 791 to 1,021 feet bgs. As seen on this hydrograph, there is a close correspondence in water elevations recorded at all screened intervals being monitored. This indicates a clear connection across the aquifer zones.

Hydrographs for selected monitoring wells in the Vina Chico MA 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 MA shows water levels in the intermediate and lower zones closely tracking those in the upper zone indicating strong connection among the three zones.

Hydrographs for selected monitoring wells in the Vina South MA show groundwater elevations lower than those in MA to the north, an indication of the general north-to-south gradient of flow in the Vina Subbasin. Most of the hydrographs in the Vina South MA also display more pronounced responses to the drought than do wells to the north. The nested monitoring wells in the south of the MA (Well ID Nos. 20N02E24C001M-003M) show the close communication among aquifer zones displayed in the nested sites in the Vina North and Vina Chico MAs. 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.

2.2.2.3 Change in Storage

Hydrographs from monitoring wells show cyclical fluctuations of groundwater levels over a four- to seven-year cycle consistent with variations in water year type according to the Sacramento Valley Water Year Hydrologic Classification (Figure 2-17). Groundwater levels typically decline during dry years and increase during wet years. Superimposed on this four- to seven-year short-term cycle is a long-term decline in groundwater levels. In other words, groundwater levels during more recent dry-year cycles are lower than groundwater levels in earlier dry-year cycles. This downward trend during dry years indicates an overall decline in groundwater storage.

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 BBGM (BCDWRC, 2021). A graph depicting estimates of 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, is provided in Figure 2-17. 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. Values are reported in thousands of acre-feet (TAF).

As indicated in the figure, groundwater storage generally decreases in below normal, dry, and critical years and increases in above normal and wet years. Groundwater pumping, shown by the solid black line, generally reflects higher pumping volumes during below normal, dry, and critical years and lower pumping volumes during above normal and wet years. Since the year 2000, there has been a cumulative decline in March 1 groundwater storage of about 400,000 acre-feet (AF). This indicates that the cycles of groundwater pumping are not in balance with the cycles of recharge that replenish the aquifer and that groundwater depletion has occurred consistent with long-term decline in groundwater levels. In general, it shows that wetter periods are able to recover around 100,000 to 150,000 AF of storage, but that dryer cycles result in storage declines of 200,000 to 300,000 AF. Historical and projected changes in storage are discussed in greater detail in Section 2.3, Water Budget. The BBGM estimates the total freshwater storage of the basin at about 16,000,000 AF, indicating the estimated yearly decline in storage is about 0.1 percent.

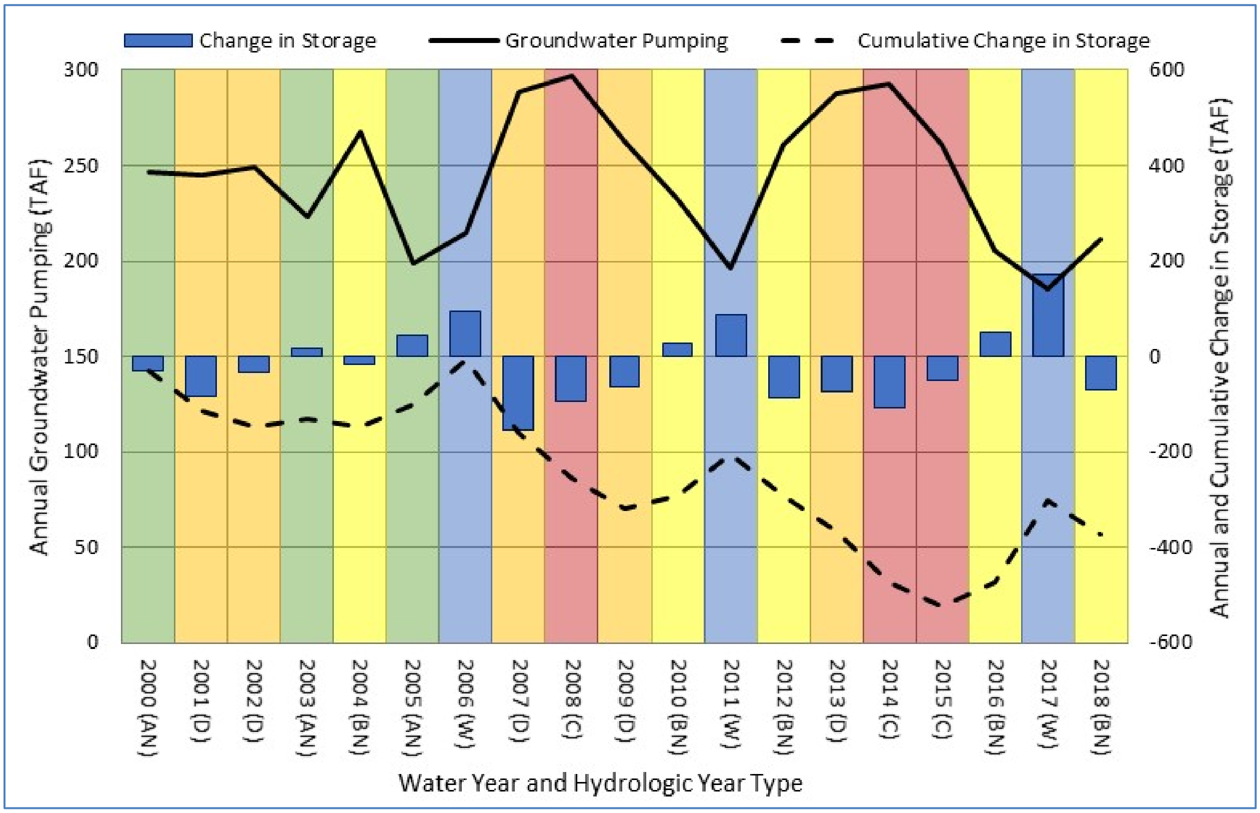


Figure 2-17: Change in Storage and Groundwater Pumping by Water Year Type. Values calculated from March to March for each water year. AN – above normal, D – dry, BN – below normal, W – wet, C – critical.

2.2.3 Seawater Intrusion

Intrusion of seawater is not a consideration in the Vina Subbasin because of the subbasin's inland location and distance from the coastline where saline intrusion originates from the ocean's influence on freshwater aquifers. For this reason, no monitoring of seawater intrusion is required nor is there a need for projects and management actions to mitigate seawater intrusion.

2.2.4 Groundwater Quality

2.2.4.1 General Water Quality of Principal Aquifer

DWR Bulletin 118 Vina Subbasin Report (DWR, 2004) characterized the water quality of groundwater in the Vina Subbasin as predominantly Calcium-magnesium bicarbonate and magnesium-calcium bicarbonate. Total dissolved solids range from 48 to 543 milligrams per liter, averaging 285 milligrams per liter (DWR unpublished data as cited in DWR, 2004). Impairments include localized high calcium and high nitrates and total dissolved solids in the Chico area.

The Lower Tuscan Aquifer study also conducted a water quality analysis on monitoring well and pumping wells used in the study and constructed piper diagrams. They show that groundwater samples from these wells indicate calcium bicarbonate waters (Brown and Caldwell, 2013). 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 SMC 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. Because irrigated agriculture is the predominant land use in the Vina Subbasin, monitoring of the groundwater quality data developed through the GQTMWP being implemented by the SVWQC for compliance with the Central Valley Regional Board's 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 and per- and polyfluoroalkyl substances 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.

2.2.4.2 Description and Map of Known Sites and Plumes

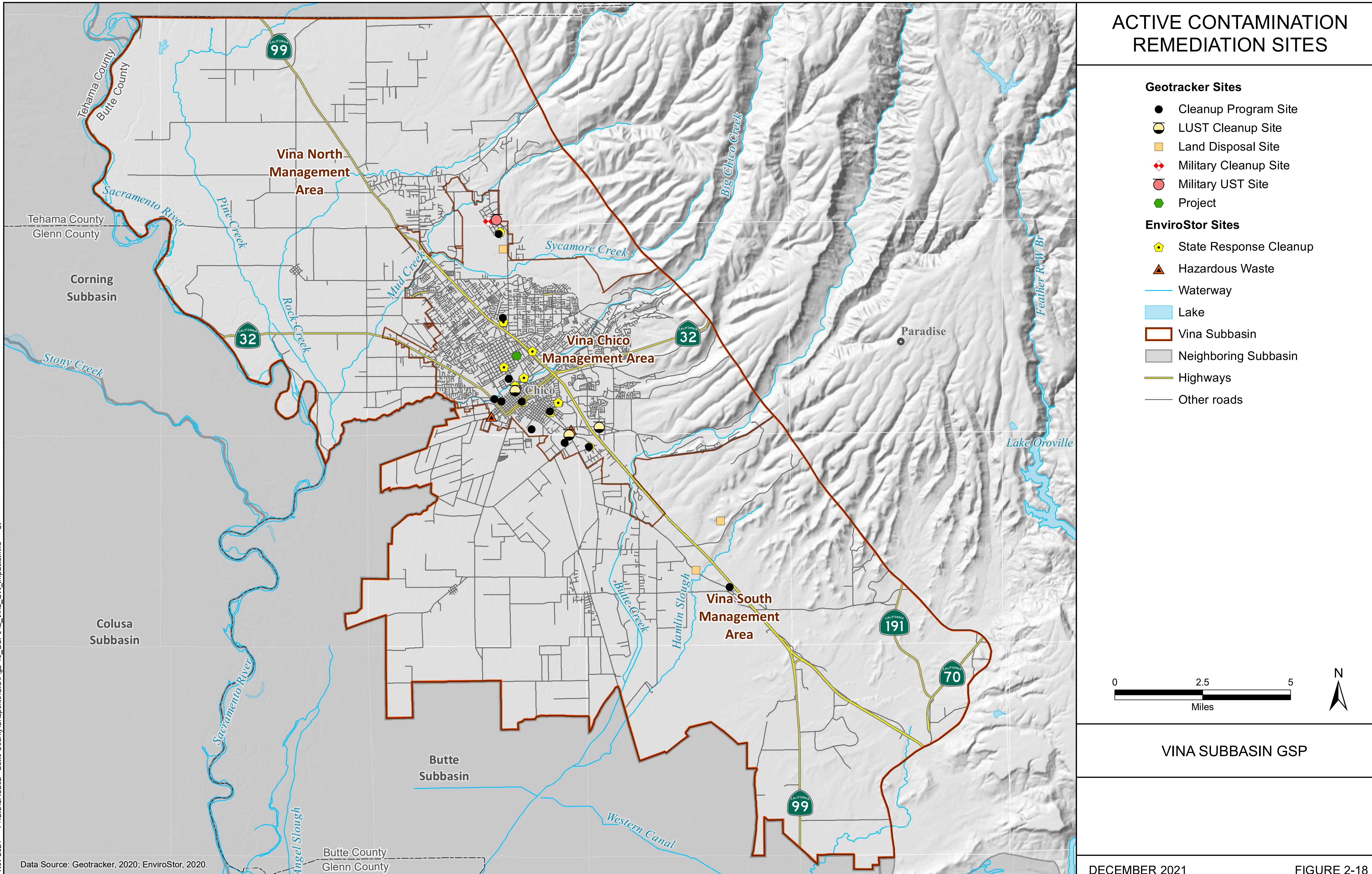
The SGMA regulations require that GSPs describe locations, identified by regulatory agencies, where groundwater quality has been degraded due to industrial and commercial activity. Locations of impacted groundwater were identified by reviewing information available on the SWRCB Geotracker/GAMA website,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

Figure 2-18 shows sites of known or potential groundwater impacts from EnviroStor and Geotracker/GAMA databases 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
- Leaking 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, tetrachloroethene (PCE), trichloroethene (TCE)



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- 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: 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: 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: 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: 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: 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: 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: cis-1,2-dichloroethene, trans-1,2-dichloroethene, 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: TCE
    - Potential media affected: Aquifer used for drinking water supply, well used for drinking water supply, soil

Of the nine 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.

2.2.5 Subsidence

2.2.5.1 Rates and locations

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
- Compressional strain in engineering structures and houses

To date, no land subsidence has been recorded in Butte County. 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 (DWR, 2018c) 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 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 SGMA Data Viewer.[3] 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.

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.

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 are limited to a period from 2015 through 2017, TRE ALTIMIRA InSAR available through DWR was used for this analysis, as data from this source are available for a period extending from June 2015 through September 2019.

2.2.5.2 Historical and Recent Cumulative Subsidence and Rates of Subsidence

The data shown in Table 2-4 include 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 are 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

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

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 2-4: 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 2-19 and 2-20 show historical and recent levels of subsidence within the Vina Subbasin. Historical levels for the period from 2008 to 2017 are shown in Figure 2-19 – 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 in Figure 2-20 – Recent Subsidence. The values presented in Table 2-4 and in Figures 2-19 and 2-20 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 surface elevations, the InSAR mapping presented in Figure 2-20 shows a clear distinction between changes in elevations observed on the northern and eastern flanks of the Vina Subbasin versus changes observed in the center.

2.2.6 Interconnected Surface Water Systems

2.2.6.1 Definitions

Interconnected surface water is defined under SGMA as "surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted."[4] There are two key terminology references in this statement. First, the surface water must be connected to the underlying aquifer by a "continuous saturated zone." This implies that the connection can be via a "zone" that is not the same as the underlying aquifer, and that deeper aquifer zones are, through connections upward to shallower aquifer zones, hydraulically connected to surface water. This is consistent with most conceptual representations of how groundwater is interconnected with surface water systems. The second reference implies that an overlying surface water that is "completely depleted" does not represent an interconnection with the underlying groundwater.

[4] Cal. Code Regs. Tit. 23, § 351

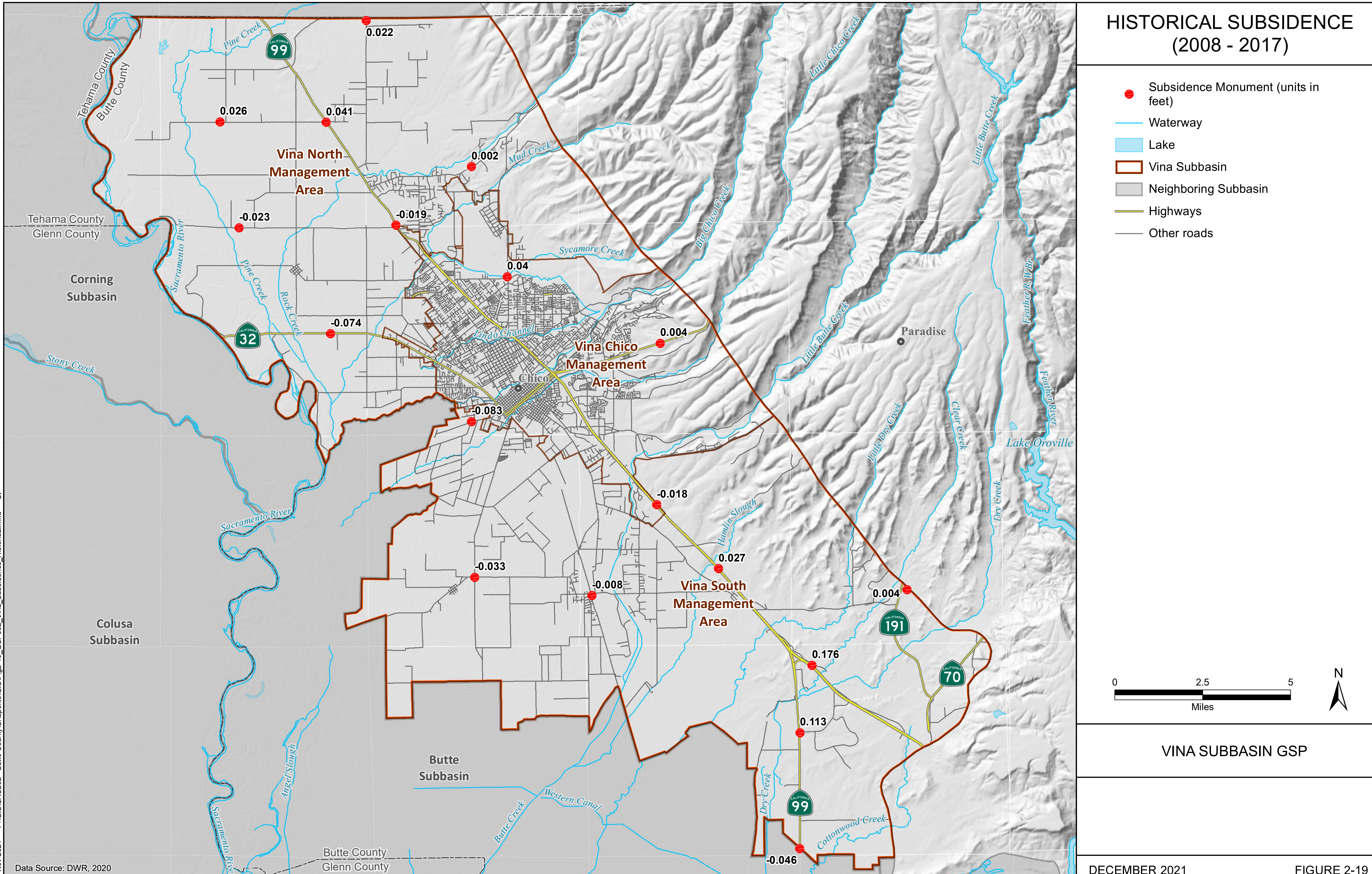

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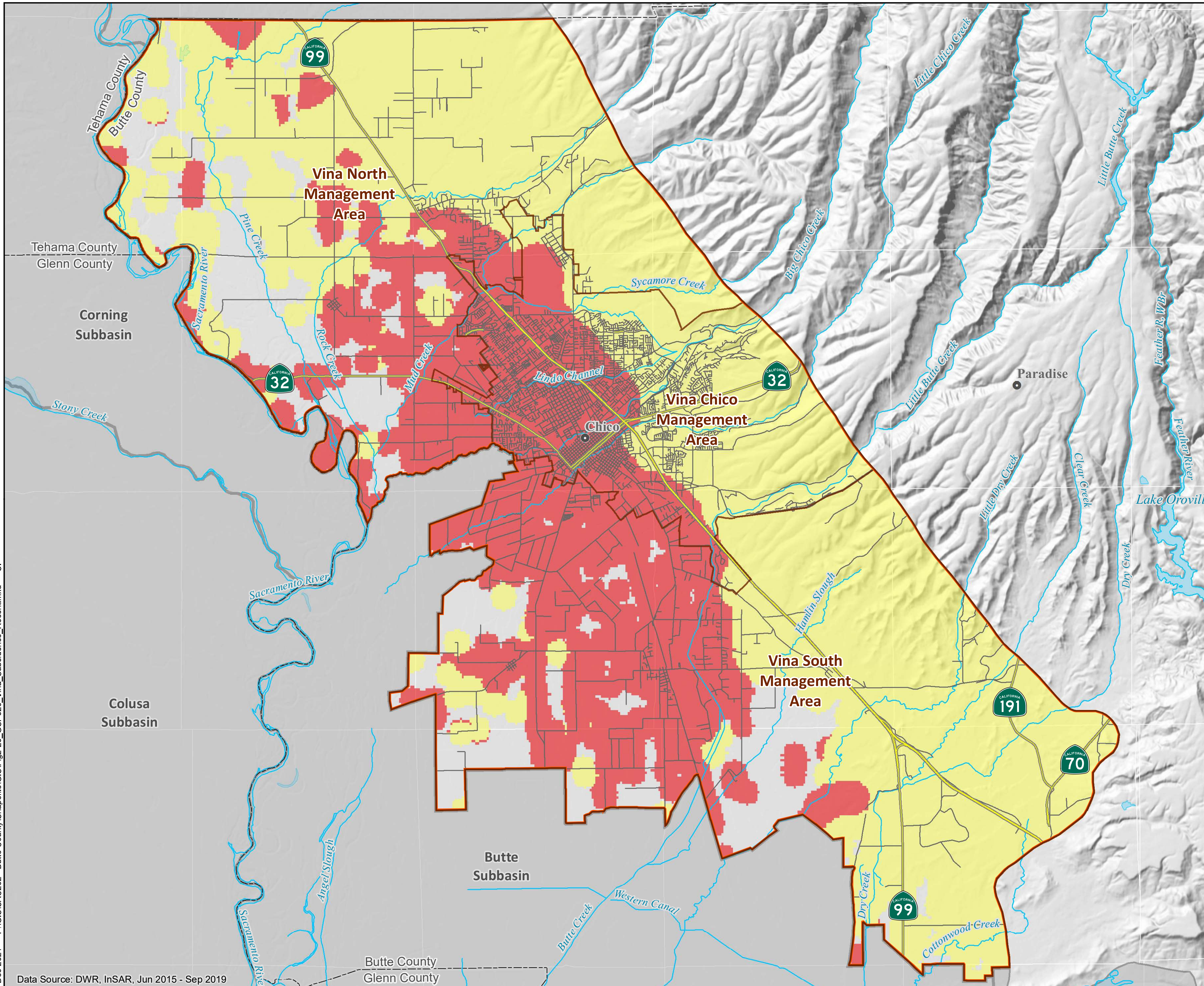
FIGURE 2-19

RECENT SUBSIDENCE (2015 - 2019)



VINA SUBBASIN GSP

DECEMBER 2021 FIGURE 2-20

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Both of these situations exist in the Vina Subbasin:

1. Within the floodplain of the Sacramento River, there is a continuous saturated zone (i.e., the floodplain sediments) that connects the shallowest aquifer to the river. The connectivity between shallow and deeper aquifer zones will dictate the overall connectivity to the River. Therefore, the Sacramento River floodplain represents a "high groundwater connectivity" zone with respect to the surface water.
2. In the upland areas outside of the Sacramento River floodplain, there are creeks that flow seasonally and often dry up in late summer or are dry for an entire year during dry conditions. In this case, the upland creeks may not be influenced by "high groundwater connectivity" and the presence of an undesirable result is not clear cut with respect to surface water depletion. The streams dry up regardless of the groundwater condition, and streams that are already dry are not considered interconnected surface water. However, the upland streams are an important source of recharge to the aquifer, so the health of these stream channels and their adjacent riparian zones is important to groundwater sustainability.

Streams and rivers are classified as either gaining, losing, or disconnected with respect to the connectivity to groundwater. The difference between gaining and losing reaches is illustrated in Figure 2-21 and dependent upon the hydraulic gradient of the river stage and head in the principal aquifer. 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. These are termed streamflow 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. These are termed streamflow losses or depletions. In both cases, there is a continuous hydraulic gradient between the stream and the underlying sediments (i.e., there is no unsaturated or partially saturated zone present beneath the streambed). A disconnected system is present when there is an intervening unsaturated or partially saturated zone between the streambed and the water table. A disconnected system is also present when the stream is dry and therefore cannot interact with the underlying water table.

It is important to recognize that these interconnections are dynamic and are affected by many factors along an entire reach of a stream or river. Variations in local geology, hydrology, vegetation patterns, and water use can all influence how these interconnections occur. Monitoring groundwater levels in appropriate zones of the aquifer near available stream stage data is needed to understand and analyze these dynamics, which ultimately help characterize interconnected surface waters and stream depletions.

Two examples of this complexity are described below:

- At a single point in time, a stream may have both gaining, losing, and disconnected reaches. For this reason, defining stream reaches and key points in the stream system where flows are managed is very important. The volume of water that is "gained" or "lost" depends, in part, on how individual stream reaches are defined and the amount of streamflow data available to calculate gains or losses to each reach. In general, it is not possible to directly measure gains or losses to streamflow using groundwater data alone.

Streamflow data is extremely important in determining how groundwater interacts with surface water.

- Reaches that are gaining under certain seasonal or longer-term conditions may become losing under others. In this case, understanding the magnitude of groundwater level fluctuation adjacent to a stream reach and the hydraulic properties of the streambed is important. The volume of water that is gained or lost is proportional to the head difference between the stream, the elevation of the streambed, the elevation of the groundwater adjacent to the stream, and the hydraulic properties of the streambed.

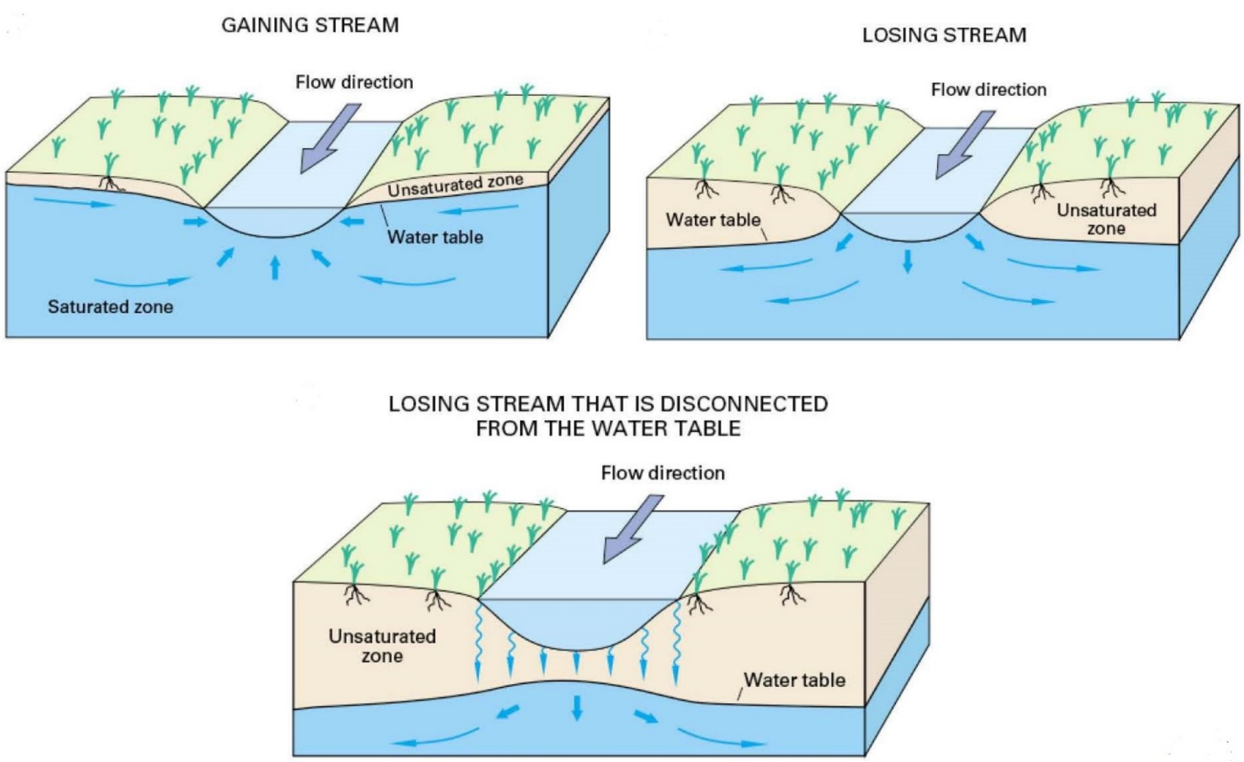


Figure 2-21: Illustration of Gaining and Losing Interconnected and Disconnected Stream Reaches (Source: United States Geological Survey [USGS])

2.2.6.2 Evaluation of Surface Water Connectivity

This section presents a general evaluation of surface water connectivity based on limited discrete data sets that do not encompass the entire Vina Subbasin. The results of the BBGM model are discussed separately in Section 2.2.6.3.

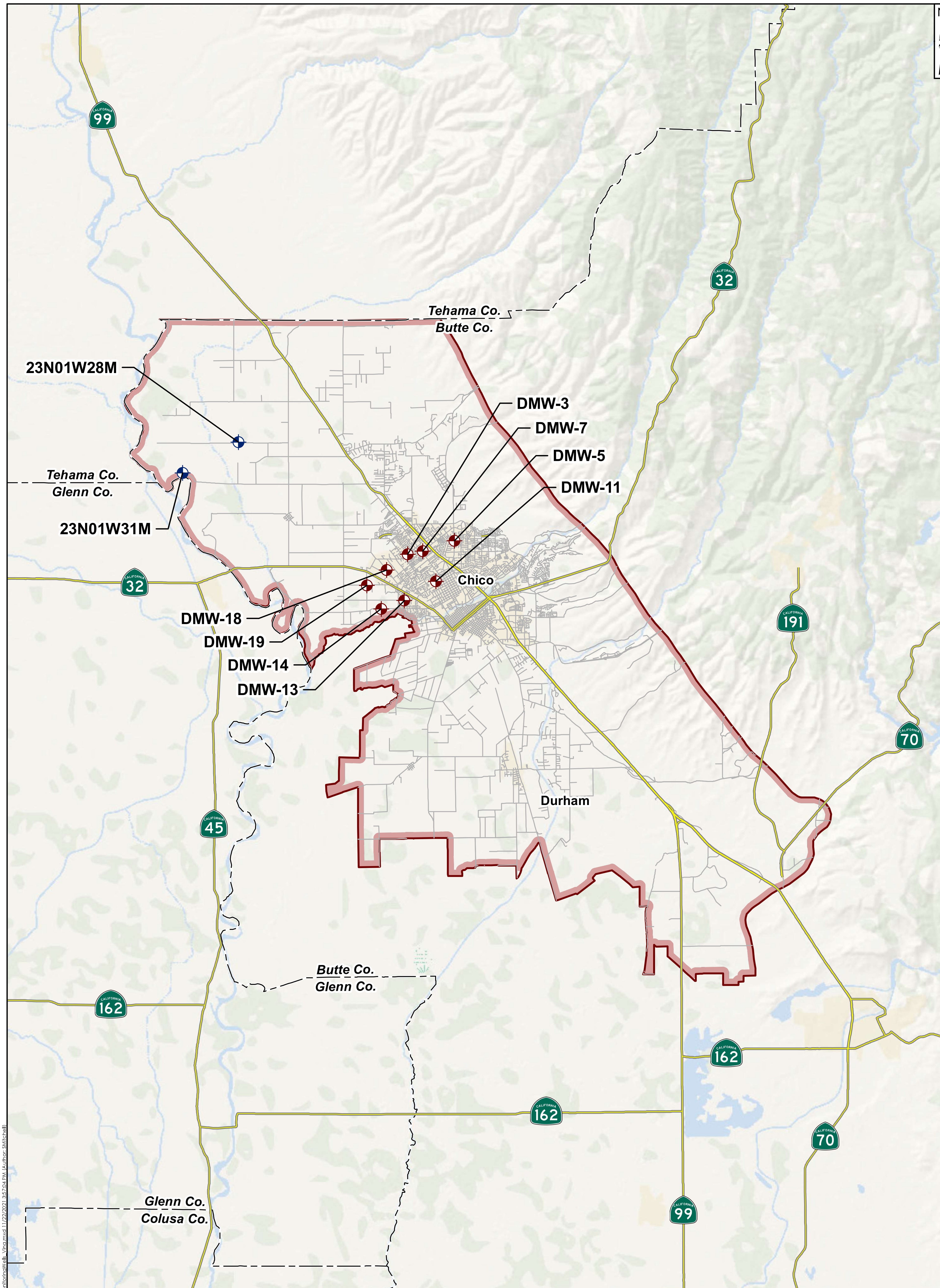
The data sets used to evaluate surface water connectivity in general include:

- Hydrograph for a nested well located adjacent (about 0.8 miles) to the Sacramento River, well 23N01W31M)
- A second nested hydrograph farther from the Sacramento River, well 23N01W28M
- A streamflow gaging study conducted by Chico State University (Davids et al., 2020)

- Groundwater levels measured in seven shallow monitoring wells as part of a nitrate study conducted in the City of Chico (AECOM, 2020)

Each data set has limitations with respect to an integrated evaluation of surface water connectivity across the Vina Subbasin. Locations of the wells referenced above are provided in Figure 2-22. A summary of the findings is provided below.

- Section 2.2.2.2 provides an initial discussion of the nested wells located adjacent to and further away from the Sacramento River, and Figure 2-14 provides hydrographs for these wells covering their period of record. To allow for a more detailed assessment of trends within each of the zones screened, Figure 2-23 provides hydrographs for these wells (23N01W31M and 23N01W28M) over a shorter time period (January 2014 through December 2016).



Legend

Groundwater Subbasin[1]

Vina Groundwater Subbasin

Monitoring Wells

Nested monitoring wells

Chico nitrate wells

Roads[3]

Highways

Other roads

Boundaries[3]

County boundaries

Notes:
1) California Department of Water Resources (CA DWR).
3) TIGER/Line, U.S. Census Bureau.

5 2½ 0 5 Miles

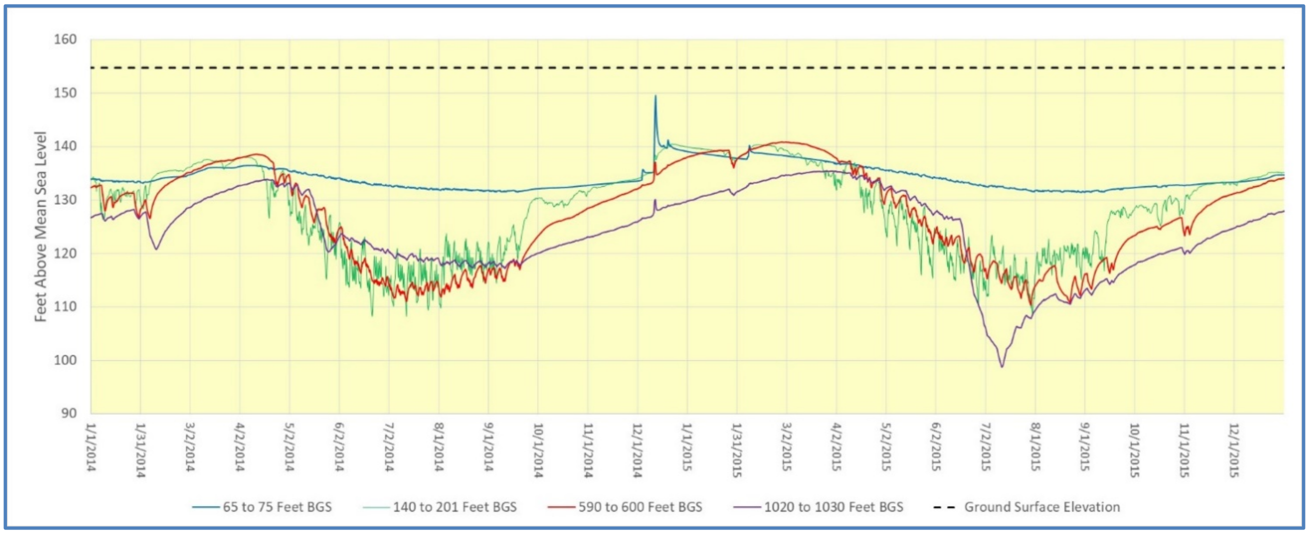
Location of Selected Nested and Chico Nitrate Monitoring Wells
Vina Groundwater Subbasin GSP

Geosyntec consultants

Figure **2-22**

Project No.: SAC282

December 2021



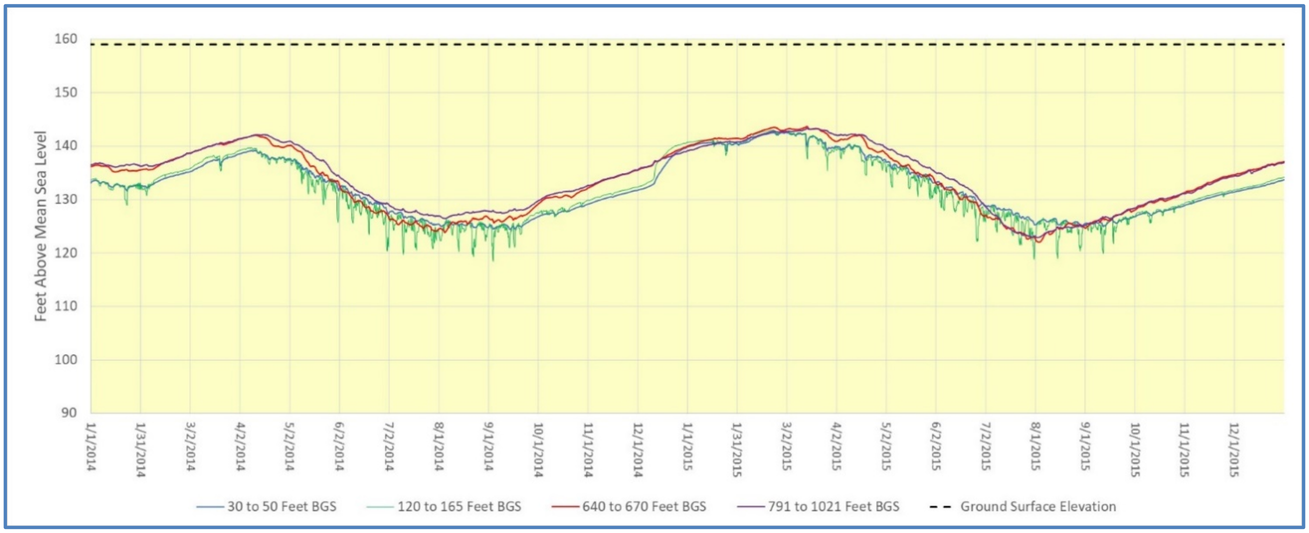


Figure 2-23: Hydrographs for Nested Well Located Near Sacramento River (Upper Hydrograph, Well 23N01W31M) and Nested Well Located Further from the Sacramento River (Lower Hydrograph, Well 23N01W28M)

As seen in this figure, the hydrograph for the nested well located adjacent to the Sacramento River (23N01W31M, upper graph in Figure 2-23) shows that water levels in the shallowest well display little annual fluctuation and are similar to the elevation of the river. This indicates that this shallowest well completion interval is in direct continuity with river levels and the adjacent floodplain supported by the up-tick of water levels in December 2014 that are most likely due to increases in river flows. It is likely that this shallow well is completed in what could be termed "floodplain sediments," as opposed to a regional shallow aquifer that extends across the Vina Subbasin. The deeper wells within this nest display greater fluctuation in seasonal water levels that generally tend to track each other, indicating less direct continuity with river levels and the adjacent floodplain.

The hydrograph for the nested well farther from the river (well 23N01W28M, lower graph on Figure 2-23) shows a close correspondence in water elevations recorded at all screened intervals being monitored. This indicates a clear connection across the aquifer zones. The trend in these zones is also similar to the trends observed for the three deeper wells within the nested well located adjacent to the Sacramento River.

The streamflow gaging study conducted by Chico State University on Big Chico Creek in 2020 (Davids et al., 2020) consisted of repeated measurements of streamflow at six different locations along Big Chico Creek between June and mid-October. The study consisted solely of streamflow data and no groundwater information or analysis of the floodplain/riparian area was conducted. The results clearly show a progressive decrease in streamflow from the uppermost station to the lowermost station for each of the time points measured. The results also clearly show a rapid decrease in streamflow from June to July, followed by a more gradual decrease after July. Finally, the results clearly show that the lower 8 kilometers of Big Chico Creek (below Rose Drive Bridge) become dry by early July and flows in the middle portion of the Creek decrease to below 5 cubic feet per second (cfs) by late July. This recent data indicates that, in general, within the subbasin Big Chico Creek is a losing stream during high flood flows and becomes a disconnected stream in its lower reaches by early to mid-summer. There is no indication in the streamflow data at the measured time and locations to suggest groundwater interactions contribute to the streamflow behavior, thereby suggesting Big Chico Creek was observed to be a losing stream disconnected from the water table. Similar conditions would be expected for other creeks that traverse the Vina Subbasin (Little Chico, Sycamore, Rock, and Butte Creek) since they flow across a similar fan topography and similar shallow subsurface geology. The overall conclusion from this study in relation to interconnected surface water is that, for significant portions of the year, the upland creeks in the Vina Subbasin would be classified as disconnected streams and the surface water would be considered “completely depleted” as defined under SGMA.

Eight shallow monitoring wells installed within the City of Chico in the vicinity of Little Chico Creek (AECOM, 2020: Figure 2-23) provide similar findings to the streamflow study on Big Chico, but are based on groundwater data. All the monitoring wells were completed at depths of less than 60 feet bgs and are therefore representative of groundwater levels that could directly interact with the adjacent stream channels (i.e., Little Chico Creek and the Lindo Channel). Figure 2-24 provides hydrographs for these eight wells for data collected since 2012. All the groundwater levels collected across all time periods are below the elevation of the stream channel adjacent to the monitoring wells. This indicates that groundwater levels are not capable of interacting directly with the adjacent stream channel.

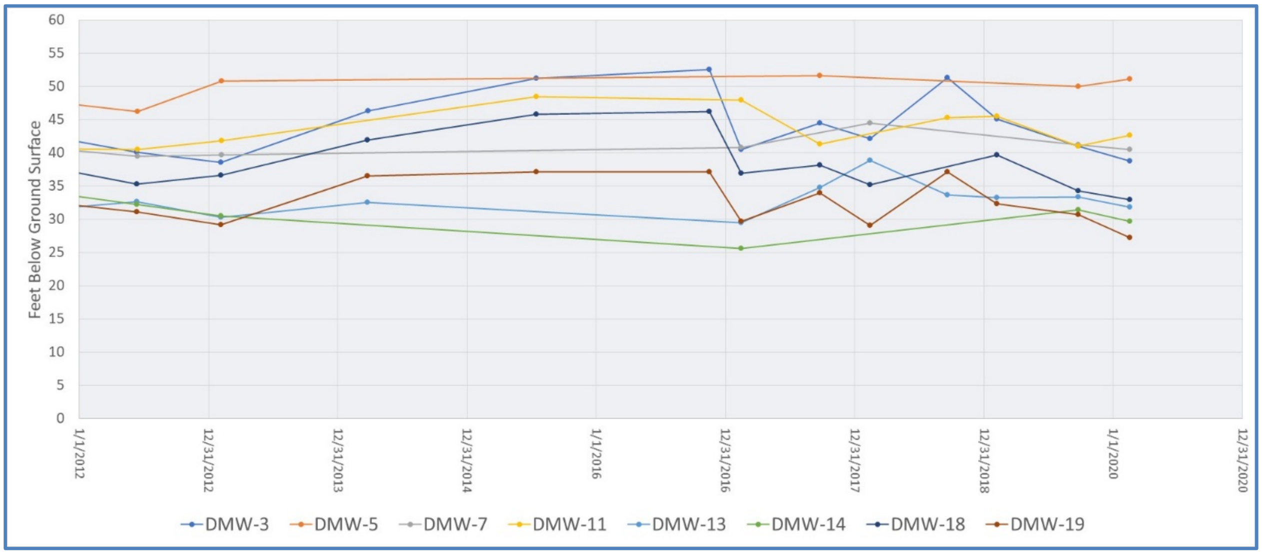


Figure 2-24: Hydrographs Showing Feet Below Ground Surface for Eight Shallow Wells Monitored as Part of Chico Nitrate Study (AECOM, 2020)

At the downstream end of the stream channel, groundwater levels were somewhat closer to the bottom of the stream channel, but still did not intersect the stream channel. This downstream area represents the edge of the upland area and the transition zone to the Sacramento River floodplain. Some groundwater interaction may occur in these lower reaches but is more representative of surface water interactions in the floodplain as opposed to the upland area.

Finally, it should be noted that only the northern portion of the Vina Subbasin extends to the Sacramento River (north of its confluence with Big Chico Creek). The southern portion of the Vina Subbasin does not extend into the Sacramento River floodplain, and therefore consists only of upland creeks that dissect the alluvial fan system emanating from the foothills. Any direct interaction with the Sacramento River south of its confluence with Big Chico Creek occurs in the Butte Subbasin.

2.2.6.3 Estimates of Surface Water Connection Based on BBGM

The interactions between groundwater systems and surface water features within the Vina Subbasin are estimated at a basin scale in the BBGM. A total of 32 stream segments traversing or bounding the Vina Subbasin with a total length of approximately 115 miles are defined in the BBGM. The segments range in length from 1 to 9 miles with an average length of 3.6 miles and are shown in Figure 2-25. Streamflows are defined in each stream at the eastern edge of the model based on available stream gage data. Streamflow data in upland creeks between the edge of the model and the Sacramento River were not available for use in model calibration. The floodplain of the Sacramento River is not explicitly defined in the BBGM, so there is no distinction between floodplain sediments that may interact directly with the Sacramento River and more regional shallow aquifers that extend east to the recharge areas along the foothills.

Figure 2-26 shows the model-predicted stream interaction from 2000 to 2018. The results are expressed as a percentage based on number of months that either a gaining or losing condition was predicted. The figure shows that the upland stream segments above the Sacramento River floodplain are predominantly losing reaches that provide recharge to the aquifer. Streambed elevations at individual stream nodes from the BBGM were also compared to groundwater elevations from spring groundwater level measurements provided by DWR as part of the SGMA Data Viewer.[5] As indicated in Figure 2-27, the estimated average distance between the streambed and groundwater over a five-year period (2014-2018) was 20 feet for upland streams before they entered the Sacramento River floodplain. This disconnection between upland streams and shallow groundwater is consistent with the evaluation of shallow well groundwater levels described previously.

Reaches of the Sacramento River showed more variable model response, with a broader distribution of gaining and losing months. As indicated in Figure 2-27, the estimated average distance between the streambed and groundwater over a five-year period (2014-2018) was 10 feet or less in the Sacramento River floodplain. This is consistent with a more complex and large-scale interaction between floodplain sediments, underlying aquifer zones, and the elevation profile of the Sacramento River.

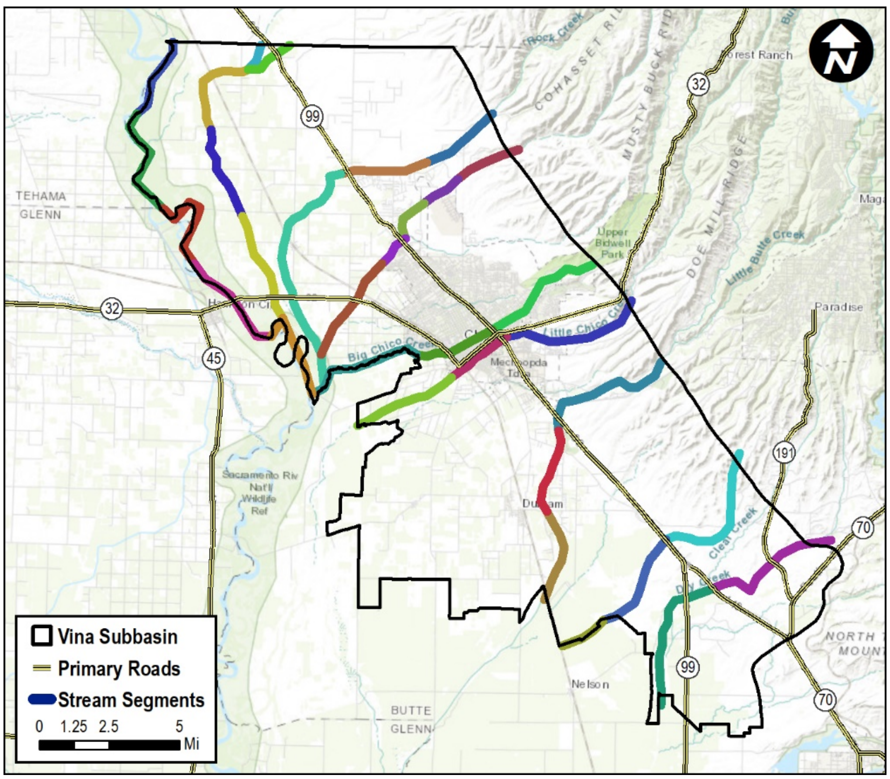


Figure 2-25: Vina Subbasin Stream Segments

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

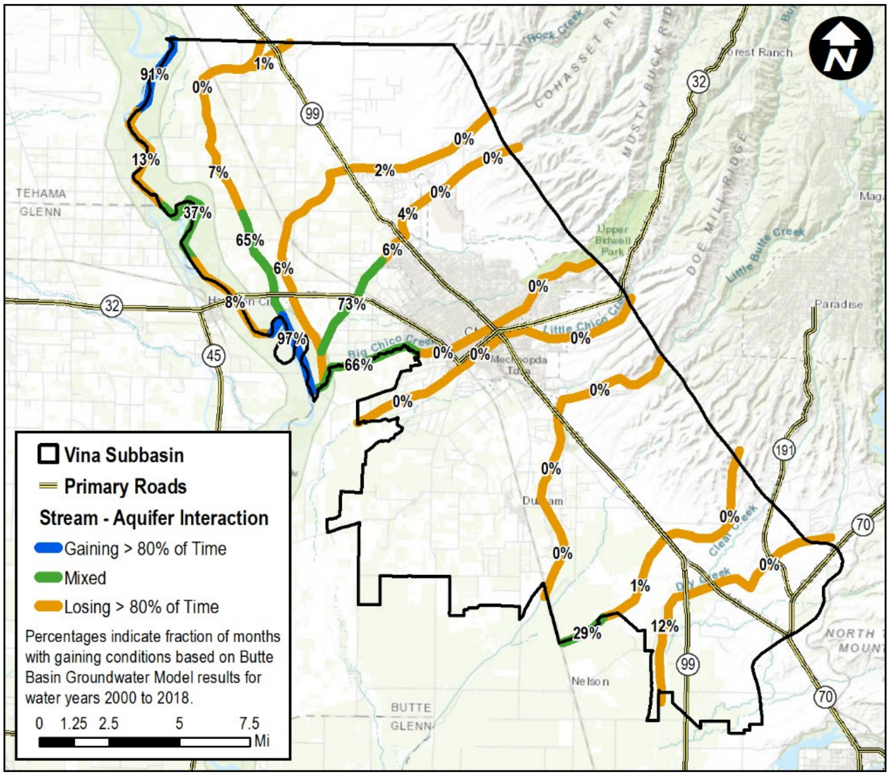

Figure 2-26: Vina Subbasin Gaining and Losing Stream Reaches based on Butte Basin Groundwater Model, Water Year 2000 to 2018

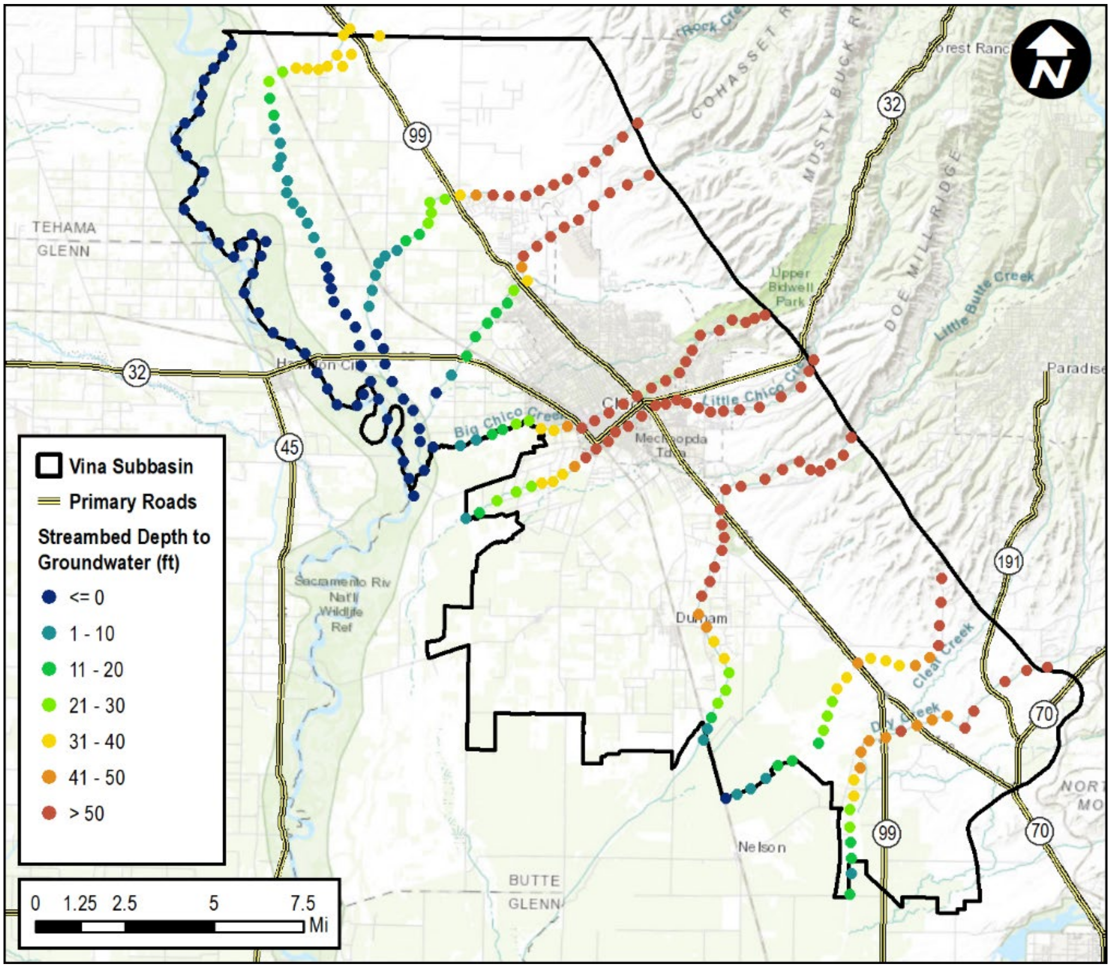

Figure 2-27: Vina Subbasin Average Streambed Spring Depth to Groundwater, 2014 to 2018

2.2.6.4 Water Balance for Surface Water – Groundwater Interaction

The water balance for surface water – groundwater interaction was estimated using the BBGM on a monthly time step. The volume of interaction was calculated across the entire length of each stream. Monthly net streamflow gains or losses from groundwater were calculated by the model water balance for the historical period from water year 2000 to 2018. These results are summarized in Table 2-5. Average monthly gains to streamflow are expressed in cfs. Negative values denote losses from streamflow to groundwater (i.e., seepage or depletion).

Table 2-5: Average Monthly Gains to Streamflow from Groundwater, Water Years 2000 to 2018 (cubic feet per second)

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**

Table 2-5 shows that most of the streams that traverse the alluvial fan from the foothills to Sacramento River lose water to the groundwater system at a rate of between 1 and 12 cfs, with Butte Creek showing the highest amount of seepage to groundwater. Total streamflow loss to groundwater averages about 23 cfs or about 16,650 AFY.

Mud Creek and Pine Creek, which are located near or within the Sacramento River floodplain, show more variation (with both gaining and losing months), but are, on an annual basis, neutral with respect to total volume of stream interaction.

The Sacramento River shows net gaining conditions along the reaches adjacent to the Vina Subbasin for all months except January. On average, there is approximately 70 cfs of streamflow gain, or 50,600 AF per year, which represents about 23% of the total modeled recharge to the Vina Subbasin (Section 2.3). The remaining 77% of recharge to the Vina Subbasin discharges into pumping wells and model boundaries.

2.2.7 Groundwater Dependent Ecosystems

Groundwater Dependent Ecosystems (GDEs) are defined in the SGMA regulations as "ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface" (California Code of Regulations [CCR] Title 23, § 351(m)). GDEs exist within the Vina Subbasin largely where vegetation accesses shallow groundwater for survival and in areas with streams and creeks where a connection to groundwater exists. Without access to shallow groundwater, these plants and the ecosystems supported by the hydrology would die.

2.2.7.1 NCCAG Database

The initial identification of GDEs for this GSP was performed by using the Natural Communities Commonly Associated with Groundwater (NCCAG) database to identify and map potential GDEs (iGDEs) in the Vina Subbasin. The NCCAG database was developed by a working group comprised of DWR, CDFW, and The Nature Conservancy (TNC) by reviewing publicly available state and federal agency datasets that have mapped California vegetation, wetlands, springs, and seeps and by conducting a screening process to retain types and locations of these commonly associated with groundwater. The results were compiled into the NCCAG database with two habitat classes defined. The first class includes wetland features commonly associated with the surface expression of groundwater under natural, unmodified conditions. The second class includes vegetation types commonly associated with the sub-surface presence of groundwater (phreatophytes). Figures 2-28 and 2-29 show the locations of all iGDEs identified by the NCCAG database within the Vina Subbasin.

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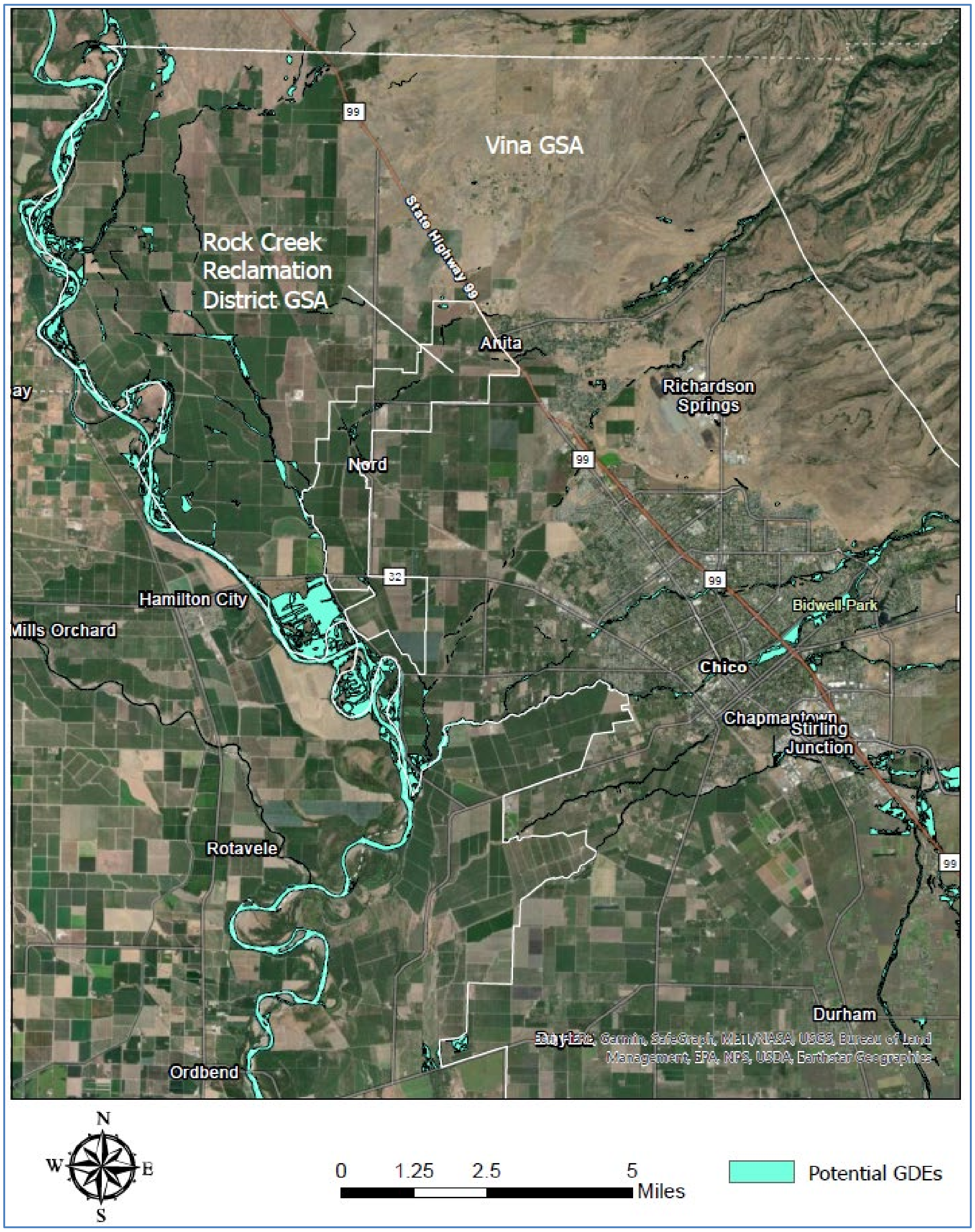

Figure 2-28: Potential Groundwater Dependent Ecosystems (iGDEs) in the Northern Portion of the Vina Subbasin as Identified in the NCCAG Database Developed by TNC

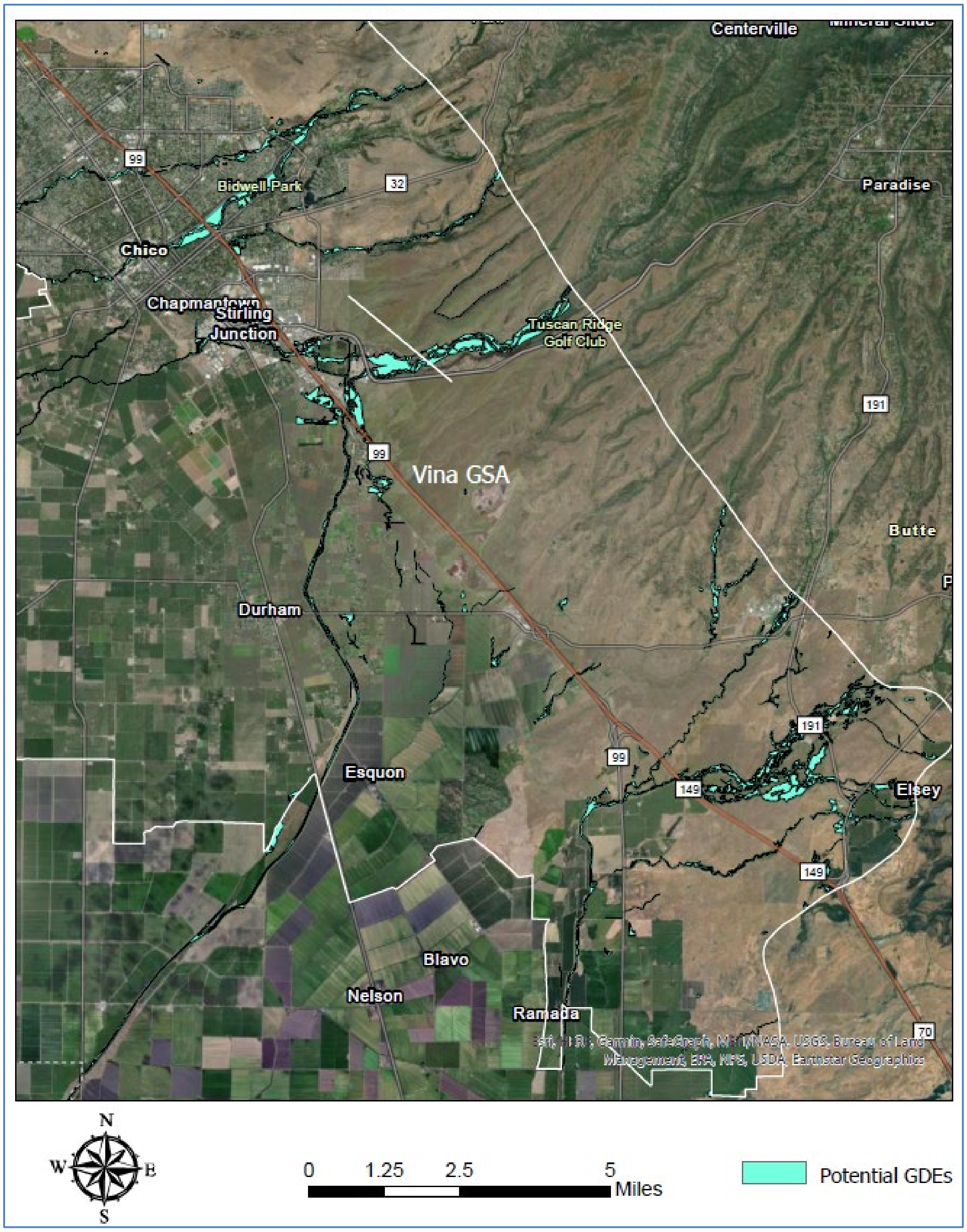

Figure 2-29: Potential Groundwater Dependent Ecosystems (iGDEs) in the Southern Portion of the Vina Subbasin as Identified in the NCCAG Database Developed by TNC

The NCCAG dataset is based on 48 layers of publicly available data developed by state or federal agencies that map vegetation, wetlands, springs, and seeps in California (DWR, 2019b). A NCCAG technical working group with representatives from DWR, CDFW, and TNC reviewed the datasets compiled to assemble the NCCAG dataset. The NCCAG dataset attempts to extract mapped vegetation and wetland features that have indicators suggesting dependence on groundwater. The data presented in NCCAG dataset display vegetation polygons that have indicators of GDEs based on published and/or field observations of phreatophytic vegetation defined as a "deep-rooted plant that obtains water that it needs from the phreatic zone (zone of saturation) or the capillary fringe above the phreatic zone" (Rohde et al., 2018). The dominance of phreatophytic plant species in a mapped vegetation type is a primary indicator of GDEs. A list of plant species considered to be phreatophytes based on peer-reviewed scientific literature on rooting depths, published lists of phreatophytes, expert field observations, and vegetation alliance descriptions is publicly available (Klausmeyer et al., 2018; DWR, 2018b).

While developing the NCCAG dataset of areas with indicators of GDEs, the technical working group attempted to exclude vegetation and wetland types and polygons that are less likely to be associated with groundwater (Klausmeyer et al., 2018). The NCCAG working group attempted to remove any polygons that are not likely to be GDEs where they occurred in areas where they are likely to be supported by alternate artificial water sources (e.g., local seepage from agricultural irrigation canals), or where appropriate available data indicated the shallow groundwater depth is located well below the rooting zone, (Klausmeyer et al., 2018).

The vegetation data presented in the NCCAG dataset is the latest available starting point for the identification of GDEs, as the dataset includes the best available public datasets and has been screened to include only areas that have indicators of groundwater dependent vegetation. DWR has stated that use of the NCCAG dataset is not mandatory and does not represent DWR's determination of a GDE (DWR, 2018b). Rather, the NCCAG dataset can provide a starting point for the identification of GDEs within a groundwater basin.

Additional information, such as near surface groundwater depth obtained from piezometers, information about subsurface stratigraphy and geology on confining layers, and information on local land use and hydrology can be used to confirm whether vegetation in areas identified by the NCCAG as iGDEs is, in fact, reliant on groundwater.

2.2.7.2 Initial iGDE Analysis

GSA Managers from the Vina Subbasin used this database as a starting point to analyze a portion of the total iGDEs in the NCCAG database to evaluate local groundwater dependence. Specific criteria to each polygon to answer a series of questions led to an eventual characterization for each iGDE. These iGDEs were designated as either "Likely a GDE," "Not likely a GDE," or "Uncertain" based on evaluations. The criteria aimed at understanding each iGDE's dependence on groundwater, including questions about land use changes, proximity to perennial surface water supplies, irrigated agriculture and agricultural dependent surface water, condition of vegetation during drought years and water applications to the iGDEs.

The first phase of the analysis was conducted by thorough review of aerial photographs from Google Earth across multiple years specifically focusing on the 2007, 2009, 2013, and 2015 drought years as well as the Managers' local knowledge of these areas.

2.2.7.3 iGDE Designations

While there were some areas identified as "Not likely a GDE" during this effort, Managers were also able to add any iGDEs into the map that were not captured in the original NCCAG database.

NCCAG areas identified as "Not likely a GDE" from the initial analysis by Managers can be categorized as follows.

Not Likely a GDE Due to Significant Land Use Change
Some areas in the NCCAG database have changed in land use since the database was published. Developed areas where there have been significant land use changes to the iGDE (i.e., land that transitioned into cultivated irrigated agricultural lands, industrial, or residential development) occurred or lands had undergone man-made changes such as golf courses or other obvious anthropogenic changes were labeled as "Not likely a GDE."

Not Likely a GDE Due to Perennial Surface Water Supplies
Areas with perennial water supplies such as those near reservoirs were labeled as "Not likely a GDE." Reservoirs provide water year-round for adjacent ecosystems. If any iGDEs were located within 150 feet of reservoirs, they were assumed to be able to access the nearby surface water bodies and were labeled as "Not likely a GDE."

Not Likely a GDE Due to Supplemental Water Supplies
Irrigated agriculture, irrigated refuge / managed wetlands or irrigated urban areas with supplemental water deliveries were identified by Managers during the initial GDEs analysis effort. These areas are assumed to be accessing supplemental water supplies and not reliant on groundwater and were labeled as "Not likely a GDE."

Not Likely a GDE Due to Adjacency to Irrigated Agricultural Fields
Agricultural lands are dependent on reliable water supplies to ensure a successful harvest. Surface water and / or groundwater pumped from the aquifer is used to irrigate crops in the Vina Subbasin. Such irrigation benefits not only the crops, but also surrounding vegetation. Potential GDEs further than 150 feet from irrigated rice fields and areas further than 50 feet from all other irrigated agriculture were assumed to be unable to access irrigation water. These distances are based on professional judgment, including past experience in the region and consideration of the physical characteristics of the Vina Subbasin, such as hydraulic conductivity. Rice fields, along with other irrigated agriculture, are known to have percolation and lateral seepage, supplying water to the aquifer and into adjacent areas. Lateral seepage in Sacramento Valley rice areas has been estimated at between 1.0% and 1.9% of the total irrigation volume (LaHue and Lindquist, 2019). A larger distance was used for rice due to the long-term ponding of water and due to restrictive layers in the subsurface that result in the horizontal spreading of irrigation water. Potential GDEs near these irrigated areas are assumed to be accessing irrigation water through lateral movement through the soils; thus, they were labeled as "Not likely a GDE."

Not Likely a GDE Due to Dependence on Agricultural-dependent Surface Water
Similar to areas adjacent to reservoirs, iGDEs adjacent to surface water bodies that are perennial due to agricultural practices and those near drainage canals, are able to access surface water throughout the year. Agricultural water conveyance features, i.e., the Cherokee Canal is included in this definition however, this does not include the Sacramento River, Butte Creek, or Honcut Creek because these natural waterways also convey non-agricultural water. Potential GDEs within 150 feet of these agricultural-dependent surface water bodies were assumed to be accessing water from them thus, they were labeled as "Not likely a GDE."

Not Likely a GDE Due to Non-Survival during Drought Conditions

To assess if the iGDE was groundwater dependent, Managers reviewed the condition of the iGDE over multiple dry drought years using aerial photographs from Google Earth. Specifically, the group focused on the drought years of 2007, 2009, 2013, and 2015 in addition to the Managers' local knowledge of these areas. Green vegetation over multiple drought years during summer months indicated survival of the iGDE as well as an assumed connection to groundwater. Potential GDEs that did not indicate any surviving conditions over multiple drought years were assumed to not be connected to groundwater and were labeled as "Not likely a GDE."

Uncertain – All Other Areas

The iGDEs analyzed by the Managers in this initial effort, which did not receive a designation as either "Not likely a GDE" or "Likely a GDE" based on the conclusions from the analysis above, were labeled as "Uncertain" and were further analyzed as described below.

2.2.7.4 Additional Geographical Information Systems (GIS) Analysis

Irrigated Agricultural Land Use

After the initial analysis was completed for a selection of the total iGDEs in the NCCAG database as described above, a geographical information systems (GIS) analysis was performed for all remaining iGDEs in this Vina Subbasin by Butte County staff to determine each iGDE's proximity to rice and other irrigated agriculture as described below. The DWR / Land IQ land use and crop mapping data for 2016 (DWR, 2019b) was used to determine the dominant crop type throughout the Vina Subbasin.

Land classified as "Rice" for the "Crop Type 2016" in the dataset was identified. Then all polygons in the TNC iGDEs dataset within 150 feet of land classified as Rice were identified and designated as "Not likely a GDE near irrigated rice" for the same reasons as described above in the "Not Likely a GDE Due to Adjacency to Irrigated Agricultural Fields" section of this document above.

Land with "Crop Type 2016" classifications other than "Managed Wetland," "Urban," "Rice," and "Mixed Pasture" in the dataset were identified and for this purpose referenced as "Other Irrigated Agriculture" for this GIS analysis, as all other remaining irrigated crop types. All polygons in the NCCAG dataset within 50 feet of land classified as "Other Irrigated Agriculture" were designated as "Not likely a GDE near irrigated agriculture (Non-Rice)" for the same reasons as described above in the "Not Likely a GDE Due to Adjacency to Irrigated Agricultural Fields" section of this document.

Valley Oak Dominated Areas

The dataset provided by TNC indicates the dominant species of vegetation for each polygon, including Valley oak (*Quercus lobata*) in the Vina Subbasin. Those polygons were classified as "Likely a GDE" due to feedback from TNC staff that this species can access groundwater over a wide range of depths (M. Rohde personal communication March 2, 2021).

Sacramento River Corridor Areas

Using GIS analysis tools, polygons located within the active floodplain of the Sacramento River were selected manually. These polygons were classified as "Likely a GDE" due to their proximity to the Sacramento River, which is classified as a gaining river throughout most, if not all of its length throughout the Vina Subbasin.

2.2.7.5 Mapping

The maps in Appendix 2-A shown as Figures 3 and 4 show iGDEs classified as “Likely a GDE” or “Not Likely a GDE” for one of the reasons described above. The iGDEs classified as “Not Likely a GDE” in the Vina Subbasin were designated this way due to either their proximity to irrigated agriculture as rice, proximity to irrigated agriculture other than rice, or because they did not survive dry conditions as determined during the initial analyses performed by the GSAs Managers.

2.3 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 2-30.

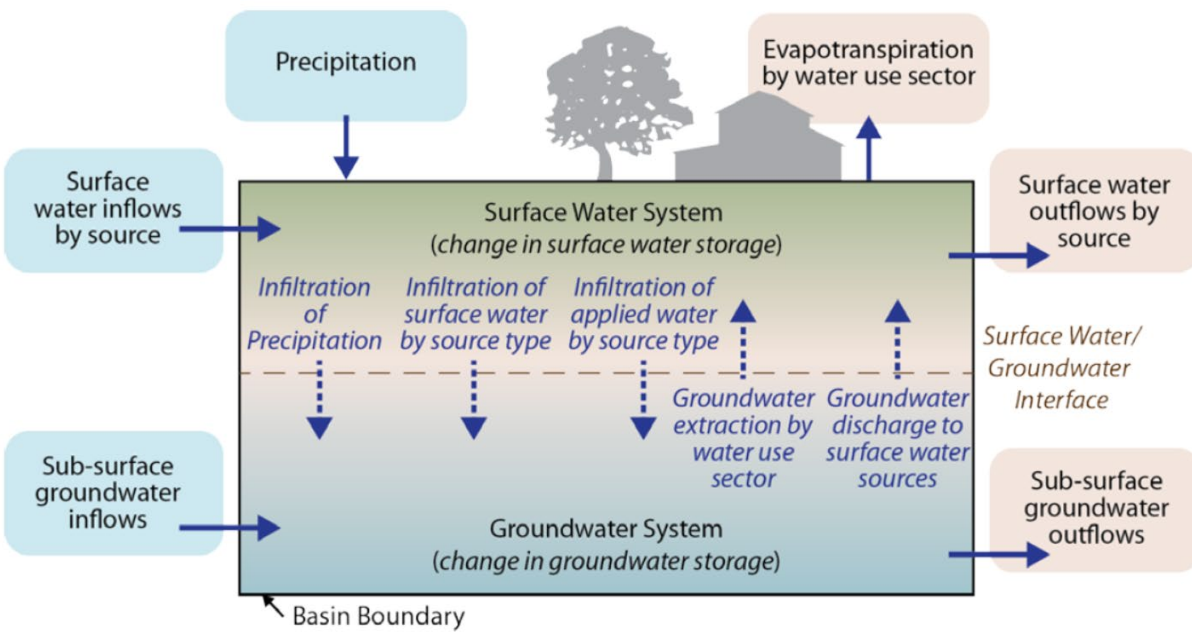

Figure 2-30: Water Budget Components (DWR, 2016)

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.

2.3.1 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[6] 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 (Appendix 2-B). 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 and 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 and 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 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[7] 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 2-31).
    - The selected period includes a combination of wet and dry cycles, including relatively wet periods in the early 1970s, mid 1980s, and late 1990s and dry periods in the late 1970s, early 1990s, and from approximately 2007 to 2015.

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.

[6] 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.
[7] 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).

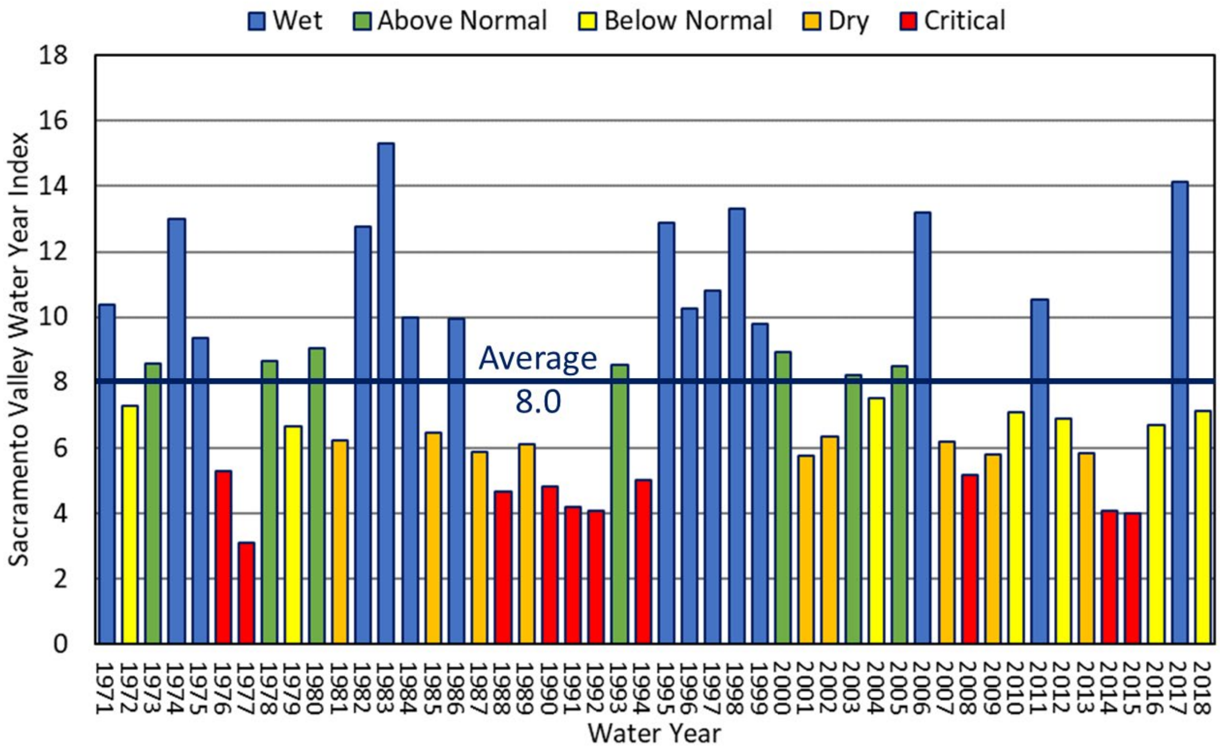

Figure 2-31: 1971 – 2018 Sacramento Valley Water Year Index and Water Year Types

2.3.2 Usage of the Butte Basin Groundwater Model

Development of the original 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 is described in more detail in (BCDWRC, 2021).

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.

2.3.3 Water Budget Assumptions

Assumptions utilized to develop the historical, current, and projected water budgets are described below and summarized in Table 2-6.

Table 2-6: Summary of Water Budget Assumptions

Water Budget	Analysis Period	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

2.3.3.1 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,[8] 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 10 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 un-gaged streams, inflows were estimated using the National Resource Conservation Service (NRCS) rainfall runoff method applied at the watershed scale, considering precipitation timing and amount, soil characteristics, and other factors.

[8] Sacramento Valley Water Year Index = 0.4 * Current Apr-Jul Runoff Forecast (in MAF) + 0.3 * Current Oct-Mar Runoff in (MAF) + 0.3 * Previous Water Year's Index (if the Previous Water Year's Index exceeds 10.0, then 10.0 is used). This index, originally specified in the 1995 SWRCB Water Quality Control Plan, is used to determine the Sacramento Valley water year type as implemented in SWRCB D-1641.

Additional detail describing stream inflows is described in the BBGM model report (BCDWRC, 2021).

- 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, 2021).
- 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[9] – Urban and industrial demands were estimated based on a combination of pumping data provided directly by water suppliers (e.g., Cal Water) 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, 2021).
- 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 the estimated groundwater pumping required to meet the remaining demand.

2.3.3.2 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 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

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[9] 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.

the understanding of uncertainty in groundwater conditions over time, establishment of SMC, 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 was 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 diversions assumed for extreme dry years and 2016 diversions assumed for other years. For the current condition's 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.

2.3.3.3 Future Conditions

Three projected water budget scenarios were developed considering a range of future conditions in the Vina 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 was 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 on projected urban demands. Specifically, future urban demands were estimated based on preliminary draft demand estimates provided by urban water suppliers (e.g., Cal Water) as part of 2020 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 for 11 years within the 50-year simulation period.
  - For the 2070 central tendency scenario, extreme dry conditions occurred for 13 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.

2.3.4 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 the basin. 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 (2021).

Average annual water budget estimates for the historical water budgets and for the current and projected water budget scenarios are summarized in Table 2-7 for the land and surface water system and in Table 2-8 for the groundwater system.

As seen in Table 2-8, there is a significant difference in the calculated change in storage for the historical scenario (-19,600 AFY) versus the current and future scenarios (-1,200 to -2,700 AFY). The primary reason for this difference is the time period used for the calculations. As discussed above, the historical scenario only uses a 19-year period from 2000 to 2018; whereas. the other scenarios use a 50-year period as required by SGMA from 1971 to 2018 (2004 and 2005 repeated after 2018). Figure 2-32 illustrates the sensitivity to the time period selected for the calculation of change in storage using the current scenario graph of change in storage.

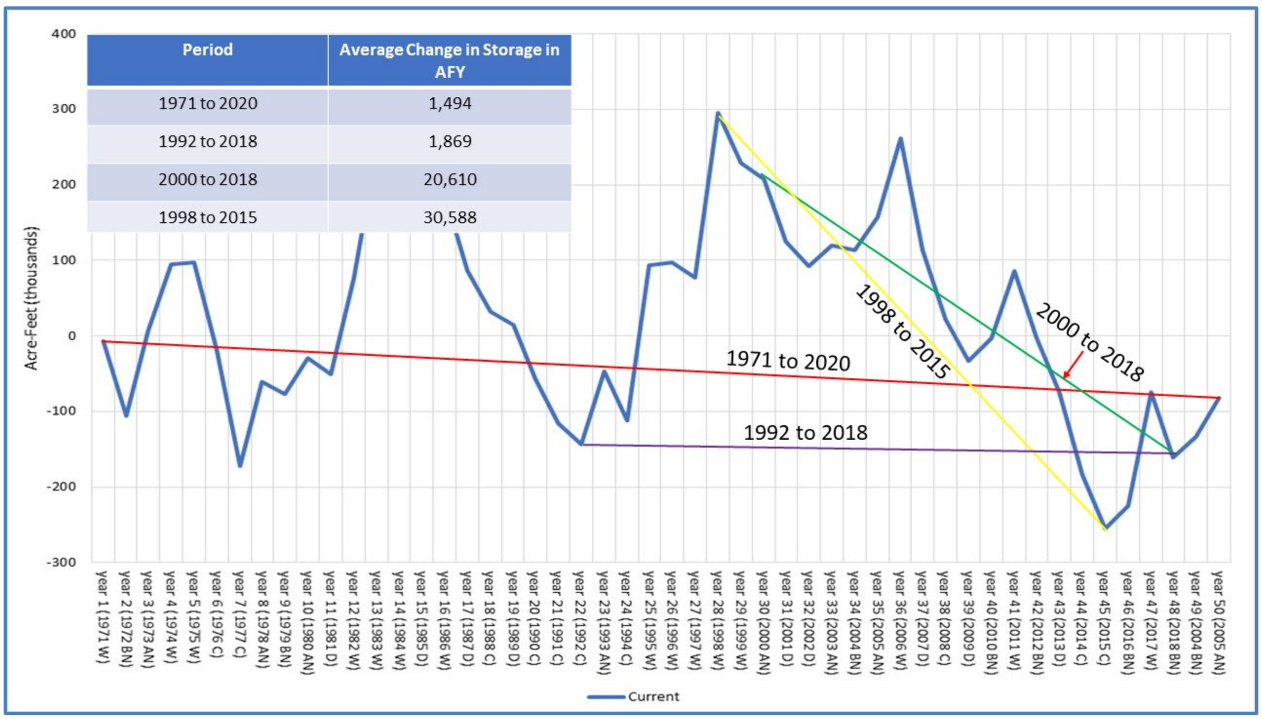


Figure 2-32: Sensitivity to the Change in Storage to the Time Period Selected for the Calculation.
Graph used is the current conditions scenario as discussed in Section 2.3.3.2.

As seen in this figure, a wide range of change in storage values are calculated depending on the time period selected. However, for development of the SMC, as discussed in Section 3, it is important to view these values in relationship to the total storage of the Vina Subbasin. As estimated by the BBGM, total storage of the Vina Subbasin is about 16-million acre-feet (MAF), indicating that the calculated annual change in storage values shown in Figure 2-32 is only 0.009 to 0.2 percent of the total storage of the Vina Subbasin. The calculated change in storage values is also within the range of error for the BBGM.

Additional information and discussion regarding the water budgets are 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 2-7: 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

Component	Historical (AFY)	Current (AFY)	Future, No Climate Change (AFY)	Future, 2030 Climate Change (AFY)	Future, 2070 Climate Change (AFY)
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	***1,212,900***	***1,234,100***	***1,240,300***	***1,295,600***	***1,344,300***
Change in Storage (Inflow - Outflow)	***0***	***200***	***100***	***100***	***0***

Notes:

AFY = Acre feet per year.

1. Totals are the sum of numbers in bold

Table 2-8: 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	***354,100***	***362,700***	***359,900***	***366,900***	***369,700***
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	***373,700***	***363,900***	***361,800***	***368,600***	***372,400***
Change in Storage (Inflow - Outflow)	***-19,600***	***-1,200***	***-1,900***	***-1,700***	***-2,700***

Notes:
AFY = Acre feet per year.
1. Totals are the sum of numbers in bold

2.3.4.1 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 10 years, 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. The Vina Subbasin opted to use the 19-year period from 2000 to 2018. The historical analysis period experienced somewhat less precipitation than the long-term average and included historic drought conditions from approximately 2007 to 2015.[10]

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 MAF per year. Average annual values were presented previously in Table 2-7 and are shown graphically in Figure 2-33.

Primary inflows to the land and surface water system include surface water inflows (555 TAF/year), precipitation (411 TAF/year), and groundwater pumping (243 TAF/year), with estimated stream gains from groundwater (i.e., accretions) of approximately 4 TAF/year. 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/year), evapotranspiration (363 TAF/year), deep percolation (193 TAF/year), and stream losses (also referred to as seepage) (24 TAF/year). 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 2-B.

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

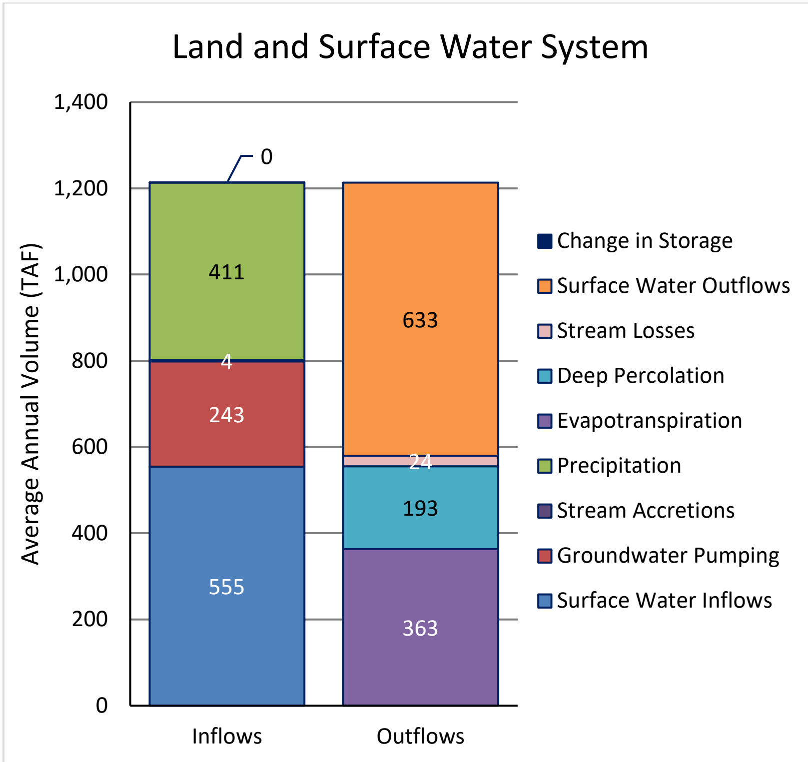


Figure 2-33: Average Annual Historical Land and Surface Water System Water Budget

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\year during the historical simulation period. Average annual values were presented previously in Table 2-8 and are shown graphically in Figure 2-34.

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

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 2-B.

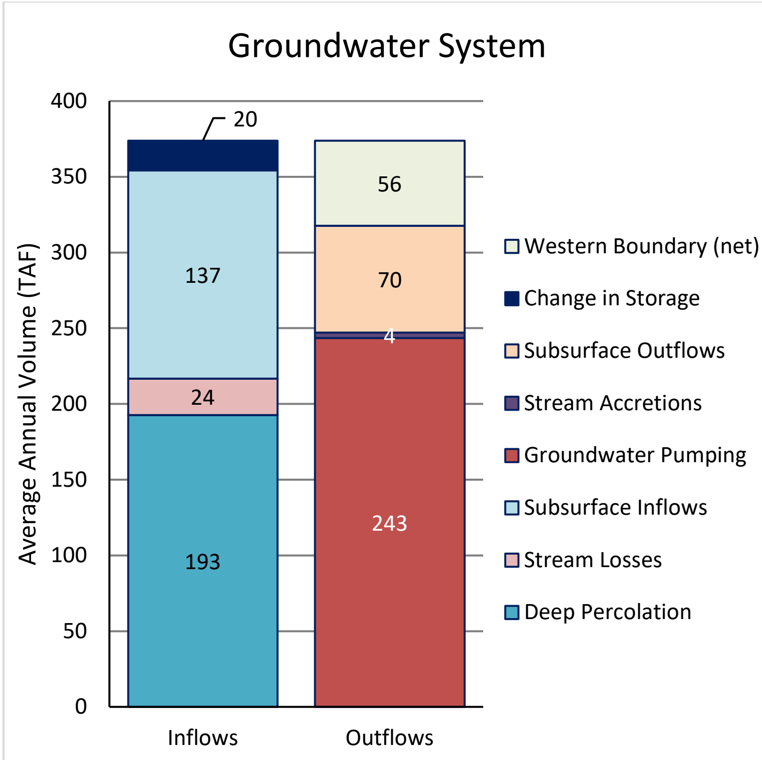


Figure 2-34: Average Annual Historical Groundwater System Water Budget

Historical water supplies and change in groundwater storage are summarized by water year type in Table 2-9 based on the Sacramento Valley Water Year Index, 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 2-9: 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 2-9, 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 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 State 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 HCM 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 Vina 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 SMC, 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 (2021).

2.3.4.2 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 capture effects of long-term hydrologic variability.

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 MAF per year. Average annual values were presented previously in Table 2-7 and are shown graphically in Figure 2-35.

Primary inflows to the land and surface water system include surface water inflows (602 TAF/year), precipitation (422 TAF/year), and groundwater pumping (209 TAF/year), with estimated stream gains from groundwater (i.e., accretions) of approximately one TAF/year. 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/year), evapotranspiration (348 TAF/year), deep percolation (192 TAF/year), and stream losses (also referred to as seepage) (28 TAF/year). 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.

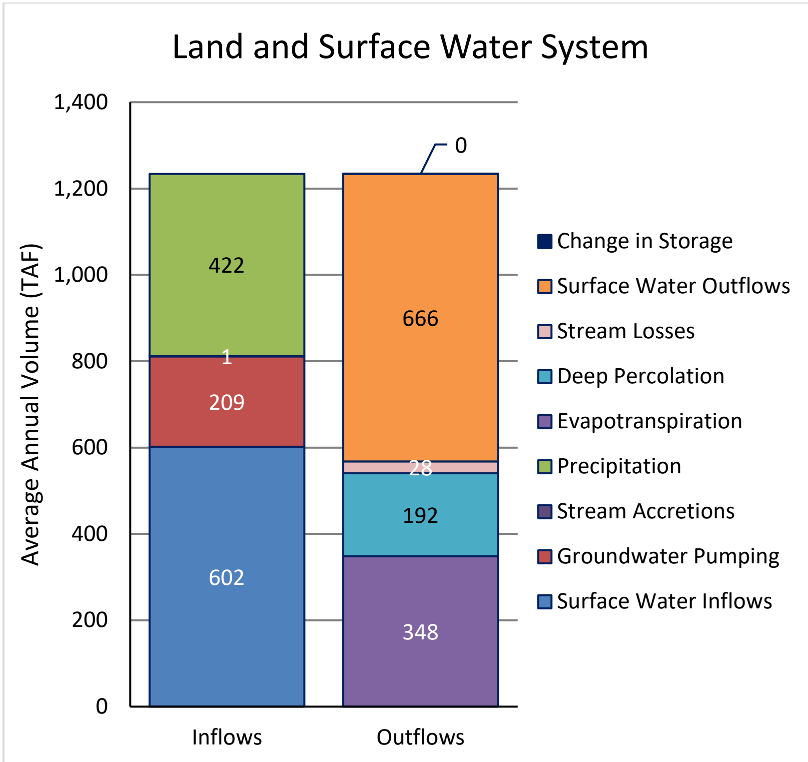


Figure 2-35: Average Annual Current Conditions Land and Surface Water System Water Budget

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 one TAF per year during the 50-year simulation period. Average annual values were presented previously in Table 2-8 and are shown graphically in Figure 2-36.

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

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.

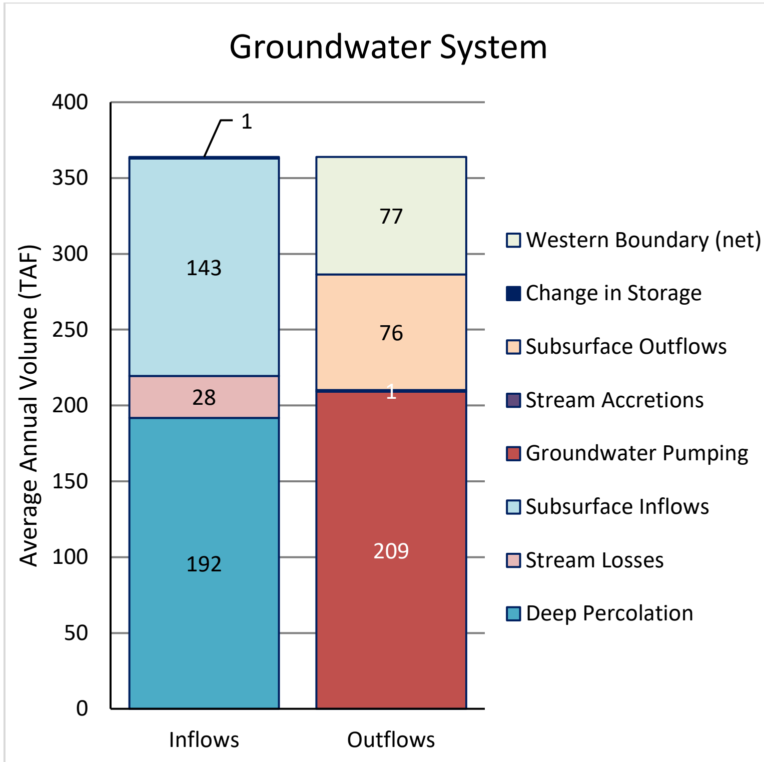


Figure 2-36: Average Annual Current Conditions Groundwater System Water Budget

2.3.4.3 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 captures effects of long-term hydrologic variability.

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 MAF/year. Average annual values were presented previously in Table 2-7 and are shown graphically in Figure 2-37.

Primary inflows to the land and surface water system include surface water inflows (602 TAF/year), precipitation (422 TAF/year), and groundwater pumping (216 TAF/year), with estimated stream gains from groundwater (i.e., accretions) of approximately one TAF/year. 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/year), evapotranspiration (347 TAF/year), deep percolation (189 TAF/year), and stream losses (also referred to as seepage) (28 TAF/year). 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.

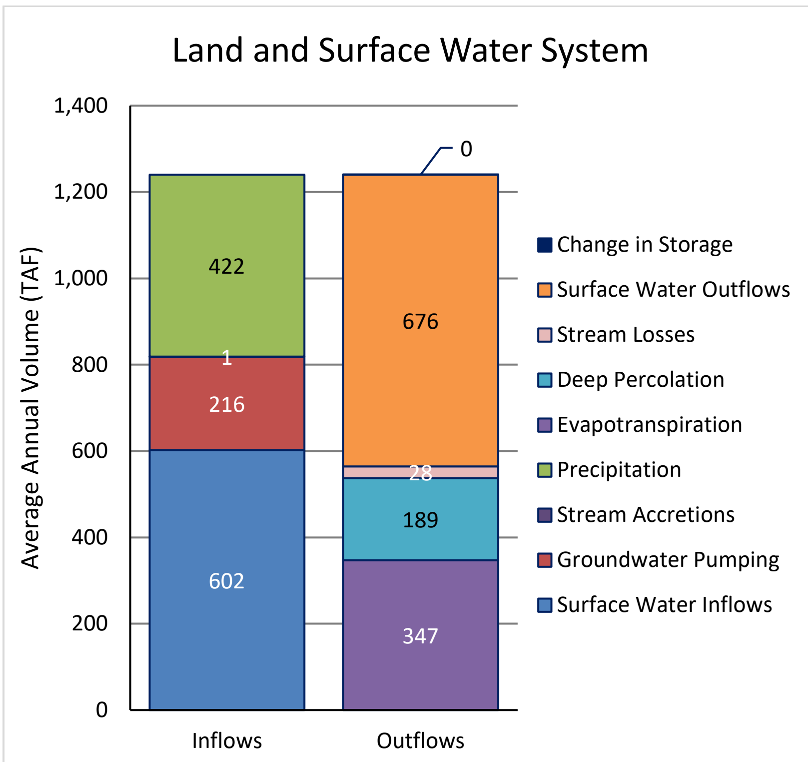


Figure 2-37: Average Annual Future Conditions without Climate Change Land and Surface Water System Water Budget

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 two TAF/year during the 50-year simulation period. Average annual values were presented previously in Table 2-8 and are shown graphically in Figure 2-38.

Inflows to the groundwater system include deep percolation (189 TAF/year); subsurface inflows from the Los Molinos, Butte, and Wyandotte Creek Subbasins and from the foothill area (143 TAF/year); and stream losses (28 TAF/year). Outflows from the groundwater system include groundwater pumping (216 TAF/year); subsurface outflows to the Butte, Los Molinos, and

Wyandotte Creek Subbasins and to the foothill area (72 TAF/year); western boundary net outflows (73 TAF/year); and stream gains from groundwater (1 TAF/year).

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.

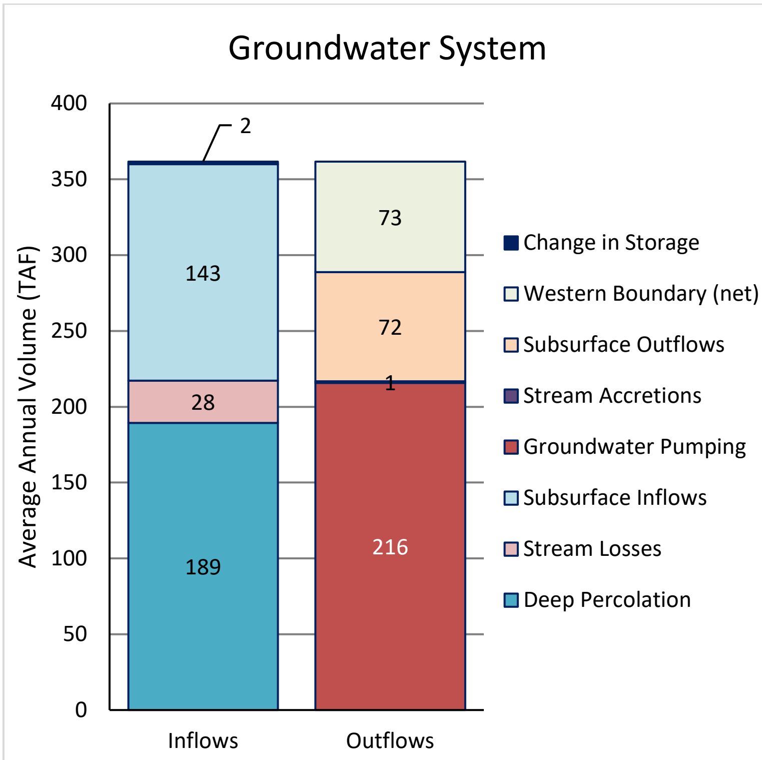


Figure 2-38: Average Annual Future Conditions without Climate Change Groundwater System Water Budget

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 MAF/year. Average annual values were presented previously in Table 2-7 and are shown graphically in Figure 2-39.

Primary inflows to the land and surface water system include surface water inflows (631 TAF/year), precipitation (438 TAF/year), and groundwater pumping (226 TAF/year), with estimated stream gains from groundwater (i.e., accretions) of approximately one TAF/year. 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/year), evapotranspiration (358 TAF/year), deep percolation (194 TAF/year), and stream losses (also referred to as seepage) (28 TAF/year). 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.

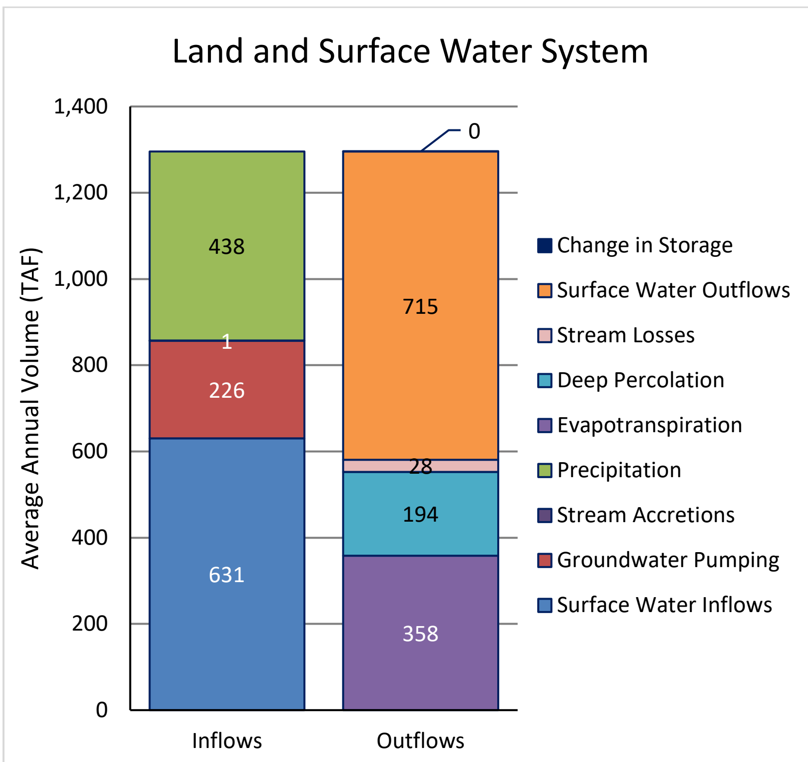


Figure 2-39: Average Annual Future Conditions with 2030 Climate Change Land and Surface Water System Water Budget

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 two TAF/year during the 50-year simulation period. Average annual values were presented previously in Table 2-8 and are shown graphically in Figure 2-40.

Inflows to the groundwater system include deep percolation (193 TAF/year); subsurface inflows from the Los Molinos, Butte, and Wyandotte Creek Subbasins and from the foothill area (145 TAF/year); and stream losses (28 TAF/year). Outflows from the groundwater system include groundwater pumping (226 TAF/year); subsurface outflows to the Butte, Los Molinos, and

Wyandotte Creek Subbasins and to the foothill area (71 TAF/year); western boundary net outflows (71 TAF/year); and stream gains from groundwater (one TAF/year).

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.

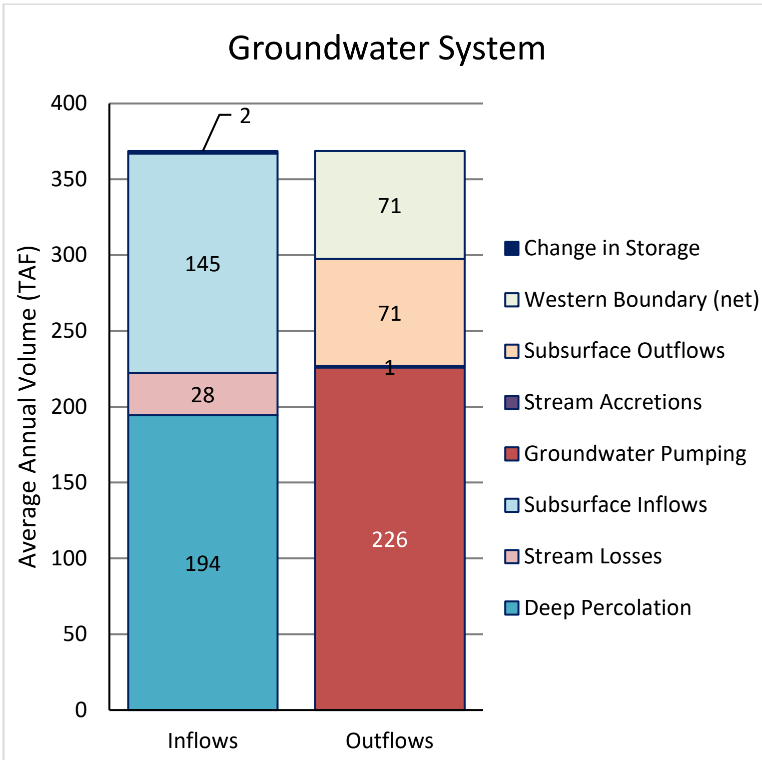


Figure 2-40: Average Annual Future Conditions with 2030 Climate Change Groundwater System Water Budget

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 MAF/year. Average annual values were presented previously in Table 2-7 and are shown graphically in Figure 2-41.

Primary inflows to the land and surface water system include surface water inflows (652 TAF/year), precipitation (453 TAF/year), and groundwater pumping (238 TAF/year), with estimated stream gains from groundwater (i.e., accretions) of approximately one TAF/year. 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/year), evapotranspiration (371 TAF/year), deep percolation (197 TAF/year), and stream losses (also referred to as seepage) (27 TAF/year). 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.

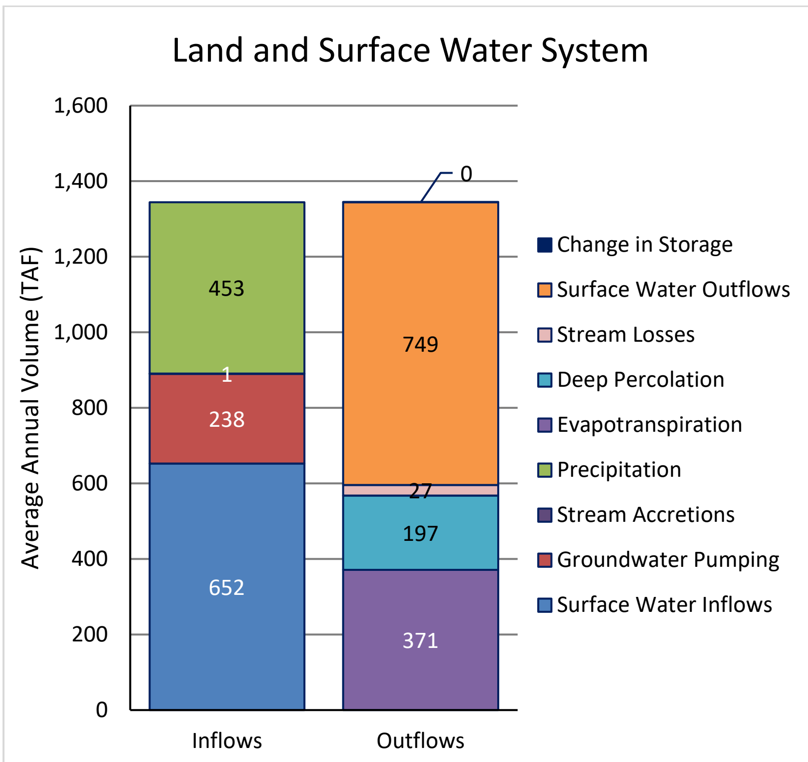


Figure 2-41: Average Annual Future Conditions with 2070 Climate Change Land and Surface Water System Water Budget

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 three TAF/year during the 50-year simulation period. Average annual values were presented previously in Table 2-8 and are shown graphically in Figure 2-42.

Inflows to the groundwater system include deep percolation (197 TAF/year); subsurface inflows from the Los Molinos, Butte, and Wyandotte Creek Subbasins and from the foothill area (145 TAF/year); and stream losses (27 TAF/year). Outflows from the groundwater system include groundwater pumping (238 TAF/year); subsurface outflows to the Butte, Los Molinos, and

Wyandotte Creek Subbasins and to the foothill area (68 TAF/year); western boundary net outflows (66 TAF/year); and stream gains from groundwater (one TAF/year).

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.

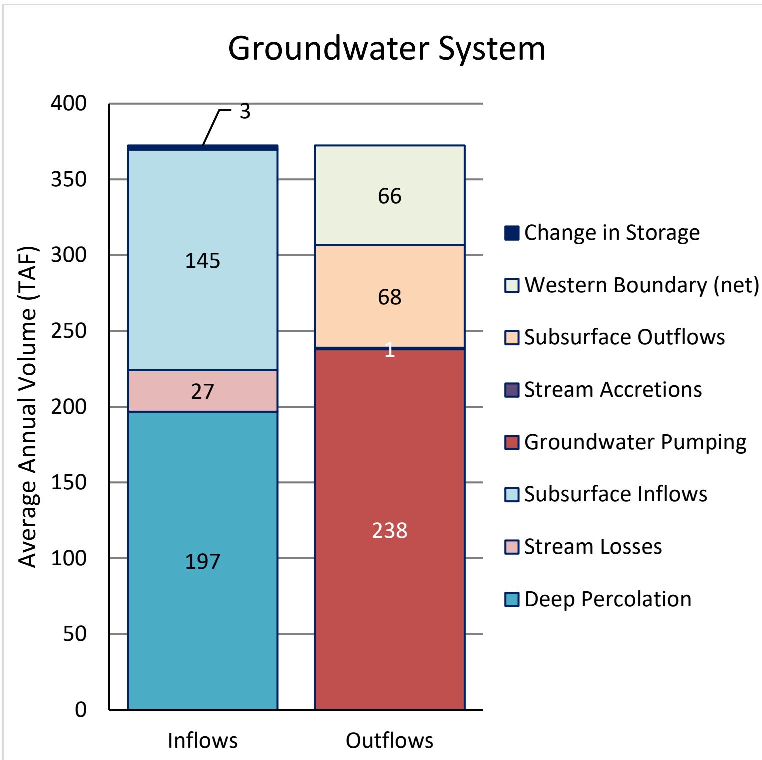
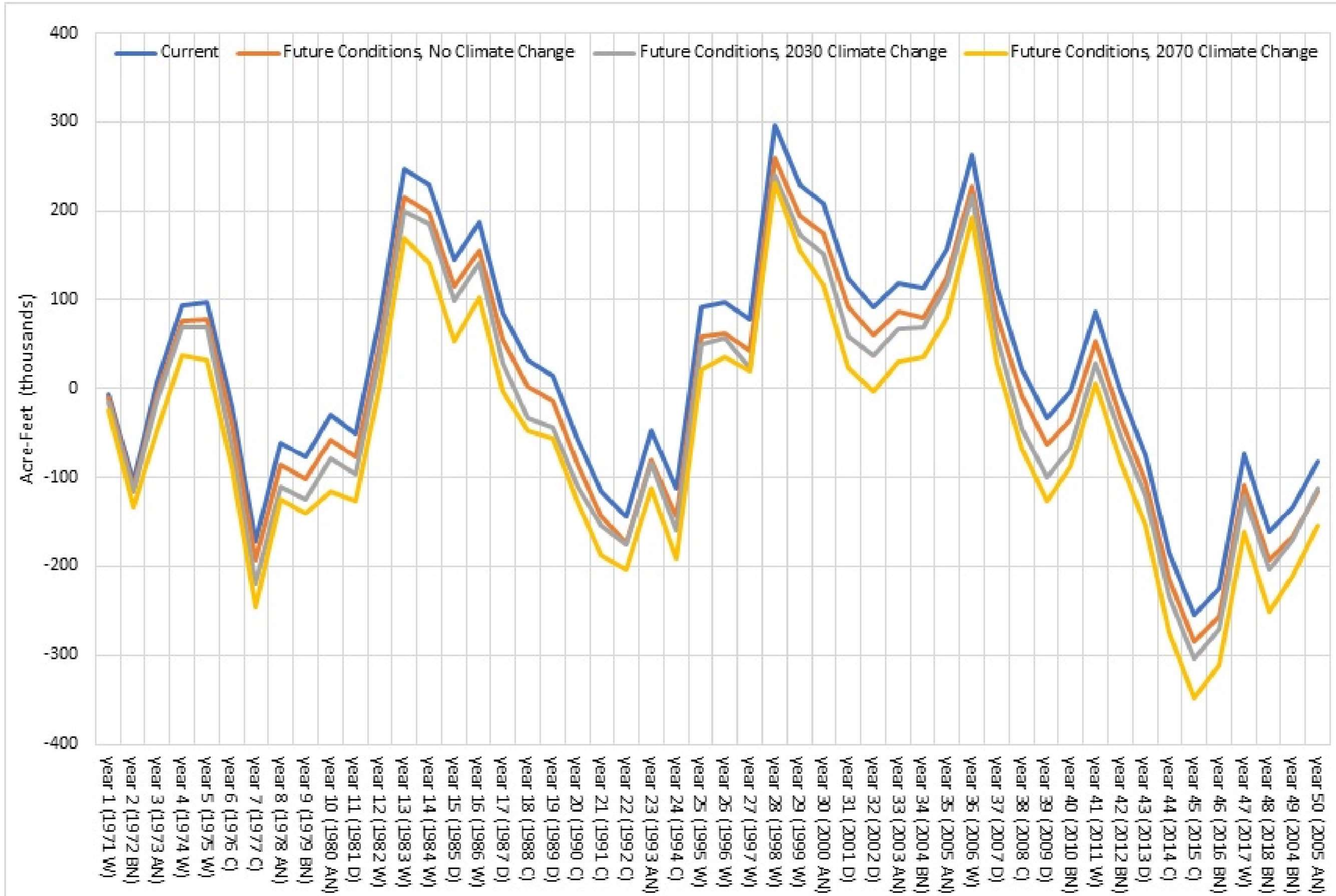


Figure 2-42: Average Annual Future Conditions with 2070 Climate Change Groundwater System Water Budget

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 2-43). 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).



Cumulative Change in Groundwater Storage for Current and Future Conditions Baseline Scenarios
Vina Groundwater Subbasin GSP

Project No.: SAC282

December 2021

Figure **2-43**

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 Vina Subbasin.

2.3.5 Water Budget Uncertainty

Uncertainty refers to a lack of understanding of the basin setting that significantly affects an agency's ability to develop SMC 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 SMC 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.

2.3.6 Sustainable Yield Estimate

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 (SIs). Historical water budget estimates indicate an average annual decrease in storage of 20,000 AFY for the period from 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.

For development of SMCs, as discussed in Section 3, the MO was developed to address the long-term trend of the "peaks and valleys" of the short-term cycles and stop the long-term decline in groundwater levels during dry years. Using this method, the average depth below the MO at compliance points (see Section 3 for discussion of representative monitoring sites [RMS]) if no actions are taken before the end of the implementation period in 2042 is about 21 feet. Using this value, a sustainable yield can be estimated based on the reduction in pumping needed to stop the observed decline in water levels across the Vina Subbasin. This value is sensitive to the specific storage. Specific storage is the parameter that translates the change in groundwater elevation to an associated change in volume (i.e., change in storage).

As discussed in Section 2.1.8.3, the average specific storage value used in the BBGM is 0.04 (unitless). Specific storage values estimated from pumping tests by Brown and Caldwell (2013) ranged from 0.001 to 0.00004. Table 2-10 provides estimates of sustainable yield to maintain the MO in 2042 using this range of storativity values and the average decline in water levels across the Vina Subbasin in 2042. The groundwater pumping rate for the historical scenario is used for the calculation of sustainable yield.

Table 2-10: Estimated Sustainable Yield Using Average Depth Below Measurable Objective in 2042 and Range of Storativity Values

Feet Below MO in 2042	Specific Storage	Area of Subbasin (square miles)	Volume Storage Below MO in 2042 (acre-feet)	Average Change in Storage Between 2030 and 2042 (AFY)	Groundwater Pumping[1] (AFY)	Estimated Sustainable Yield (AFY)
21	0.1	289	388,410	32,368	243,500	211,132
21	0.04	289	38,841	12,840	243,500	230,660
21	0.001	289	3,884	324	243,500	243,176
21	0.0001	289	388	32	243,500	243,468
21	0.00001	289	39	3	243,500	243,497

Note:
1. Historical scenario pumping.

As seen in the above discussions (Section 2.3.4), the calculated decrease in storage value is highly sensitive to the time period used to assess the annual average and the specific storage value used for calculations. The range of values for the decrease in storage based on the variations for time period is 1,700 to 19,600 AFY and for specific storage is 3 to 32,368 AFY as discussed above.

Considering these variations, this GSP defines the estimate of the sustainable yield as 233,500 AFY based on average historical groundwater pumping of 243,500 AFY and a decrease in storage of 10,000 AFY. The historical groundwater pumping value is based on the average annual groundwater pumping that occurred between 2000 and 2018 as discussed in Section 2.3.4 and summarized in Table 2-8. The decrease in storage value of 10,000 AFY was selected based on the range of values shown in Table 2-10 and calculated for the Water budget as shown on Table 2-8.

2.3.7 Opportunities for Improvement to the Water Budget

2.3.7.1 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.

2.3.7.2 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.

2.3.7.3 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.

2.3.7.4 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.

2.3.7.5 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.

2.3.7.6 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.