FINAL REPORT

Los Molinos Subbasin

Sustainable Groundwater Management Act

Groundwater Sustainability Plan

(Chapter 2B – Basin Setting)

January 2022

Prepared For:

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LIST OF ACRONYMS & ABBREVIATIONS

AB	Assembly Bill
bgs	Below Ground Surface
BLM	Bureau of Land Management
BOD	Board of Directors
BLM	Bureau of Land Management
CASGEM	California Statewide Groundwater Elevation Monitoring
CCR	California Code of Regulations
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CDPH	California Department of Public Health
CE	Communications and Engagement
CFS	Cubic Feet per Second
CV-SALTS	Central Valley Salinity Alternatives
CVRWQCB	Central Valley Regional Water Quality Control Board
CWC	California Water Code
dS/m	Decisiemens per Meter
DAC	Disadvantaged Community
DDW	Division of Drinking Water
DOI	Department of the Interior
DWR	California Department of Water Resources
DPR	Department of Pesticide Regulation
EC	Electrical Conductivity
ft^2/d	Square Feet Per Day

ft/d	Feet Per Day
ft/mile	Feet per Mile
ft bgs	Feet Below Ground Surface
ft msl	Feet Above Mean Sea Level
GAMA	Groundwater Ambient Monitoring and Assessment Program
GDE	Groundwater Dependent Ecosystem
GMP	Groundwater Management Plan
GPS	Global Positioning Systems
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
HCM	Hydrogeologic Conceptual Model
iGDE	Indicators of Groundwater Dependent Ecosystems
ILRP	Irrigated Lands Regulatory Program
InSAR	Interferometric Synthetic Aperture Radar
IRWMP	Integrated Regional Water Management Plan
JPA	Joint Powers Authority
LLNL	Lawrence Livermore National Laboratory
LSCE	Luhdorff & Scalmanini, Consulting Engineers
MCL	Maximum Contaminant Level
mg/L	Milligrams per Liter
MO	Measurable Objective
MOA	Memorandum of Agreement
MT	Minimum Threshold
MTJ	Mendocino Triple Junction
MWELO	Model Water Efficient Landscape Ordinance
NCCAG	Natural Communities Commonly Associated with Groundwater
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
SAGBI	Soil Agricultural Groundwater Banking Index
SB	Senate Bill
SGMA	Sustainable Groundwater Management Act

SVWQC	Sacramento Valley Water Quality Coalition
SWRCB	State Water Resources Control Board
TAC	Technical Advisory Committee
TDS	Total Dissolved Solids
Tehama County FCWCD	Tehama County Flood Control and Water Conservation District
TM	Technical Memorandum
USDA	United States Department of Agriculture
USBR	United States Bureau of Reclamation
USFS	United States Forest Service
USFWS	United States Fish & Wildlife Service
USGS	United States Geological Survey
UWMPA	Urban Water Management Planning Act
WDL	Water Data Library
WDR	Waste Discharge Requirements
µg/L	Micrograms per liter
µmhos/cm	Micromhos per Centimeter

SUBBASIN PLAN AREA AND BASIN SETTING (REG. § 354.8)

2.1 Description of Plan Area

2.2 Basin Setting

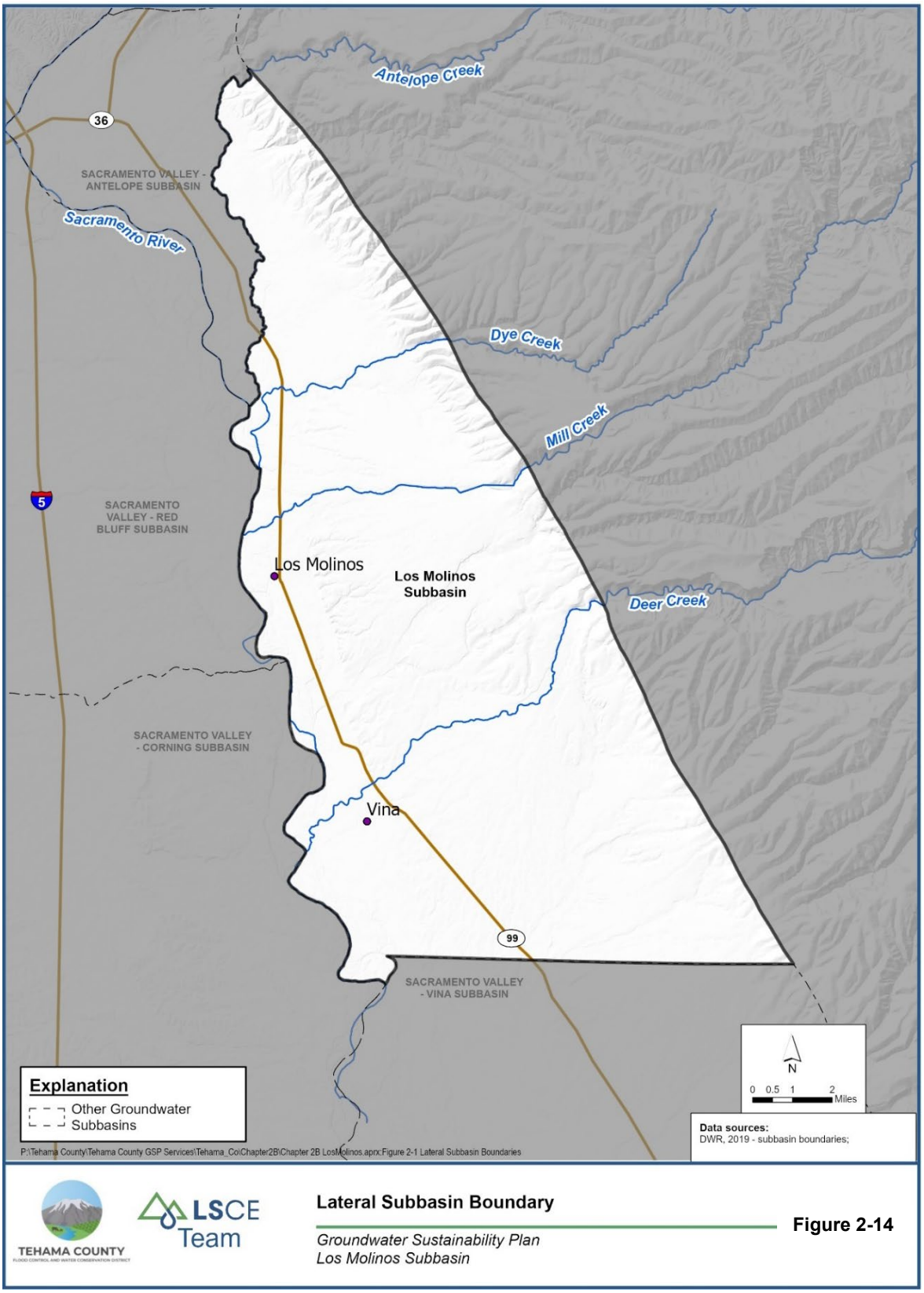
The Basin Setting section is a description of available information used as a background to develop the sustainability criteria for the Subbasin. It includes a detailed review of studies and historic groundwater conditions in the Subbasin. This information provides context about the quantity and movement of water in the Subbasin. The Basin Setting supports numerical modeling used to define groundwater budgets.

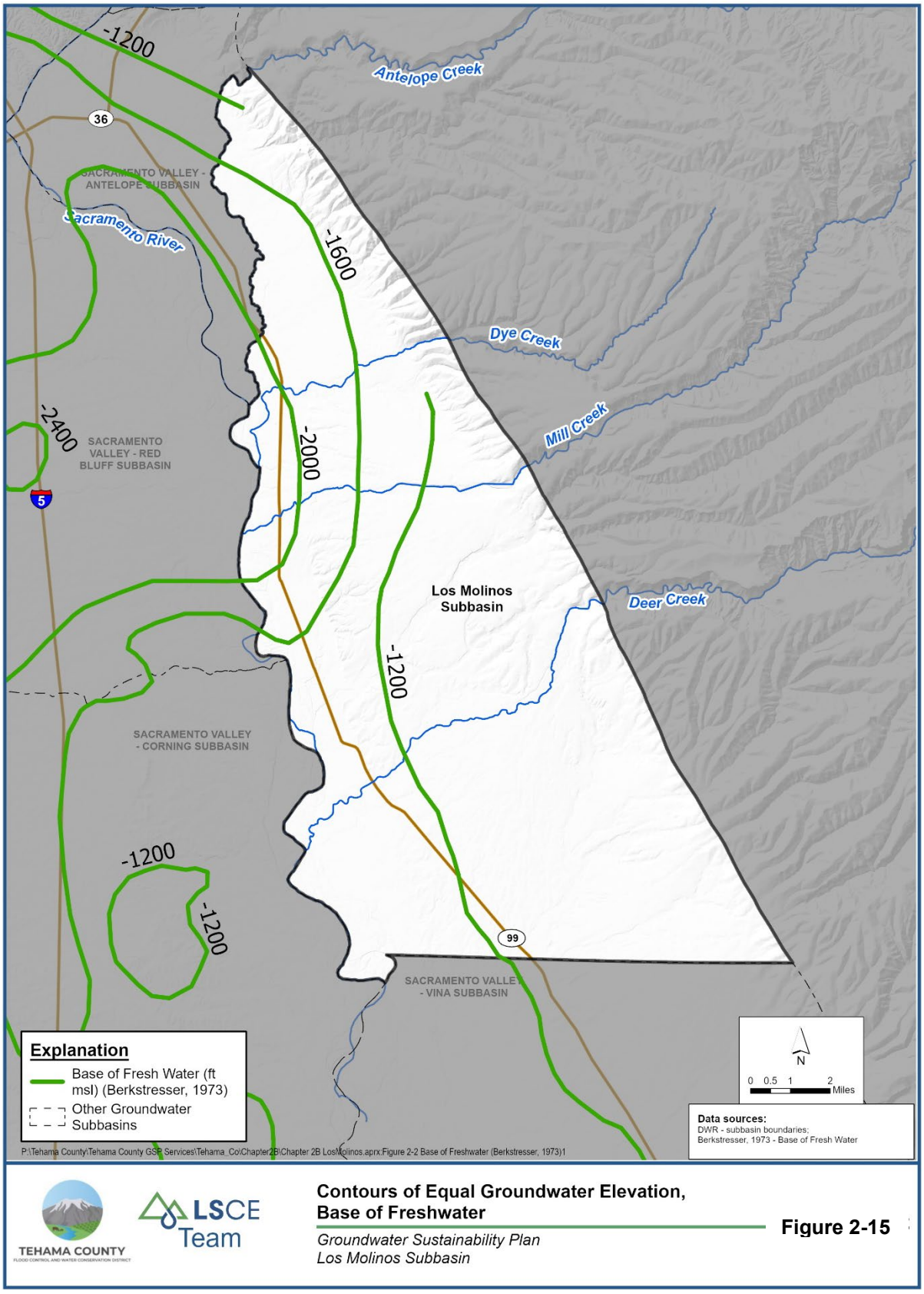
2.2.1 Hydrogeologic Conceptual Model

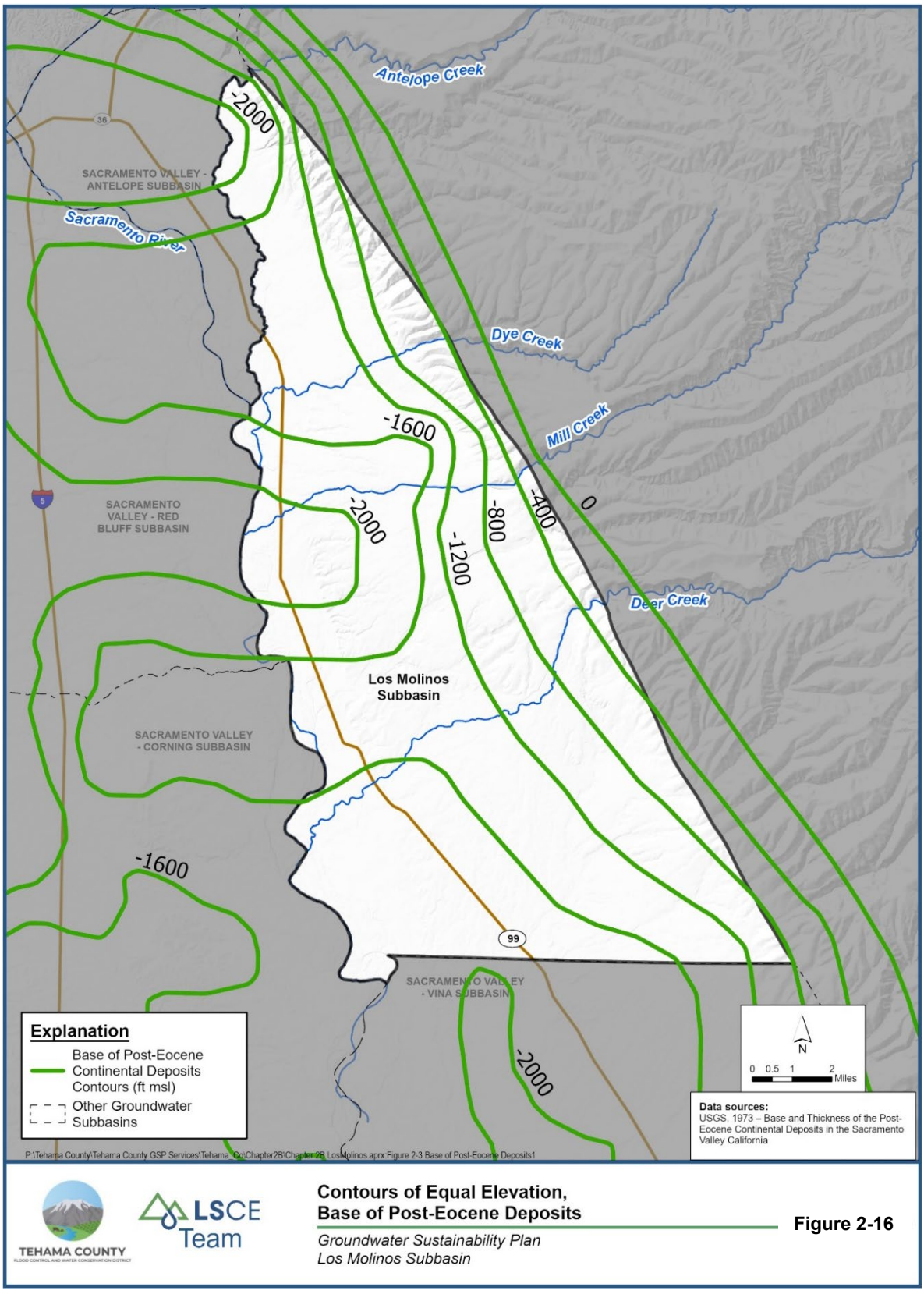
The Hydrogeologic Conceptual Model (HCM) is the framework for the movement of water in the Subbasin. An HCM is developed through the use and interpretation of historical geologic, hydrogeologic, and hydrologic data and investigations to describe the geologic features, the water sources, and movement of surface and groundwater. The HCM also describes groundwater quality and the origin and migration of chemicals of concern to beneficial users. The development of the HCM is based on the availability of data and is updated periodically as new hydrogeologic data is collected, analyzed, and interpreted. The development of an HCM begins with a review of historical reports and available data. The HCM presented herein of the Los Molinos Subbasin is the result of updating previous HCMs. The HCM is also the foundation for the numerical model used to produce the historic and current water budgets and the future projections of groundwater use. The components of the HCM including the Subbasin's lateral boundaries, topography, geologic setting, soil characteristics, principal aquifers, definable bottom of the aquifer system, surface water features, and recharge areas, are presented in the following sections.

2.2.1.1 Subbasin Boundaries

The lateral extent of the Los Molinos Subbasin is defined in the DWR Bulletin 118 and based on surface water and geologic features. Initial subbasin boundaries for California were published in 2004 with updates published in 2016 and 2018. The Los Molinos Subbasin was changed to incorporate the Dye Creek Subbasin and the portion of the Vina Subbasin within Tehama County (2018). Surface water and geologic features are used as lateral bounds as they often control divergent groundwater flow (DWR, 2004). The Subbasin is bordered to the north and northwest by the Antelope Subbasin separated by Antelope Creek. The western boundary is defined as the Sacramento River and separates the Subbasin from the Red Bluff and Corning Subbasins (DWR, 2004). The Subbasin is delineated to the east by the Chico Monocline (DWR, 2004). The Tehama County border separates the Subbasin from the Vina Subbasin to the south. The bottom of the Subbasin is defined as the base of the post-Eocene continental deposits where the transition from marine derived sediments to terrestrial derived sediments corresponds to the transition from saline/brackish groundwater to fresh groundwater. Fresh groundwater is defined as water with an electrical conductivity of less than 3,000 micromhos per centimeter (µmhos/cm) as mapped by Berkstresser (1973) (DWR, 2014). This depth is corroborated by DWR's review of geophysical logs and water quality samples (DWR, 2014). The lateral subbasin boundaries are presented in **Figure 2-14** and the bottom of the basin is discussed further in section 2.2.1.6 and presented in **Figure 2-15 and Figure 2-16**.


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
5
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Los Molinos
Los Molinos Subbasin
Deer Creek
SACRAMENTO VALLEY - CORNING SUBBASIN
Vina
99
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR, 2019 - subbasin boundaries;
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B LosMolinos.aprx:Figure 2-1 Lateral Subbasin Boundaries
TEHAMA COUNTY
LSCE Team
Lateral Subbasin Boundary
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-14


-1200
Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
-1600
Dye Creek
-2400
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
-2000
Mill Creek
5
Los Molinos Subbasin
Deer Creek
-1200
SACRAMENTO VALLEY - CORNING SUBBASIN
-1200
-1200
99
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
Base of Fresh Water (ft msl) (Berkstresser, 1973)
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR - subbasin boundaries;
Berkstresser, 1973 - Base of Fresh Water
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B Los Molinos.aprx:Figure 2-2 Base of Freshwater (Berkstresser, 1973)1
TEHAMA COUNTY
LSCE Team
Contours of Equal Groundwater Elevation, Base of Freshwater
Figure 2-15
Groundwater Sustainability Plan
Los Molinos Subbasin


Antelope Creek
-2000
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
-1600
-2000
-800
-1200
-400
0
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Deer Creek
Los Molinos Subbasin
SACRAMENTO VALLEY - CORNING SUBBASIN
-1600
99
SACRAMENTO VALLEY - VINA SUBBASIN
-2000
Explanation
Base of Post-Eocene Continental Deposits Contours (ft msl)
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
USGS, 1973 – Base and Thickness of the Post-Eocene Continental Deposits in the Sacramento Valley California
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B_LosMolinos.aprx:Figure 2-3 Base of Post-Eocene Deposits1
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Contours of Equal Elevation, Base of Post-Eocene Deposits
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-16

2.2.1.2 Topographic Information

The Los Molinos Subbasin is characterized by a relatively flat topographic setting along the eastern side of the Sacramento Valley groundwater basin. Topography is highest on the eastern edge of the Subbasin where the Chico Monocline borders the valley floor. The topographic slope is steep in the transition zone (10% - >50%) and is generally shallow throughout the rest of the Subbasin (<2%) (**Figure 2-17**). The ground surface elevation ranges from over 1,000 feet above mean sea level (ft msl) on the east side of the Subbasin to less than 500 ft msl in the majority of the Subbasin (**Figure 2-18**).

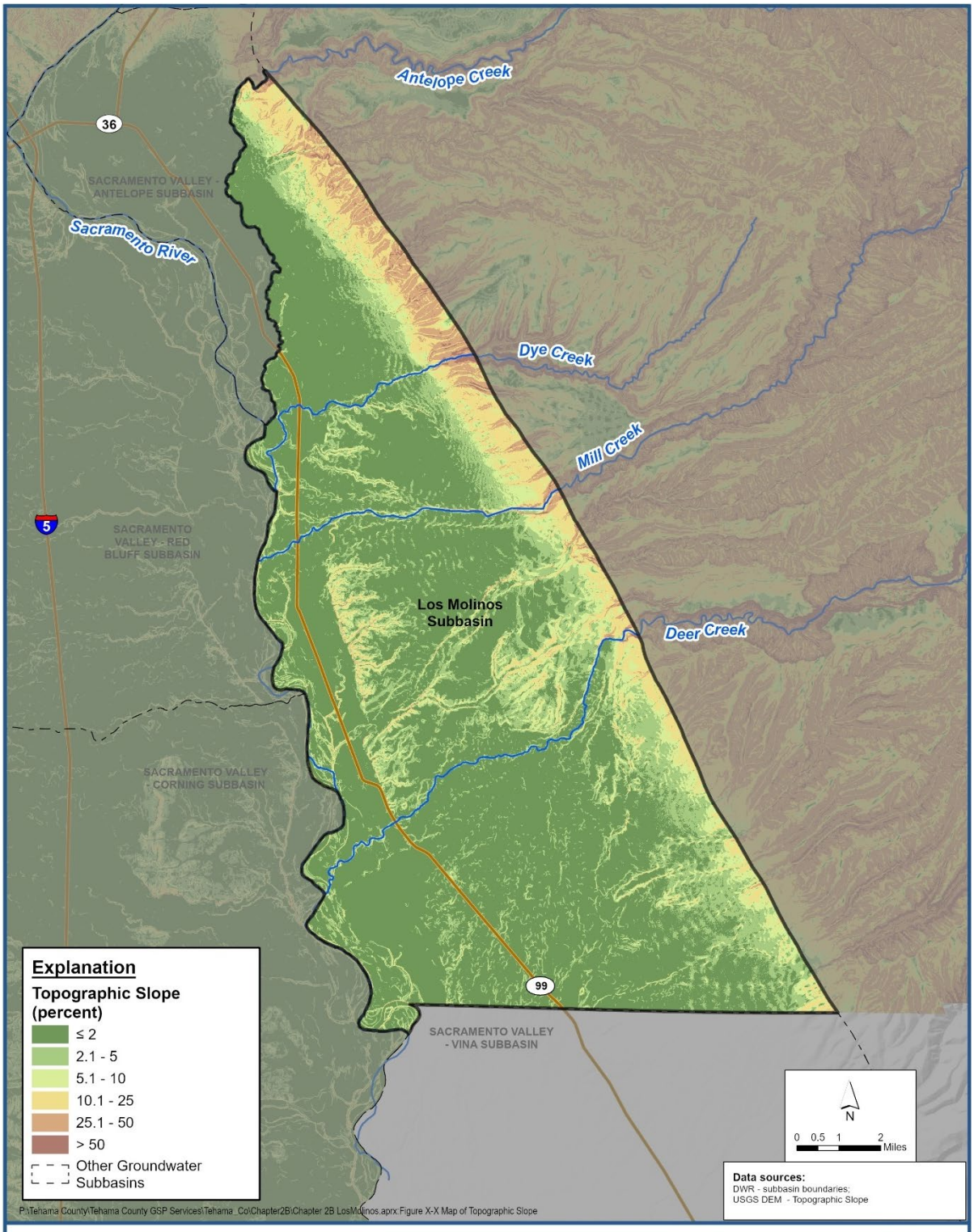
2.2.1.3 Geologic Setting

In the 1960s and 1970s, early studies of the geology in the northern Sacramento Valley were conducted for oil and gas exploration and characterization of geologic resources like groundwater. Studies by the USGS and independent researchers consolidated earlier work and conflicting nomenclature into more standardized and agreed upon definitions and characterized the water bearing potential and origin of the younger geologic units in the Sacramento Valley (Olmstead and Davis, 1961; Lydon, 1968; Ojakangas 1968). Depositional environments and geologic history of the older and deeper rocks were also characterized during the same period for oil and gas resources and academic purposes (Garrison, 1962; Bailey et al., 1970; Redwine, 1972; Dickinson and Rich, 1972; Mansfield, 1979).

In the 1980s and 1990s, further research was conducted on the older Great Valley Sequence geologic units (Ingersoll and Dickinson, 1981; Bertucci, 1983). Extensive mapping and seminal studies of the younger geologic formations were conducted by the USGS that further defined and separated the distribution and lithologic character of the geologic units in the Sacramento Valley (Marchand and Allwardt, 1981; Harwood et al., 1981; Helley and Jaworowski, 1985; Helley and Harwood, 1985; Harwood and Helley, 1987; Blake et al., 1999).

More recent studies in the 2000s and 2010s have attempted to further characterize the geologic material and contextualize the information as it relates to groundwater resources (DWR, 2004; DWR, 2008; Gonzalez, 2014). DWR conducted an extensive literature review and study to compile the most current geology and groundwater information in a 2014 report (DWR, 2014).

The geologic history of the northern Sacramento Valley, where the Subbasin is located, is dominated by a series of mountain building events leading to provenance changes in basin sedimentation. During the Mesozoic, a subduction zone created the plutonic emplacement of the Sierra Nevada. The uplift of the Sierra Nevada isolated the Pacific Ocean from its previous extent, moving the shoreline west (DWR, 2014). The uplifting mountains created a source of sediment that filled the forearc basin through erosional processes (Olmstead and Davis, 1961). On the western boundary of the forearc basin, the eastward dipping subduction resulted in accretionary forces forming the metamorphic rocks that would later make up the Franciscan Formation and Coast Range Ophiolite (DWR, 2014).



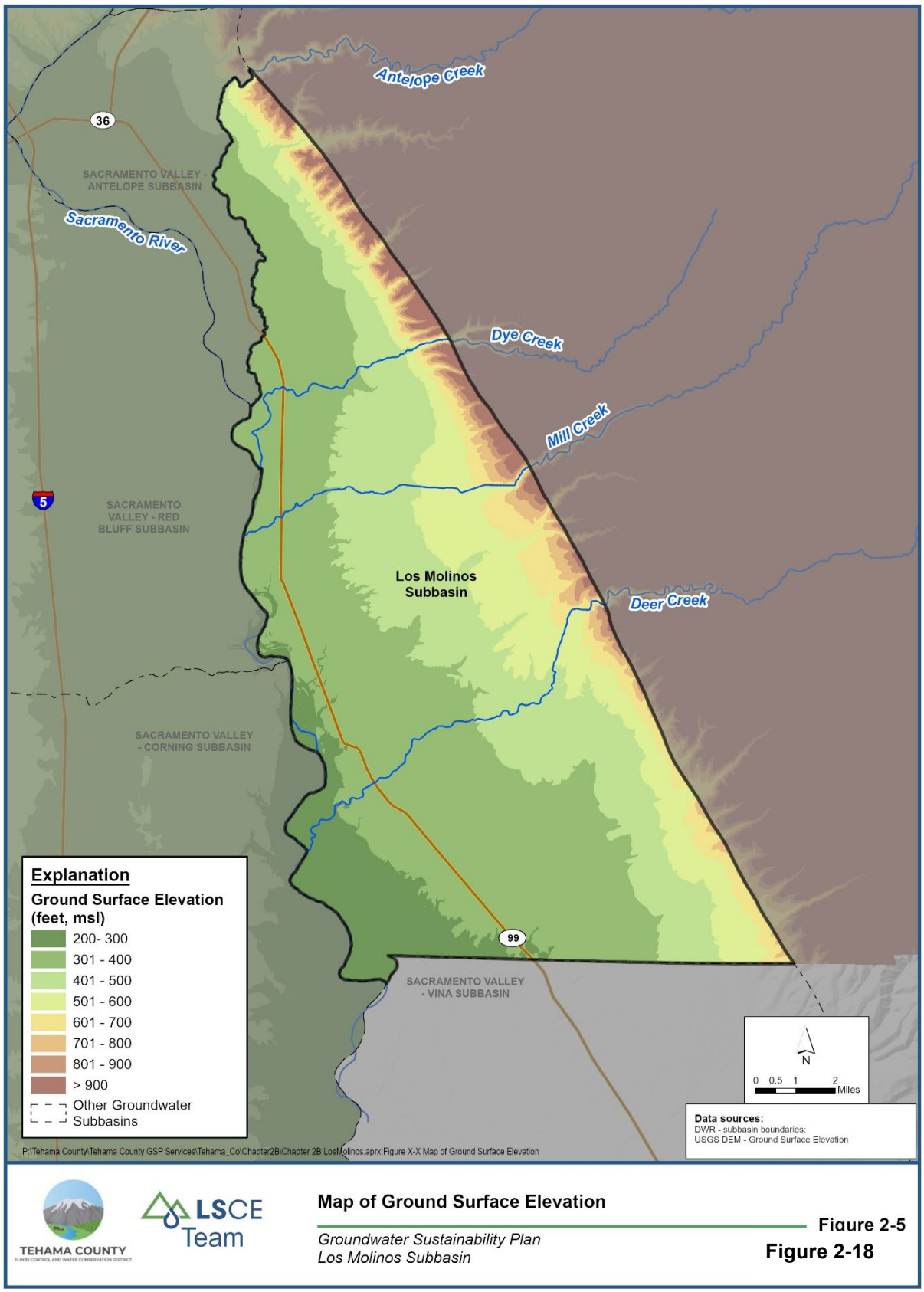
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Map of Topographic Slope

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-17


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
5
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Los Molinos Subbasin
Deer Creek
SACRAMENTO VALLEY - CORNING SUBBASIN
99
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
Ground Surface Elevation (feet, msl)
200- 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
801 - 900
> 900
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR - subbasin boundaries;
USGS DEM - Ground Surface Elevation
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B LosMolinos.aprx:Figure X-X Map of Ground Surface Elevation
TEHAMA COUNTY
LSCE Team
Map of Ground Surface Elevation
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-5
Figure 2-18

During the early part of the Cenozoic Era in the Paleogene Period, the tectonic forces that dominated during the Mesozoic were still present (DWR, 2014). These tectonic forces resulted in periods of marine regression and transgressions that carved and subsequently filled a large canyon known as the lower Princeton Submarine Valley (DWR, 2014). Marine transgressions and regressions continued throughout the Paleogene and into the Miocene while older Cascade volcanism occurred on the eastern margins of the valley (DWR, 2014).

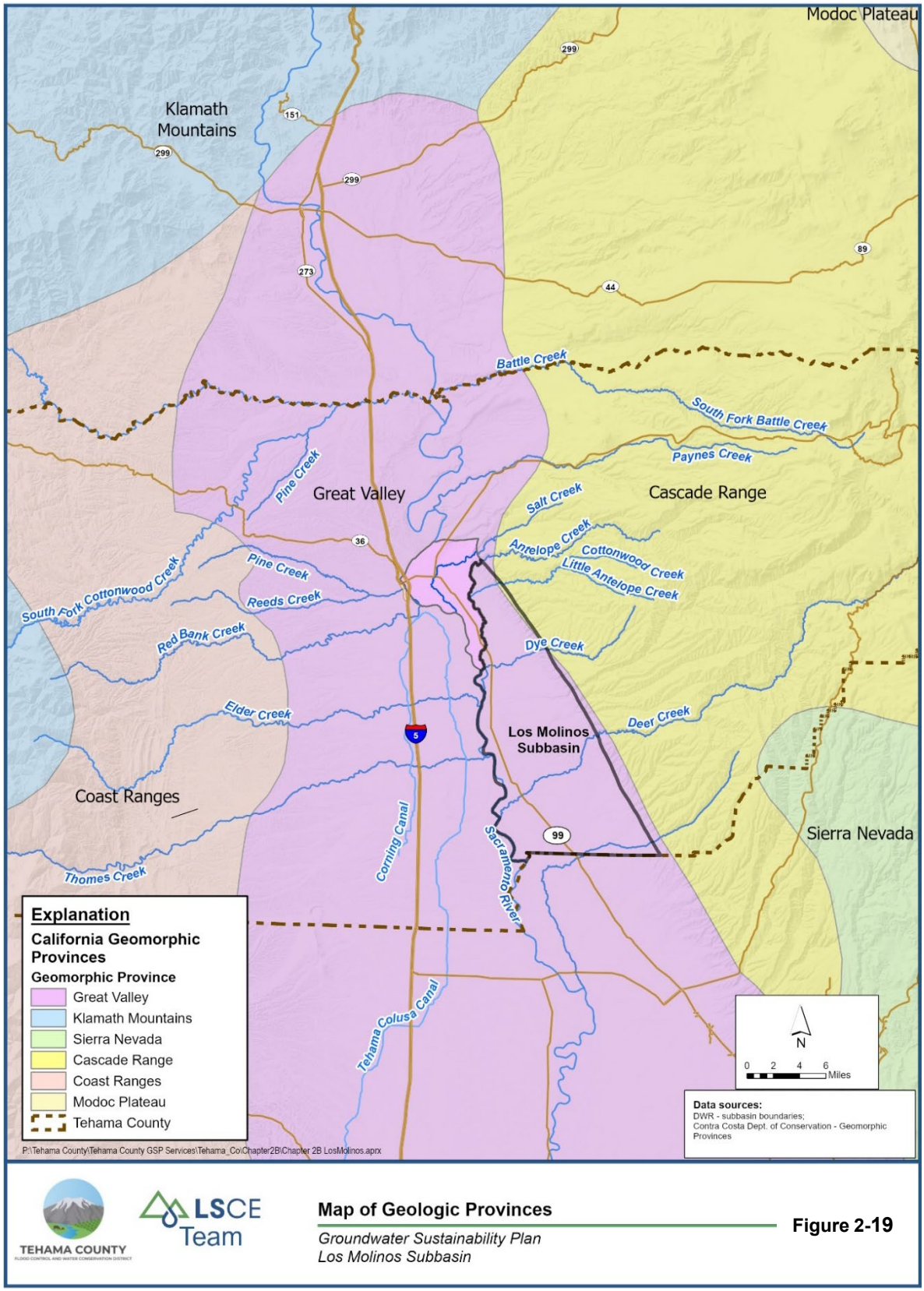
Continued sedimentation filled the valley throughout the Paleogene until a marine regression and sediment accumulation caused a transition from a marine to terrestrial depositional environment in the Neogene. During this period sedimentation sourced from the uplifting coast ranges, Klamath Mountains, and ancestral Cascades filled the basin (DWR, 2014). Throughout the Neogene epoch the tectonic regime was transitioning from subduction to transverse in a northward pattern until the present day where it is expressed as the Mendocino Triple Junction (MTJ). Tectonic forces associated with the northward migration of the MTJ resulted in geologic structures in the valley like the Chico Monocline, Red Bluff and Corning Faults, and the Los Molinos Syncline (DWR, 2014).

2.2.1.3.1 *Regional Geology*

The terrane surrounding the Subbasin is the source for the sediments that are deposited in and comprise the Sacramento Valley. It is important to understand the surrounding geologic provinces to properly characterize and contextualize the stratigraphy of the Subbasin. The northern portion of the Sacramento Valley where the Subbasin is located is bordered on the east by the Cascade Range Province and the Klamath and Coast Range Geologic Provinces are to the west (**Figure 2-19**).

Klamath Geologic Province

The mountains to the northwest of the Subbasin make up the Klamath Geologic Province. The mountain range is steep with peaks of approximately 6,000 ft to 8,000 ft. The Klamath Mountains are comprised of accreted terranes consisting of oceanic crust and accreted island arcs (Blake et al., 1999). To the northwest of the Subbasin, the province consists of Jurassic and older metamorphic-plutonic basement overlain by the east to southeast dipping Great Valley Sequence (Blake et al., 1999). Very few streams and tributaries drain the Klamath Geologic Province in the vicinity of the Subbasin.



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Map of Geologic Provinces

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-19

Coast Range Geologic Province

West of the Sacramento Valley and the Subbasin lies the northern portion of the Coast Range Geologic Province. The northern Coast Range Geologic Province in the vicinity of the Subbasin is steeply sloped with peaks around 5,700 ft.

The mountains here form the boundary between the northern Sacramento Valley and the California Coast. Major creeks that feed the Sacramento River drain this area of the Coast Ranges.

The rocks exposed in the western area of the Coast Range Province are composed of metamorphosed deep sea marine sedimentary rocks (Franciscan Complex). The Franciscan rocks are subdivided into two separate terranes, the Pickett Peak terrane and the Yolla Bolly terrane, which are further divided into sub-groups separated by thrust faults (Blake, 1999). The Franciscan Complex is separated from Jurassic and Cretaceous sedimentary rocks of the Sacramento Valley western foothills by the Coast Range Fault.

The recent and Quaternary history of the basin is similar to present day conditions. The MTJ continued its migration north to its present location causing flexural structures to form like the Inks Creek Fold system (DWR, 2014). Sedimentation continues to occur along stream channels that feed the Sacramento River and is sourced from the surrounding terrane and reworking of emplaced sediment.

Sacramento Valley western foothills

Along the west side of the Sacramento Valley are the foothills of the Coast Ranges and the Klamath Mountains. These foothills form a transition from the steeply sloped peaks of the Coast Ranges to the shallower slopes of the Sacramento Valley. Many streams drain the western foothills and feed the streams and channels in the Sacramento Valley.

The Jurassic and Cretaceous rocks of the Great Valley sequence that are exposed in the western portion of the province consist of marine sourced sedimentary rocks (DWR, 2014). These deposits are exposed due to folding and tilting and form the west limb of a structural trough (DWR, 2014). In the northwest of the province the outcrops are in depositional contact with the Coast Range Ophiolite and in the southwest they are in fault contact (Blake, 1999). In the most northern areas of the western foothills the Great Valley Sequence is in contact with the Klamath Mountains (Blake, 1999). The marine origin of the Great Valley sequence causes the groundwater contained therein to be saline and brackish (connate water).

Cascade Range Province

The Cascade Range Province immediately borders the Subbasin to the east. The Cascade Range is a series of andesitic and basaltic-andesite volcanic cones that extend from Lassen Peak in the south through Washington and Oregon in the north (USGS, 2002; Clynne and Muffler, 2010). The ancestral southernmost volcano of the Cascade Range, Mt. Yana, was the principal source of sediment for the Tuscan Formation (Lydon, 1968). The Cascade Range is an active volcanic arc that is driven by the eastward subduction off the coast of Washington, Oregon, and Northern California. Eastern outcrops of the Great Valley Sequence can be seen in the Cascade Range Province in contact with the overlying younger volcanic deposits. Streams and rivers drain the Cascade Range in the vicinity of the Subbasin, feeding the Sacramento River and transporting sediment to the Sacramento Valley Groundwater Basin.

Great Valley Province (Sacramento Valley Province)

The Great Valley Province encompasses the entire central valley of California. The northern region of the Great Valley Province where the Subbasin is located is referred to as the Sacramento Valley Province. The Sacramento Valley Province (Great Valley Province on **Figure 2-19**) is relatively flat and gently slopes on either side toward the south draining Sacramento River. Stream channels, flood plains, and natural levees dominate the interior of the province which is bordered by the Coast Ranges to the west and the foothills of the Cascades to the east. The underlying sediments are dominated by the freshwater bearing Tehama Formation in the west and the Tuscan Formation in the east (Blake et al., 1999).

The alluvial plains of the western side of the province were formed by the ancestral Sacramento River and its tributaries. The streams deposited large amounts of sediment sourced from the uplifting Coast Range and to a lesser extent, the Klamath Mountains, during the Pliocene (Blake et al., 1999). These Pliocene sediments were later cut and filled by younger streams and tributaries (Blake et al., 1999). Outcrops of these younger sediments occupy currently active streams and tributaries (Blake et al., 1999).

The topography on the east side of the Province is similar to that of the west. It has steeply sloping drainages that shallow into alluvial fans in the vicinity of the Sacramento River. The major difference between the west and the east side is the provenance of the Pliocene sediments. The Pliocene sediments of the east side were sourced from the Cascade Range (DWR, 2014).

2.2.1.3.2 *Geologic Formations*

Geologic formations were mapped by Helley and Harwood (1985) and digitized by DWR (2014). The digitized maps were modified and are presented as **Figure 2-20** and **Figure 2-20B**. Geologic Cross sections were constructed using available data, locations of cross sections are presented as **Figure 2-21** and **Figure 2-21B,** and cross sections are presented as **Figure 2-22** through **Figure 2-25**. In addition, DWR cross sections (DWR, 2008; DWR, 2014) that include the Subbasin and extend several miles to the west into the Red Bluff and Corning Subbasins are presented as **Figure 2-26**, **Figure 2-27,** and **Figure 2-26B and 2-27B Combined**. A summary of stratigraphic relationships and water bearing character is presented as **Table 2-8**.

Great Valley Sequence

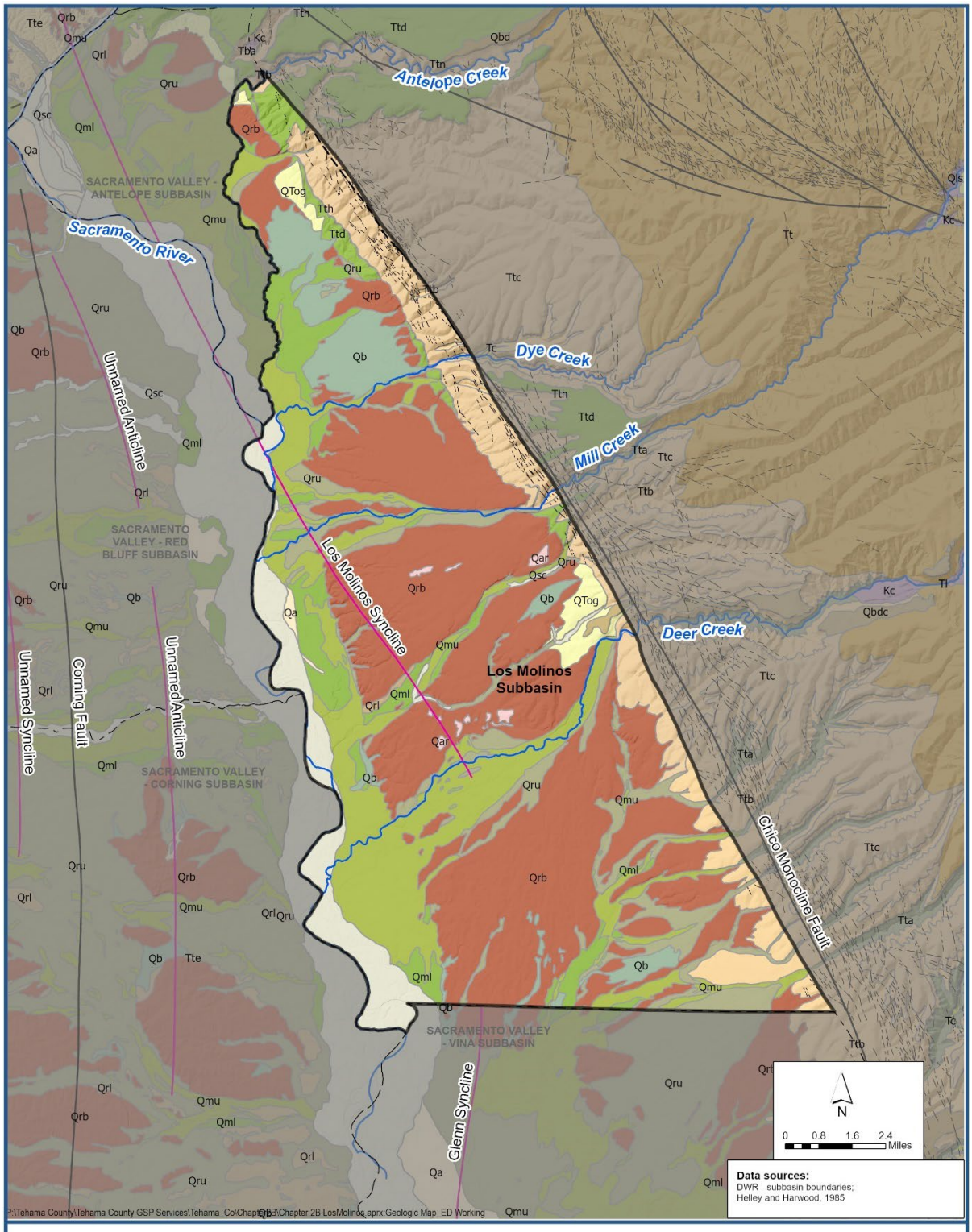
The Great Valley sequence is characterized by Late Jurassic and Cretaceous deep-marine turbidites comprised of interbedded marine sandstone, siltstone, and conglomerate (Bailey et al. 1970; Bertucci, 1983; DWR, 2014). The Great Valley sequence can be seen on the eastward edges of the northern Sacramento Valley and underly the younger deposits throughout the Subbasin. The deposits have been observed to be 45,000 feet thick (Ingersoll and Dickinson, 1981). The depth to the top of the Great Valley Sequence can be over 3,000 ft bgs (**Figure 2-26 and Figure 2-27**). The source material was the ancestral Sierran-Klamath terrane (Ojakangas, 1968; Dickinson and Rich, 1972; Mansfield, 1979; Ingersoll and Dickinson, 1981; DWR, 2014). The eroded sediments were deposited off the continental shelf as turbidity flows and submarine fans. The groundwater contained in the Great Valley sequence is primarily saline due to the marine depositional environment (DWR, 2014).

Lower Princeton Submarine Valley Fill

The lower Princeton Submarine Valley Fill is composed of Eocene aged interbedded marine shale and sandstones (DWR, 2014; Redwine, 1972). The formation is not visible at the surface but has been observed to be approximately 1,500 ft deep in the Sacramento Valley based on the interpretation of lithologic logs from oil and gas wells (Redwine, 1972). The extent of the lower Princeton Submarine Valley Fill within the Subbasin is limited to the west and thins to the east; eventually pinching out near the Chico Monocline (**Figure 2-27;** DWR, 2014). The formation was deposited under marine conditions therefore formation groundwater is saline (Redwine, 1972). The formation is unconformably overlain by the upper Princeton Valley Fill in the Subbasin (DWR, 2014).

Upper Princeton Valley Fill

The upper Princeton Valley Fill is composed of Miocene-age sandstone with frequent interbeds of pelite (mudstone) and occasional conglomerate (Redwine, 1972). The formation is not observed on the surface but extends throughout the northern Sacramento Valley from Red Bluff to the Sutter Buttes with maximum thicknesses of 1,400 ft (DWR, 2014; Redwine 1972). Similar to the lower Princeton Submarine Valley Fill, the upper Princeton Valley Fill is thickest in the west and thins to the east, eventually pinching out near the Chico Monocline (**Figure 2-27;** DWR, 2014). The formation sandstone contains interstitial brackish water and occasionally fresh water (DWR, 2014; Redwine, 1972). The formation sediments were deposited by a meandering stream, following a similar trajectory to the modern Sacramento River (Redwine 1972).



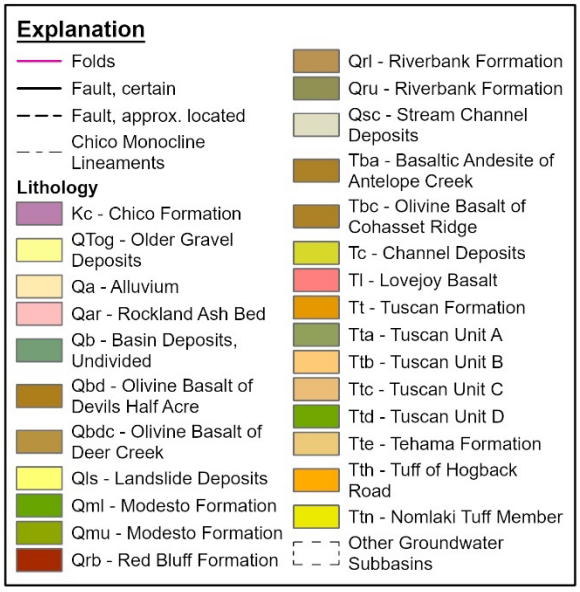
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Geologic Map with Faults

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-20



Data sources:
DWR - subbasin boundaries;
Helley and Harwood, 1985

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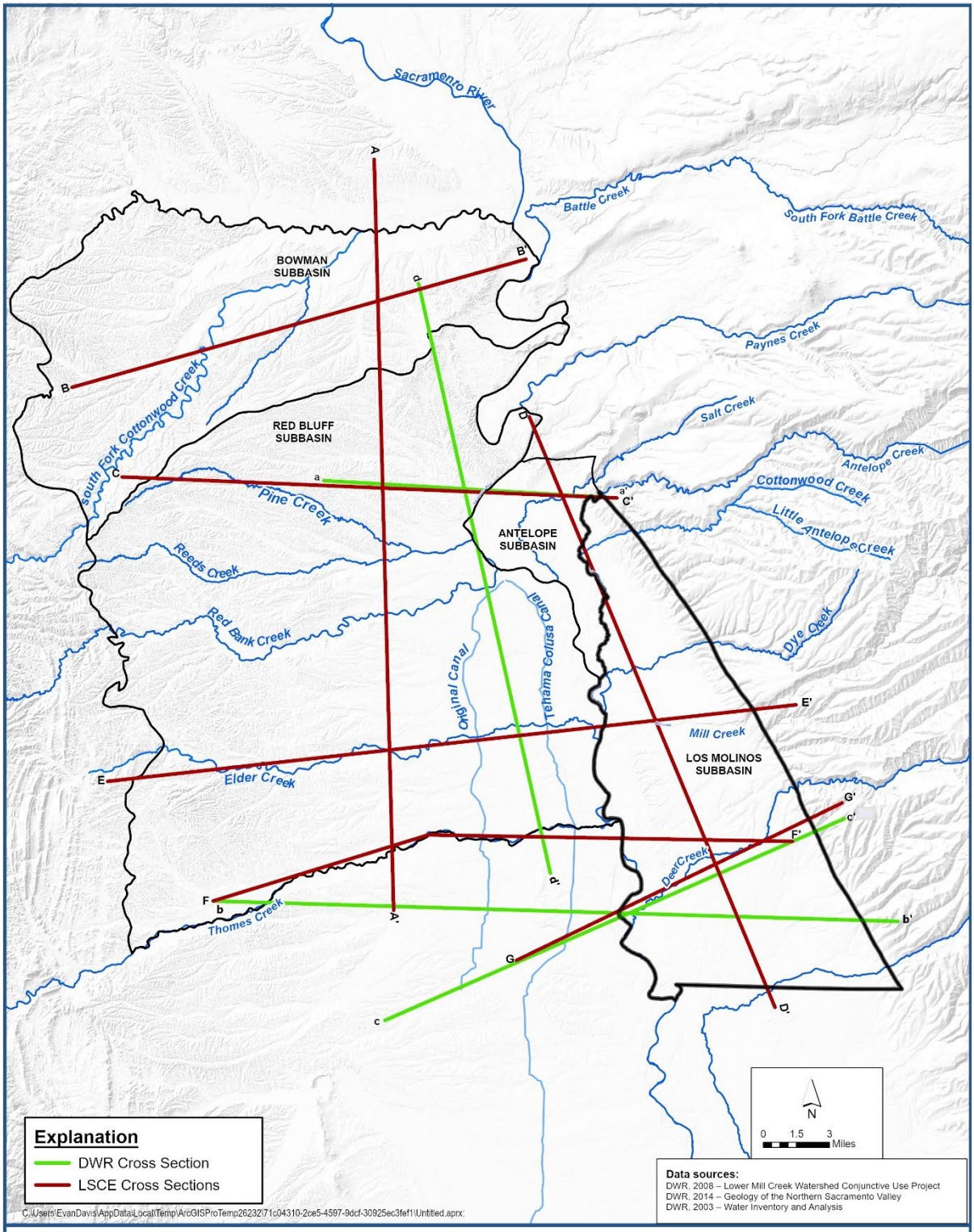
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Geologic Map with Faults

Groundwater Sustainability Plan
Los Molinos Subbasin

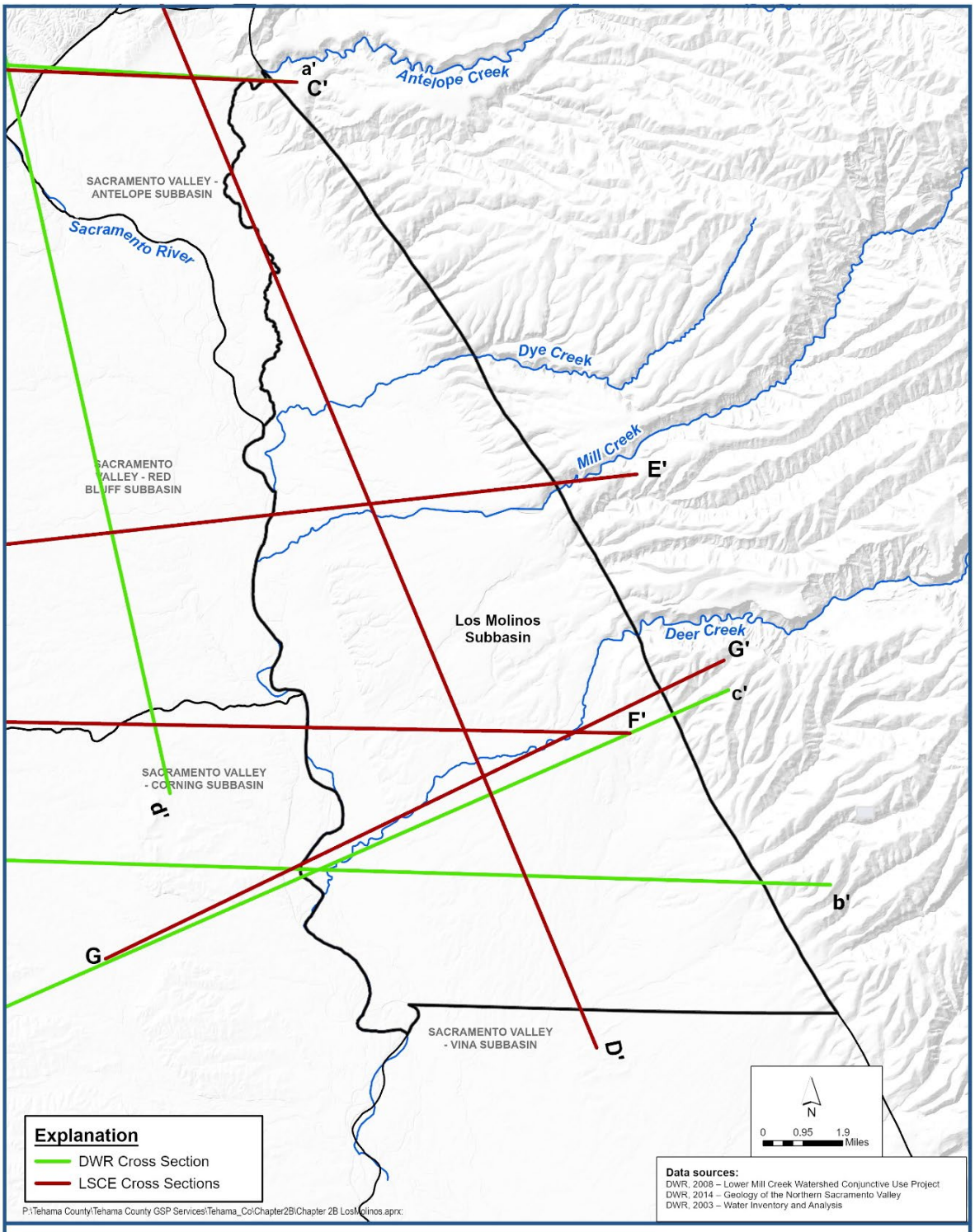
Figure 2-20B



Map of Cross Section Locations

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-21



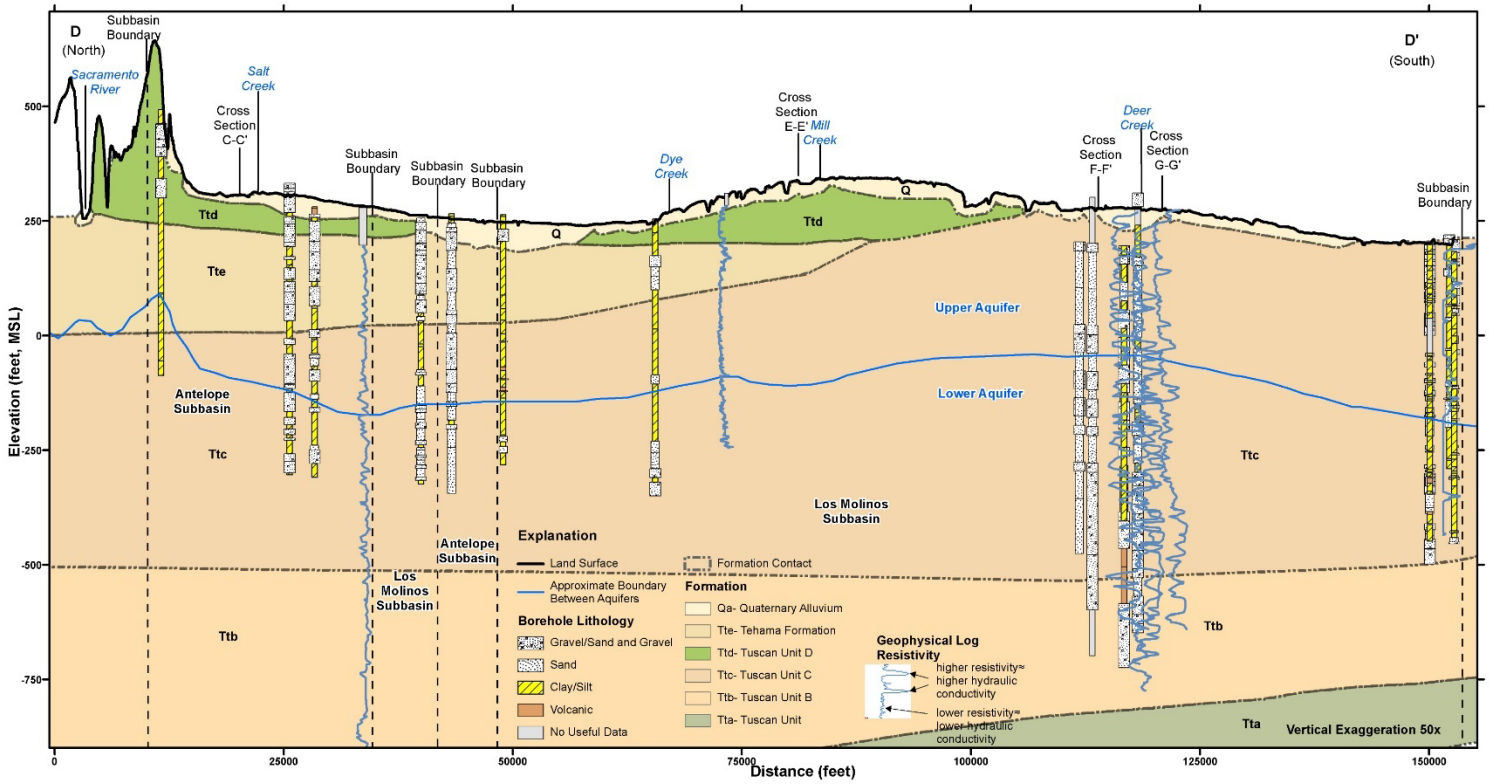
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Map of Cross Section Locations

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-21B



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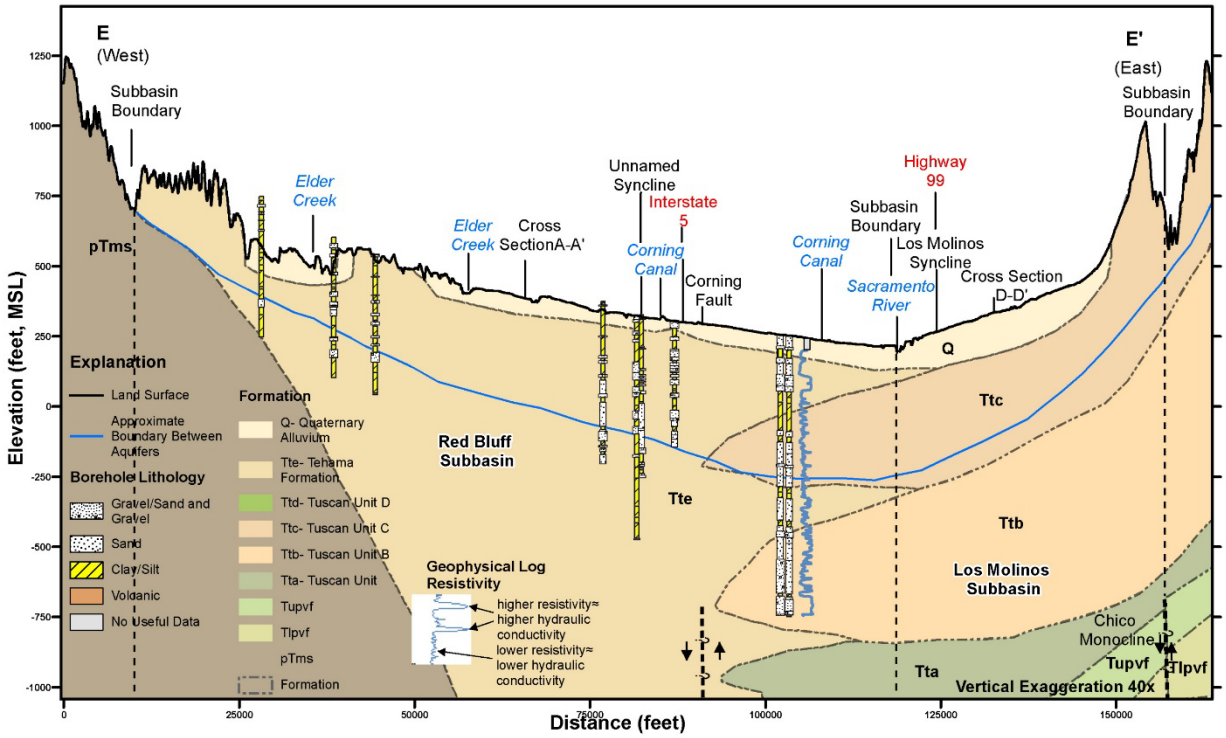
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Cross Section D-D'

Figure 2-22

Groundwater Sustainability Plan
Los Molinos Subbasin

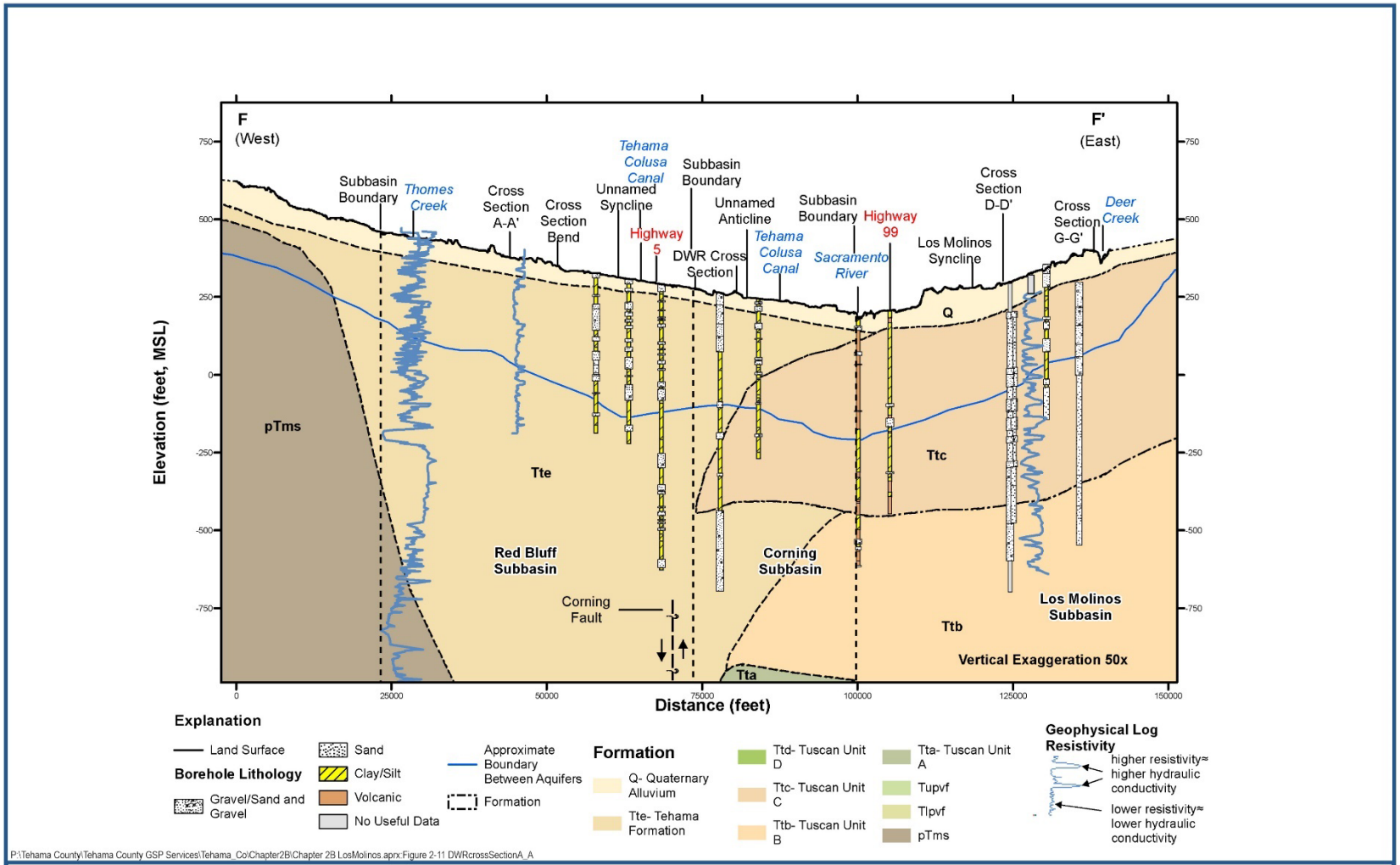


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Cross Section E-E'

Figure 2-23

Groundwater Sustainability Plan
Los Molinos Subbasin



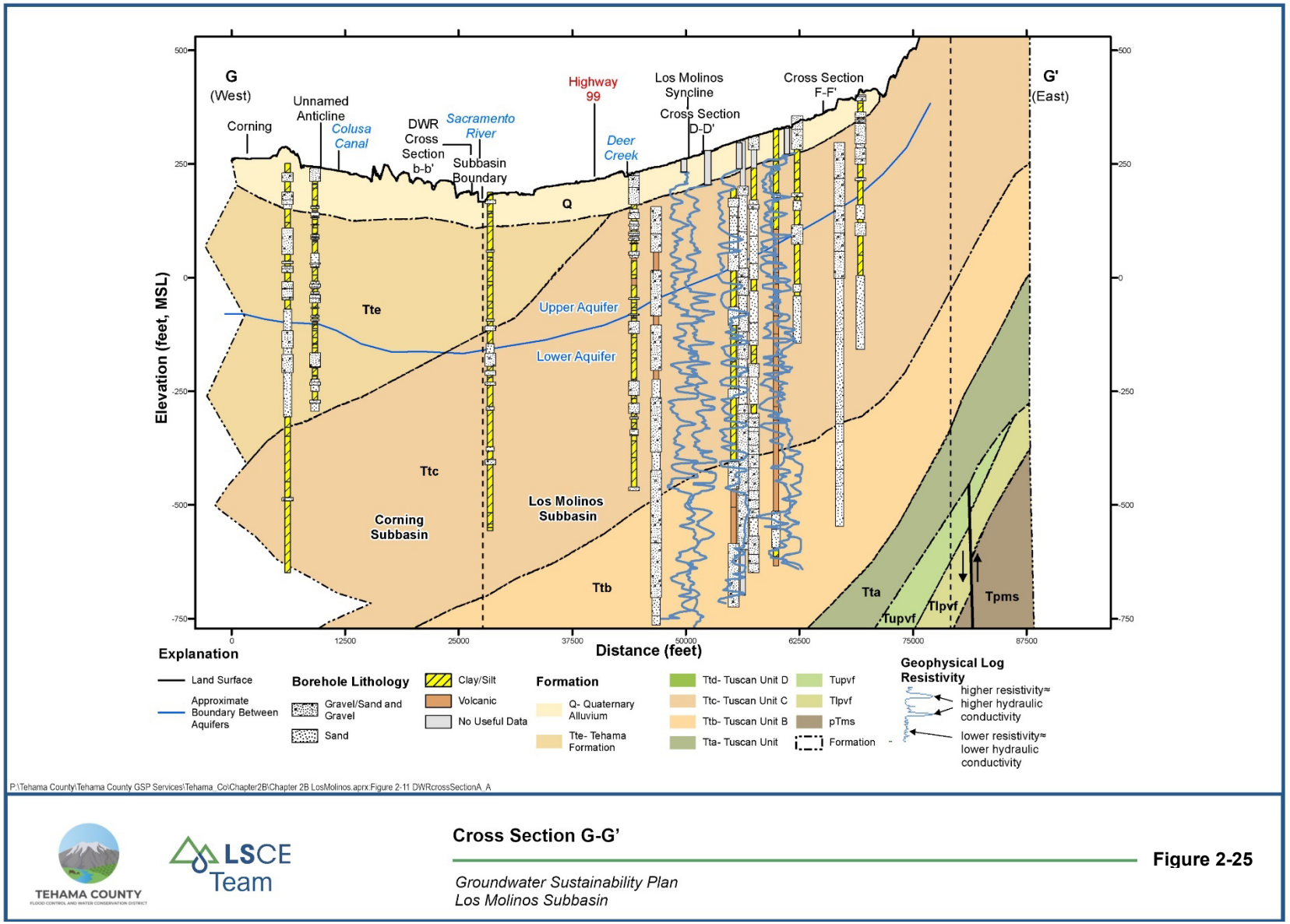
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Cross Section F-F'

Figure 2-24

Groundwater Sustainability Plan
Los Molinos Subbasin



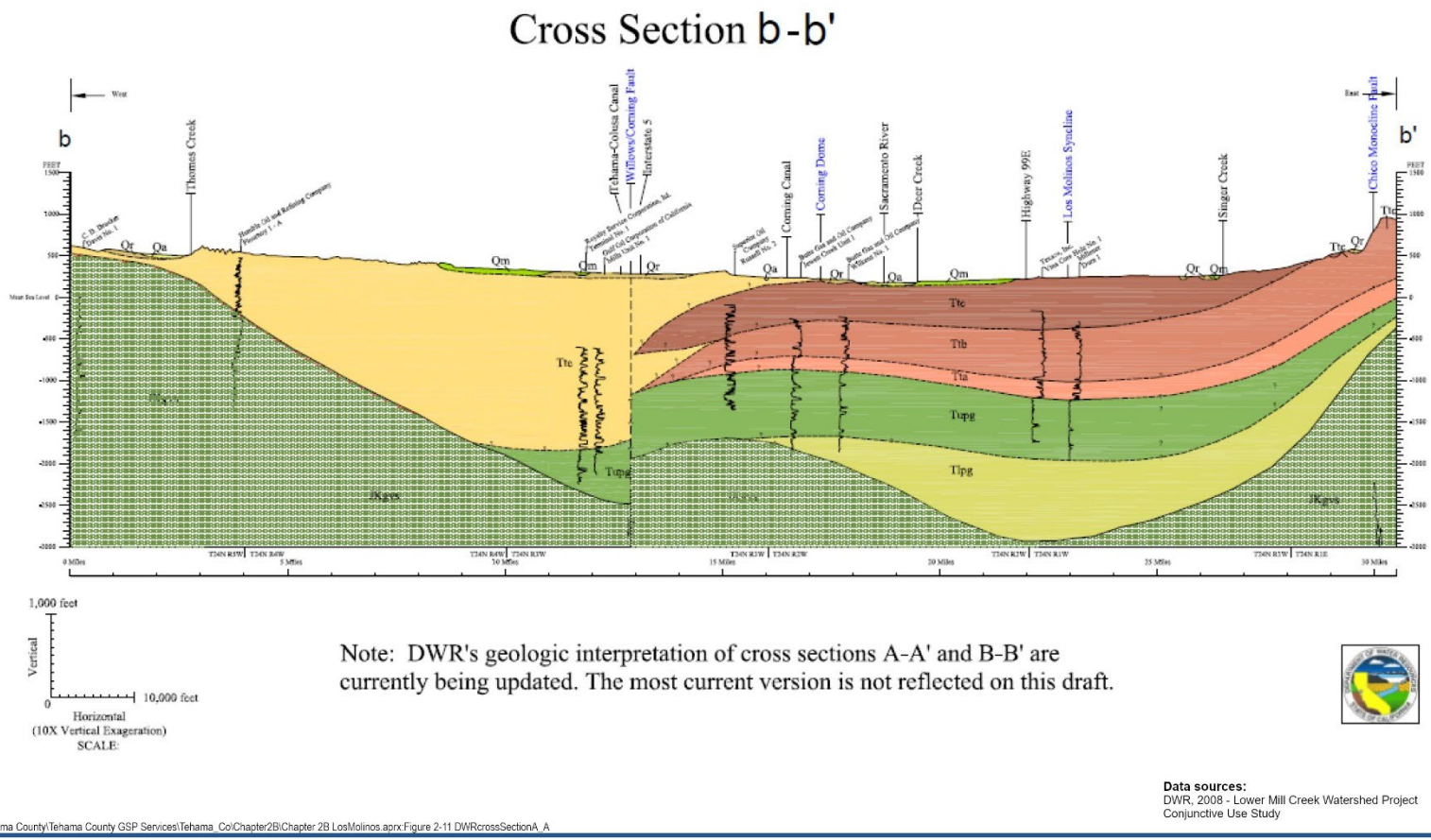
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Cross Section G-G'

Figure 2-25

Groundwater Sustainability Plan
Los Molinos Subbasin



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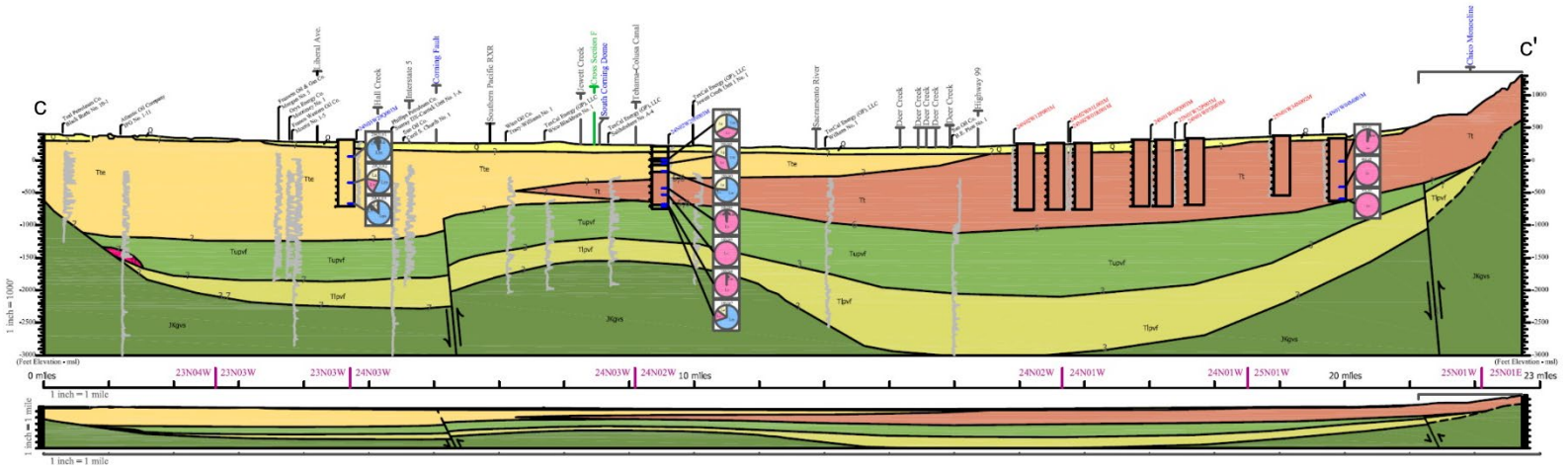
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DWR Cross Section b-b'

Figure 2-26

Groundwater Sustainability Plan
Los Molinos Subbasin

Cross Section c-c'



Data sources:
DWR, 2014 - Geology of the Northern Sacramento Valley

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DWR Cross Section c-c'

Figure 2-27

Groundwater Sustainability Plan
Los Molinos Subbasin

DESCRIPTION OF MAP UNITS

Qa	**Alluvium** (Holocene)-Includes surficial alluvium and stream channel deposits of unweathered gravel, sand and silt, maximum thickness 80 ft. *(adapted from Helley & Harwood, 1985)*.
Qb	**Basin Deposits** (Holocene)-Fine-grained silt and clay derived from adjacent mountain ranges, maximum thickness up to 200 ft. *(adapted from Helley & Harwood, 1985)*.
Qm	**Modesto Formation**, undifferentiated (Pleistocene)-Alluvial fan and terrace deposits consisting of unconsolidated weathered and unweathered gravel, sand, silt and clay; maximum thickness approximately 200 ft. *(adapted from Helley & Harwood , 1985).*
Qr	**Riverbank Formation**, undifferentiated (Pleistocene)-Alluvial fan and terrace deposits consisting of unconsolidated to semi-consolidated gravel, sand and silt; maximum thickness approximately 200 ft. *(adapted from Helley & Harwood, 1985).*
Tte	**Tehama Formation** (Plio-Pleistocene)-Includes Red Bluff Formation on west side. Pale green, gray and tan sandstone and siltstone with lenses of pebble and cobble conglomerate; maximum thickness 2,000 ft. *(adapted from Helley & Harwood, 1985).*
Ttd	**Tuscan Unit D** (Plio-Pleistocene)-Fragmental flow deposits characterized by monolithic masses containing gray hornblende and basaltic andesites and black pumice, maximum thickness 160 ft. *(adapted from Helley & Harwood, 1985).*
Ttc	**Tuscan Unit C** (Plio-Pleistocene)-Includes Red Bluff Formation on east side. Volcanic lahars with some interbedded volcanic conglomerate and sandstone, and reworked sediments; maximum thickness 600 ft. *(adapted from Helley & Harwood, 1985, DWR Bulletin 118-7, 2001, draft report).*
Ttb	**Tuscan Unit B** (Pliocene)-Layered, interbedded lahars, volcanic conglomerate, volcanic sandstone and siltstone; maximum thickness 600 ft. *(adapted from Helley and Harwood, 1985; DWR Bulletin 118-7, 2001, draft report).*
Tta	**Tuscan Unit A** (Pliocene)-Interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone containing metamorphic rock fragments; maximum thickness 400 ft. *(adapted from Helley & Harwood, 1985; DWR Bulletin 118-7 (in progress), 2001).*
Tl	**Lovejoy Basalt** (Miocene)-Black, dense, hard microcrystalline basalt; maximum thickness 65 ft. *(adapted from Helley & Harwood, 1985).*
Tupg	**Upper Princeton Valley Fill** (Late Oligocene to Early Miocene)-Non-marine sediments composed of sandstone with interbeds of mudstone and occasional conglomerate and conglomerate sandstone; maximum thickness 1,400 ft. *(adapted from Redwine, 1972).*
Ti	**Ione Formation** (Eocene)-Marine to non-marine deltaic sediments, light colored, commonly white conglomerate, sandstone and siltstone, which is soft and easily eroded; max. thickness 650 ft. *(adapted from DWR Bulletin 118-6, 1978; Creely, 1965).*
Tlpg	**Lower Princeton Submarine Valley Fill** (Eocene)-includes Capay Formation. Marine sandstone, conglomerate and interbedded silty shale, maximum thickness 2,400 ft. (*adapted from Redwine, 1972*)
JKgvs	**Great Valley Sequence** (Late Jurassic to Upper Cretaceous)-Marine clastic sedimentary rock consisting of siltstone, shale, sandstone and conglomerate; maximum thickness 15,000 ft.
JKf	**Franciscan Formation** (Jurassic to Cretaceous)-Dominated by greenish-grey greywackes with lesser amounts of dark shale, limestone and radiolarian chert, maximum thickness up to 25,000 ft. *(adapted from strand, 1962 and Norris & Webb, 1990).*

P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B LosMolinos.aprx:Figure 2-11 DWRcrossSectionA_A

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Description of Map Units for DWR Cross Sections b-b' and c-c'

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-26B and Figure 2-27B Combined

Table 2-8. Stratigraphic Summary with Hydrogeologic Properties

AGE		GEOLOGIC UNIT	LITHOLOGY DESCRIPTION	APPROXIMATE THICKNESS INTERPRETED IN SUBBASIN	AQUIFER UNIT	HYDROGEOLOGIC CHARACTER
PERIOD	EPOCH					
Quaternary	Holocene	Surficial Alluvium	Unweathered gravel, sand, and silt (DWR, 2014)	25-50 ft (DWR, 2008)	Upper	Moderately permeable but not a significant source of groundwater in the Subbasin due to limited extent (DWR, 2004)
		Basin Deposits	Fine-grained silt and clay derived from adjacent mountain ranges (DWR 2012)	10-200 ft (Helley and Harwood, 1985)	Upper	
	Pleistocene & Pliocene	Modesto Formation	Alluvial fan and terrace deposits consisting of unconsolidated to semi-consolidated gravel, sand, silt, and clay (DWR, 2014)	50 ft (DWR 2008)	Upper	Moderately to highly permeable. Limited source of groundwater due to limited thickness and extent in the Subbasin (DWR, 2004)
		Riverbank Formation	Alluvial fan and terrace deposits consisting of unconsolidated to semi-consolidated gravel, sand, and silt (DWR, 2014)	50 ft (DWR, 2008)	Upper	Moderately to highly permeable. Limited Source of groundwater due to limited thickness and extent in Subbasin (DWR, 2004)
		Red Bluff Formation	Thin veneer of highly weathered, bright red gravels (DWR, 2014)		Upper	Water is available only where local perched conditions exist. Provides limited water due to limited extent and thickness in the Subbasin (DWR, 2004)
Neogene		Tehama Formation	Pale green, gray, and tan sandstone, and siltstone with lenses of pebble and cobble conglomerate (DWR, 2014)	1,500 ft (DWR, 2008)	Upper/Lower	Low to moderate permeability with localized areas of high permeability (DWR, 2003). Well yields can range from 475 gpm to 950 gpm (DWR, 2003)
		Tuscan Formation	Interbedded lahars, volcanic conglomerate, volcanic sandstone, siltstone, and pumiceous tuff (DWR, 2014)	1,500 ft (DWR, 2008)	Upper/Lower	Low to high permeability and is the main water-bearing formation in the Subbasin (DWR, 2004)
Paleogene	Miocene	Upper Princeton Valley Fill	Non-marine sediments composed of sandstone with interbeds of mudstone, occasional conglomerate, and conglomerate sandstone (DWR, 2014)	800 ft (DWR, 2008)	Brackish	
	Eocene	Lower Princeton Submarine Fill	Marine Sandstone, conglomerate, and interbedded silty shale (DWR, 2014)	1,000 ft (DWR 2008)	Saline	
Cretaceous		Great Valley Sequence	Marine clastic sedimentary rock consisting of siltstone, shale, sandstone, and conglomerate (DWR, 2014)	1,500 ft (DWR, 2003)	Saline	

Tuscan Formation

The late Pliocene Tuscan Formation is comprised of interbedded lahars, volcanic conglomerate, volcanic sandstone, siltstone, and pumiceous-tuff sourced from ancestral Cascade Volcanoes (DWR, 2014; Helley and Harwood, 1985; Lydon 1968). The formation can be seen in outcrops along the eastern side of the Sacramento Valley groundwater basin from the Redding area in the north to near Oroville in the south (DWR, 2014). In the subsurface, the volcanic sourced deposits of the Tuscan interfinger with the metamorphic sourced sediments of the Tehama Formation in the vicinity of the Sacramento River, forming the western extent of the Tuscan Formation (Garrison, 1962; Lydon, 1968). The westward extent of this interfingering can be west of the Sacramento River (DWR, 2014). Beneath the valley sediments, the Tuscan Formation is relatively flat lying, dipping 2 to 3 degrees on the western side of the valley (Olmstead and Davis 1962). Thicknesses of the formation ranges from 300 ft at the westward extent to 1,700 ft in the east (Lydon, 1968). In the Subbasin, the thickness can be 1,300 ft (**Figure 2-27**).

The Tuscan Formation was deposited by volcanic mudflows and stream channels carrying debris from the ancestral Cascade volcanic centers (Lydon, 1968). These volcanic mudflows and stream channels flowed westward and fanned out in the valley resulting in variation of the formation thickness (DWR, 2014). The volcanic mudflow deposits were cut over time by streams flowing from the east (DWR, 2014). Lastly, the stream channels were subsequently filled by reworked volcanic sand and gravel that now contain fresh groundwater in pore spaces (DWR, 2014; Lydon, 1968).

The depositional history resulted in a formation that is heterogeneous and is divided into four units (oldest to youngest: Unit A, Unit B, Unit C, and Unit D). Tuscan Unit A is composed of metamorphic clasts in interbedded lahars, volcanic conglomerate, volcanic sandstone and siltstone, and fractured tuff breccia (DWR, 2004). Groundwater in Unit A is associated with sandstone and conglomerate layers as well as the fractured tuff breccia (DWR, 2003). Unit B similarly yields water readily. Unit B (Ttb on **Figure 2-20**) is composed of lahars, tuffaceous sandstone, and conglomerate (DWR, 2004). Groundwater in Unit B is contained in the reworked sand and gravel layers and is the main source for Tuscan Formation groundwater in Tehama County (DWR, 2003). Unit C (Ttc on **Figure 2-20**) mainly consists of low permeability volcanic mudflow deposits that act as confining layers for groundwater contained in Unit B (DWR, 2004). Unit D (Ttd on **Figure 2-20**) is characterized by masses of andesite, pumice, and fragments of black obsidian in a mudstone matrix (Gonzalez, 2014). In the Subbasin, the Tuscan Formation outcrops in the east (**Figure 2-20**).

Tehama Formation

The Tehama Formation (Tte on **Figure 2-20**) is composed of Pliocene-age noncontiguous layers of sandstone and siltstone, with lenses of pebble and cobble conglomerate (Blake et al., 1999; Helley and Harwood, 1985). The sandstone and siltstone are predominately composed of metamorphic clasts with some volcanic clasts (Blake et al., 1999; Helley and Harwood, 1985). The formation is present from the foothills of the Coast Ranges in the west to the vicinity of the Sacramento River in the east where the Tehama Formation intermixes with the Tuscan Formation in the Subsurface (DWR, 2014). The northern-most outcrops of the Tehama Formation can be seen near Redding and stretch as far south as Vacaville

(DWR, 2014). The Tehama Formation does not outcrop in the Subbasin (**Figure 2-20**). Interpreted thickness of the Tehama Formation can be up to 400 ft in the Subbasin (**Figure 2-27**).

The Tehama Formation was deposited by streams flowing eastward off the Coast Ranges and, to a lesser extent, south from the Klamath Mountains (DWR, 2014). The streams flowed and deposited sediment under floodplain conditions (DWR, 2014). This depositional environment resulted in non-continuous series of poorly sorted sediments cut by non-lenticular channels of coarser sediments (DWR, 2014; Russell, 1931). The Tehama Formation's maximum thickness over its entire mapped extent is 2,000 ft (Olmstead and Davis, 1961).

Saturated groundwater conditions exist in the gravel and sand layers of the Tehama Formation (DWR, 2014; Olmstead and Davis, 1961). The base to fresh water is widely reported to be at the base of the Tehama Formation or sometimes within the Tehama Formation (DWR, 2014; Olmstead and Davis, 1961; Springfield and Hightower, 2012). The Tehama Formation is overlain and cut by the younger Modesto, Red Bluff, and Riverbank Formations (DWR, 2014).

Red Bluff

The Red Bluff Formation (Qrb on **Figure 2-20**) is composed of sandy gravels that lie on a 0.45- to 1.08-million-year-old pediment surfaces. The Red Bluff Formation weathers to a bright-red color (Helley and Harwood, 1985; Helley and Jaworowski, 1985). The formation is discontinuously exposed in the northern Sacramento Valley overlying the Tehama and Tuscan Formations from the Redding area to the vicinity of Cache Creek (DWR, 2014; Russell, 1931; Olmstead and Davis, 1961; Helley and Harwood, 1985). Studies propose that the Red Bluff Formation is the result of alluvial fans depositing reworked metamorphic (Klamath origin) and volcanic (Cascade origin) sediments upon a pediment (Gonzalez, 2014; Harwood et al., 1981; Helley and Jaworowski, 1985). The pediment deposition has resulted in sparce perched aquifer conditions in the 3 ft to 33 ft thick formation (DWR, 2014; Olmstead and Davis, 1961). The Red Bluff Formation outcrops in the majo3rity of the Subbasin (**Figure 2-20**).

Riverbank

The Riverbank Formation is composed predominately of gravel, sand, and silt deposits that were deposited unconformably on the Tehama, Tuscan, and Red Bluff Formations (DWR, 2014; Marchand and Allwardt, 1981). The formation extends from Redding to Merced discontinuously (Marchand and Allwardt, 1981). It is generally found along higher-elevation terraces beneath the pediment surface of the western tributary systems including the Thomes, Elder, Oat, and Cottonwood Creeks (Tehama County FCWCD, 2012). The thickness varies from 1 ft to over 200 ft (Helley and Harwood, 1985). In the Subbasin the Riverbank is localized to the banks of streams and creeks that flow west to the Sacramento River (**Figure 2-20**).

It is divided into upper and lower members that are lithologically similar but differ in stratigraphic position and degree of soil development (Helley and Harwood, 1985; Blake et al., 1999). Both members contain gravel, sand, silt, and clay derived from the surrounding mountain ranges (Klamath, Coast Ranges, and Cascades). The upper member (Qru on **Figure 2-20**) occupies the lower terrace positions while the lower member (Qrl on **Figure 2-20**) occupies the higher positions (Helley and Harwood, 1985). The upper member consists of semi-consolidated sediments while the lower consists of unconsolidated but compact

alluvium (Helley and Harwood, 1985). Both members display soil development with B horizons and local hardpans however, the soils are more developed in the lower member (Blake et al., 1999). The Riverbank formation yields limited water due to its aerial extent and limited thickness (1 to 200 feet) (Helley and Harwood, 1985). The thickness in the Subbasin has been interpreted to be up to 50 ft based on cross sections constructed by DWR (2008), (**Figure 2-26**). The Formation is overlain by the younger Modesto Formation, basin deposits, or surficial alluvium (DWR, 2014).

Modesto

The Modesto Formation is composed of 0.14 to 0.42 Ma stream channel deposits that were laid down in a manner similar to the Riverbank Formation (Marchand and Allwardt 1981). It can be seen on the ground surface from Redding to the San Joaquin Valley (DWR, 2014). The formation ranges in thickness from less than 10 ft to 200 ft (Helley and Harwood, 1985). The Modesto Formation is present at the surface in the majority of the Subbasin and at thicknesses up to 50 ft (**Figure 2-20; Figure 2-26)**. Groundwater occurs in the formation under unconfined conditions (DWR, 2014).

The Modesto Formation consists of a lower member (Qml on **Figure 2-20**) occupying higher topographic areas and an upper member (Qmu on **Figure 2-20**) visible at lower topographic areas (Helley and Harwood, 1985). Both the lower and the upper members are composed of unconsolidated gravel, sand, silt, and clay. The main difference between the two is that the lower member is slightly more weathered (Helley and Harwood, 1985). The Modesto Formation sedimentary deposits often border currently active stream channels and were likely deposited by the same streams they border (Helley and Harwood, 1985).

Basin Deposits

The Basin Deposits (Qb on **Figure 2-20**) are composed of fine silts and clays that were deposited under flood conditions by the sediment-laden streams in the Subbasin rising above the natural levees into the low-lying areas (DWR, 2014; Olmstead and Davis, 1961). Exposures of the Basin Deposits in Butte, Glenn, and Colusa Counties form the soil conditions needed for farming in the area (DWR, 2014). Basin Deposit exposures are not widespread in Tehama County (**Figure 2-20**). Thickness of the deposits has been observed at a maximum of over 200 feet near the Sacramento River and at a minimum of 10 feet along the valley edges (Helley and Harwood, 1985). The formation provides limited groundwater due to its fine-grained nature (Olmstead and Davis, 1961). Basin Deposits outcrop within the Los Molinos Subbasin mainly in the north (**Figure 2-20**).

Surficial Alluvium

The surficial alluvium (QTog, Qa, and Qsc on **Figure 2-20**) is the youngest of the geologic units in the Subbasin. The alluvium consists of gravel, sand, and silt sourced from the Klamath, Coast Range, Cascade, and Sierra Nevada Ranges and transported and deposited by modern streams and rivers (Helley and Harwood, 1985). It is present throughout the northern Sacramento Valley forming natural levees and along current rivers and streams (DWR, 2014). Based on cross sections from DWR (2008), the maximum thickness in the Subbasin is interpreted to be 50 ft (**Figure 2-26)**. It is not a major source of water due to its limited thickness and extent (DWR, 2014).

2.2.1.3.3 *Geologic Structures*

Geologic structures are a result of tectonic forces leading to deformation in the geologic material. The deformation can control direction and rate of groundwater flow. This section is a description of major geologic structures in the area. The Los Molinos Syncline and Chico Monocline are the only major structure observed in the Subbasin and the other structures are discussed for regional context (**Figure 2-20**).

Los Molinos Syncline

The Los Molinos Syncline is a 1.0- to 2.5-million-year-old north northwest-trending syncline that locally controls the Sacramento River (Blake et al., 1999). The syncline generally follows the topographically low elevations and lies between the Chico Monocline and the Corning Fault. The Los Molinos Syncline may influence the direction of groundwater flow.

Red Bluff Fault

The Red Bluff Fault is a 15-mile-long south-dipping normal fault that has surface expressions northeast of the City of Red Bluff (DWR, 2014). Strike is generally 60 degrees east and has been observed to have late Cenozoic displacement as it affects the base of the Pliocene rocks, offsetting them about 500 feet (Blake et al., 1999).

Corning Fault

The Corning Fault branches off the Willows Fault south of Tehama County. It is a north-trending reverse fault with no surface expression. The main evidence for the fault is subsurface surveys performed by Harwood and Helley (1987). The fault has been observed at a dip of 74 degrees east with greater degrees of offset on older rocks (DWR, 2014; Helley and Harwood, 1985). The fault generally follows the trend of Interstate 5 until its terminus at the Red Bluff Fault north of Red Bluff (DWR, 2014).

Inks Creek Fold System

The Inks Creek Fold System is a series of northeast-trending folds that occur to the north of the Subbasin (DWR, 2004). The fold system is composed of a dome on the west side of the Sacramento River, and a southwest-plunging anticline and syncline that locally controls the major bends in the Sacramento River (Harwood and Helley, 1987). The system is a part of the Red Bluff Arch, a hydrologic drainage divide that separates the Redding Area groundwater basin and the Sacramento Valley groundwater basin (DWR, 2014).

Chico Monocline

The Chico Monocline is a flexure feature on the east side of the Subbasin that roughly follows the boundary of the valley. It is a northwest-trending feature that deforms the Tuscan Formation in the east, causing the beds to increase from a dip of 2 to 5 degrees in the middle of the valley to 25 degrees in the east (DWR, 2014).

Red Bluff Arch

The Red Bluff Arch is an area of regional compression that encompasses multiple tectonic features in the area (DWR, 2014). It is a northeast-trending feature that is made up of the Red Bluff fault, the Inks Creek Fold System; and the Seven Mile, Tuscan Springs, Salt Creek, and Hooker Creek domes (DWR, 2014). The collection of features regionally creates a barrier to groundwater flow separating the Sacramento Valley groundwater basin from the Redding Area groundwater basin (DWR, 2014).

2.2.1.4 Soil Characteristics

The characteristics of a soil influence the movement of surface water (e.g., water sourced from rainfall, stream flow, or anthropogenic activities such as irrigation). Coarse, porous soils promote infiltration of surface water, while relatively impermeable soils promote surface runoff. Chemical properties of a soil (e.g., salinity and pH) can alter the chemistry of water that percolates through it. Therefore, understanding of the spatial variability of soil characteristics is important to conceptualize the hydrogeologic system of the Subbasin. Surficial soil property data were obtained from the US Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS). NRCS soil surveys use soil "map units" to delineate geographical areas that have soils with similar characteristics. A "soil series" is a unique collection of map units. It represents a three-dimensional soil body that is composed of soils that have a relatively narrow range of properties. Detailed descriptions of soil map units and series are available in USDA Soil Survey Manual, Handbook No. 18 (Soil Science Division Staff, 2017).

Soils – Type

Surficial soil types are present in the Los Molinos Subbasin belongs to 84 unique map units. These soil types are grouped into 29 soil series and shown in **Figure 2-28** and **Figure 2-28B**. The two most dominant soil series in the Subbasin are Tuscan and Toomes, covering 39% and 12% of the Subbasin, respectively. The Tuscan series soils exist on broad gently sloping old alluvial terraces, thus commonly in the western and southern areas of the Subbasin. The Toomes series, which consists of well drained to excessively drained soils, exist in plateaus and ridges of volcanic flows and foothills of volcanic uplands in the eastern part of the Subbasin. Other dominant soil types in the Subbasin are Anita and Keefers series. Each of these soil types covers about 7% to 8% of the Subbasin. The Anita soils exist in shallow depressions, basins, and along drainageways on terraces. Keefers soils exist on flood plains. All other soil series that exist in the Subbasin collectively cover about 34% of the land surface, and the contribution of each series vary from less than 1% to 6%.

Soil Texture

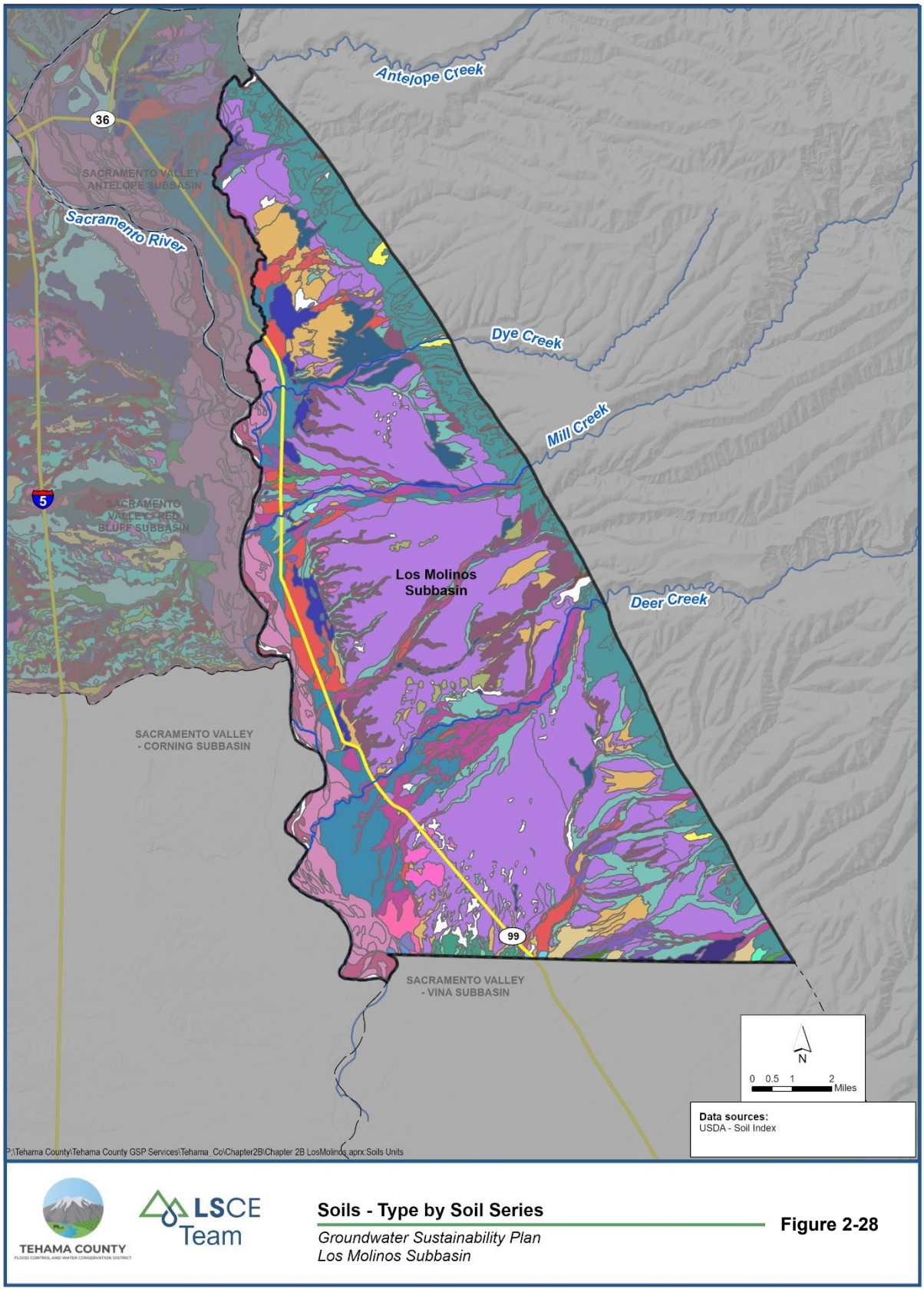
Soil textural classes are defined based on relative percentages of sand, silt, and clay (Soil Science Division Staff, 2017). Spatial distribution of soil textural classes in the Los Molinos Subbasin are shown in **Figure 2-29**. Loam and different variations of loam are the dominant surficial soil textures in the Subbasin. Loam that contains relatively high amount of coarse materials (sandy loam, gravelly loam, stony loam, very cobbly sandy clay loam, fine sandy loam, and cobbly loam) covers approximately 55% of the Subbasin. Clay and Clay loam (loam soil with abundant silt and clay) covers about 15% of mapped surface. Loam soil (a soil composed mostly of sand and silt with a small amount of clay) covers about 20% of mapped surface area and exists mainly in the southern areas of the Subbasin. The remaining 10% of the Subbasin is covered by soil textures that individually make up less than 3% of the area.

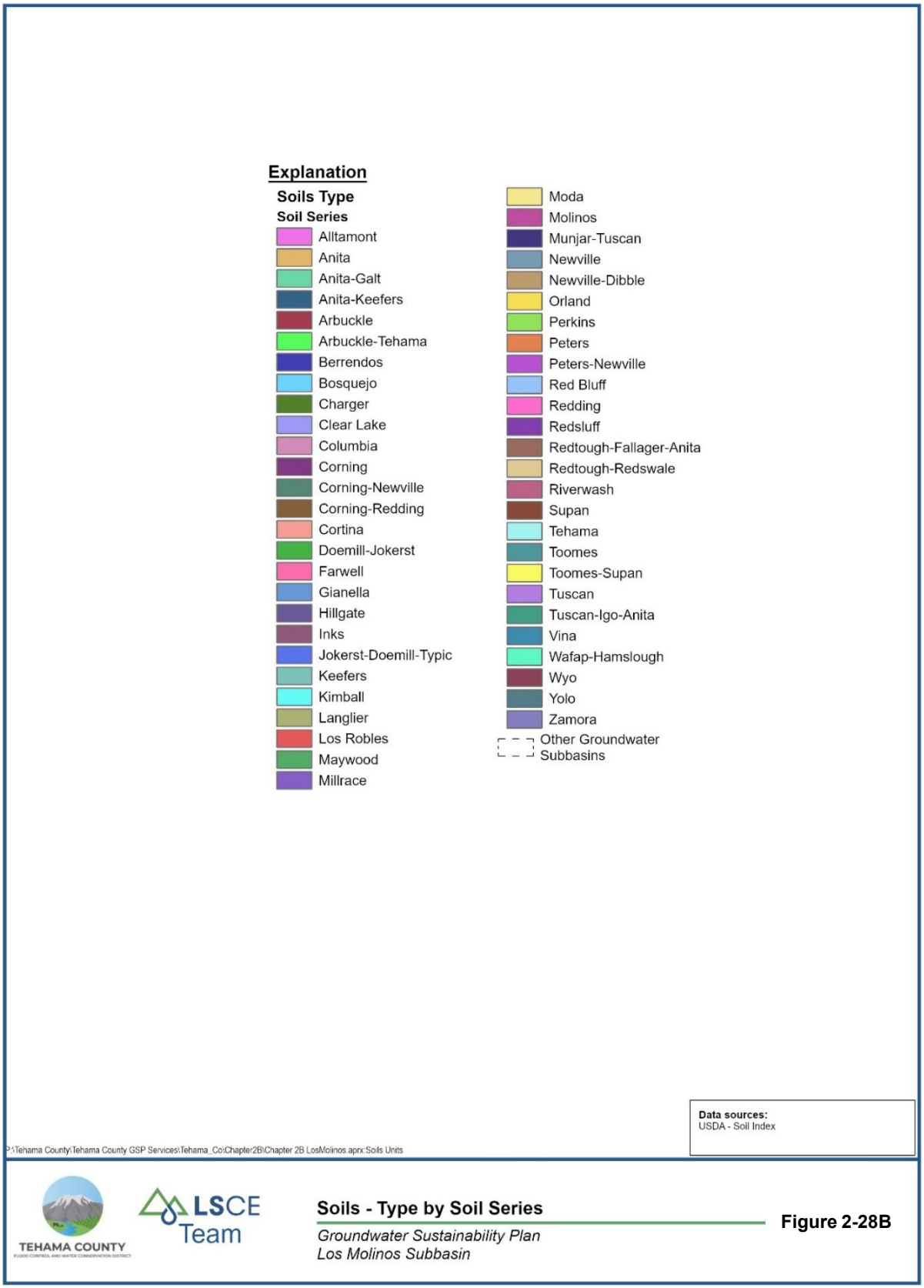
Hydraulic Conductivity

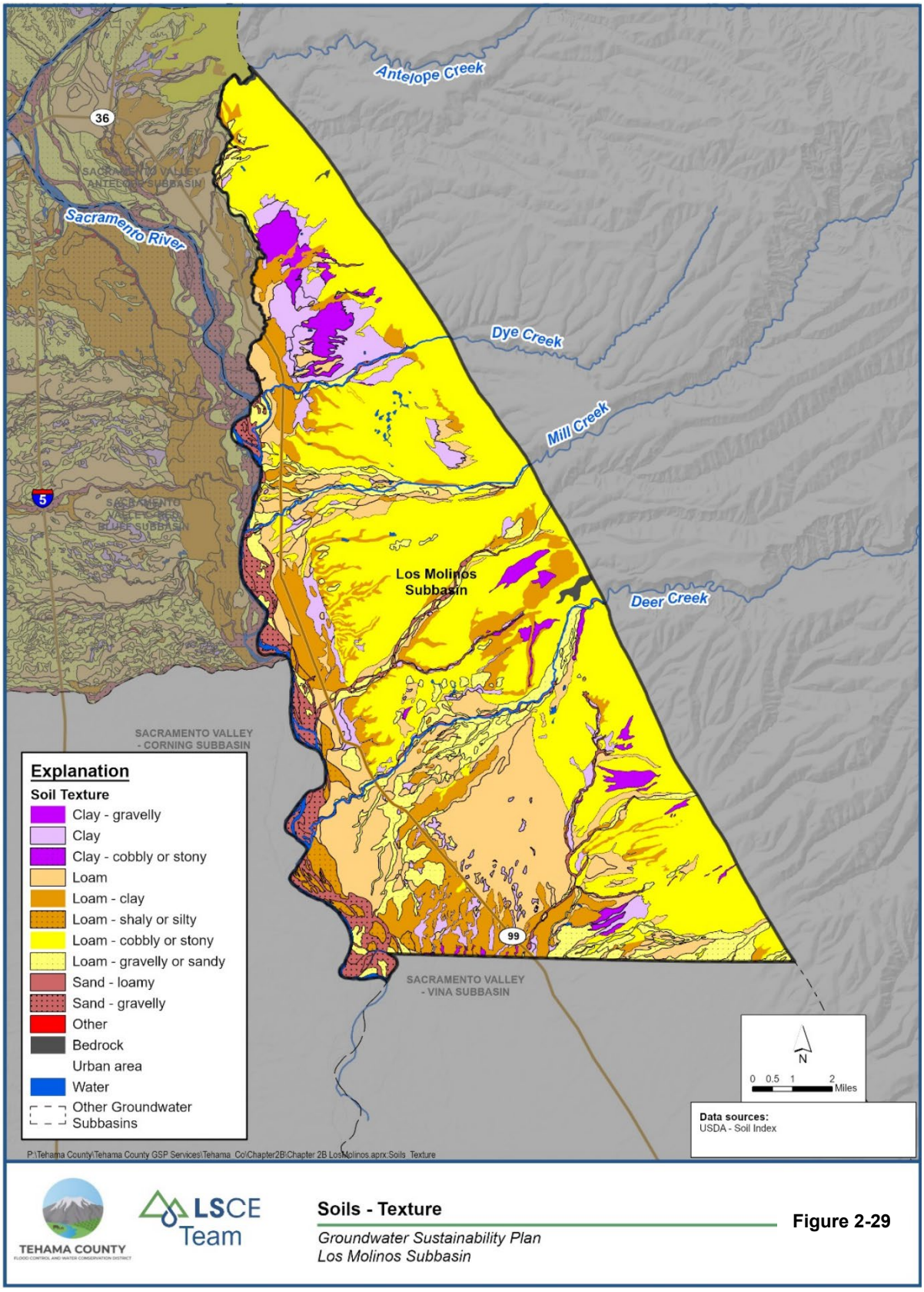
The saturated hydraulic conductivity of surficial soils, which is a measure of a soil's ability to transmit water under a hydraulic gradient, ranges from approximately 0.3 ft/d to 8 ft/d in about 90% of the Los Molinos Subbasin. Saturated hydraulic conductivity can be up to 26 ft/d in the remaining 10% of the Subbasin (**Figure 2-30**). The spatial distribution of hydraulic conductivity throughout the Subbasin is related to the distribution of soil texture. Relatively fine texture soils such as clays, clay loam and loam have low hydraulic conductivities. Therefore, low hydraulic conductivity values are common in the central part of the Subbasin. Coarse texture soils such as sandy, gravelly, or cobbly loams, and gravelly sand have high hydraulic conductivities. Therefore, high hydraulic conductivity values are common along drainage ways and in alluvial fan deposits.

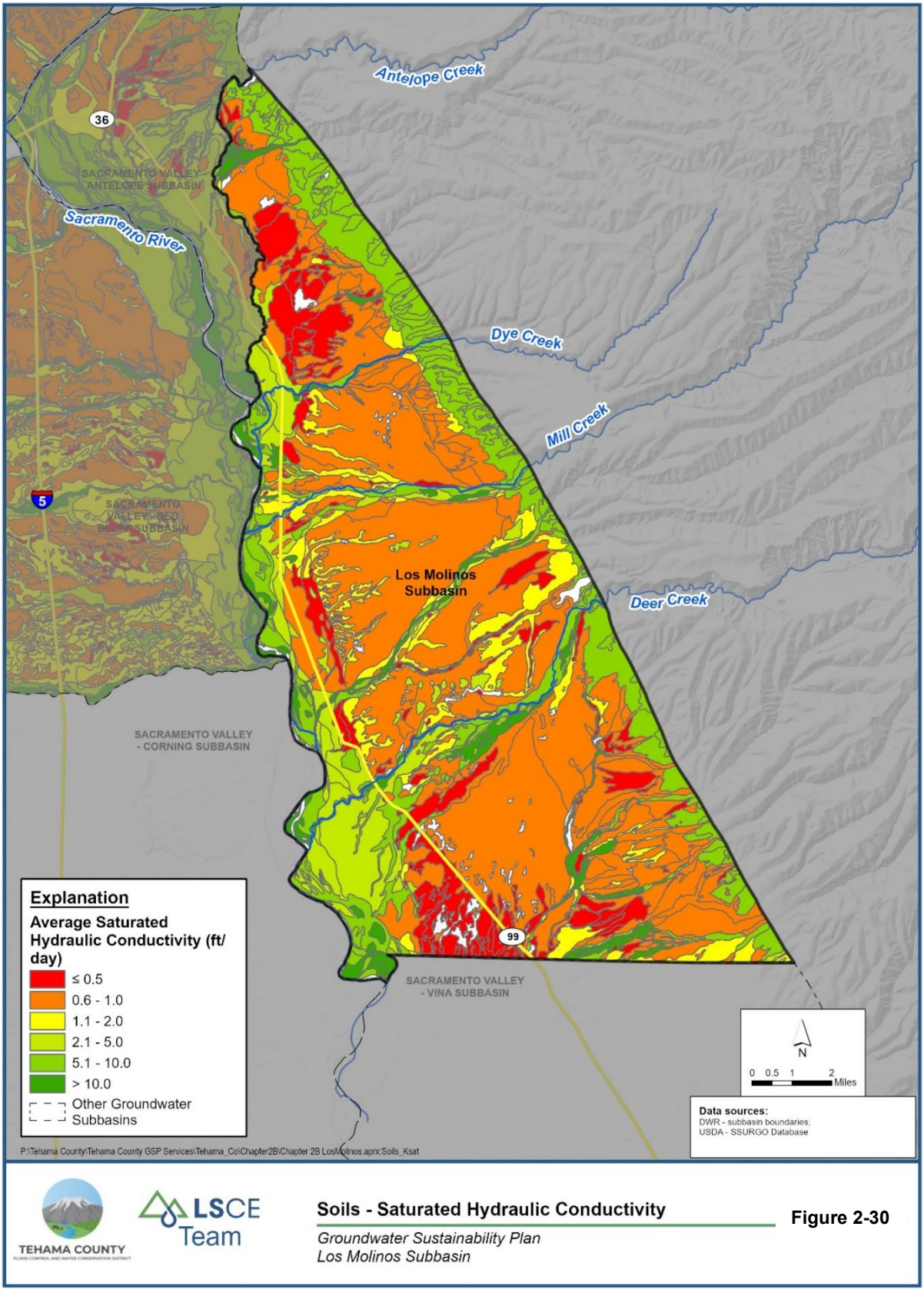
Drainage

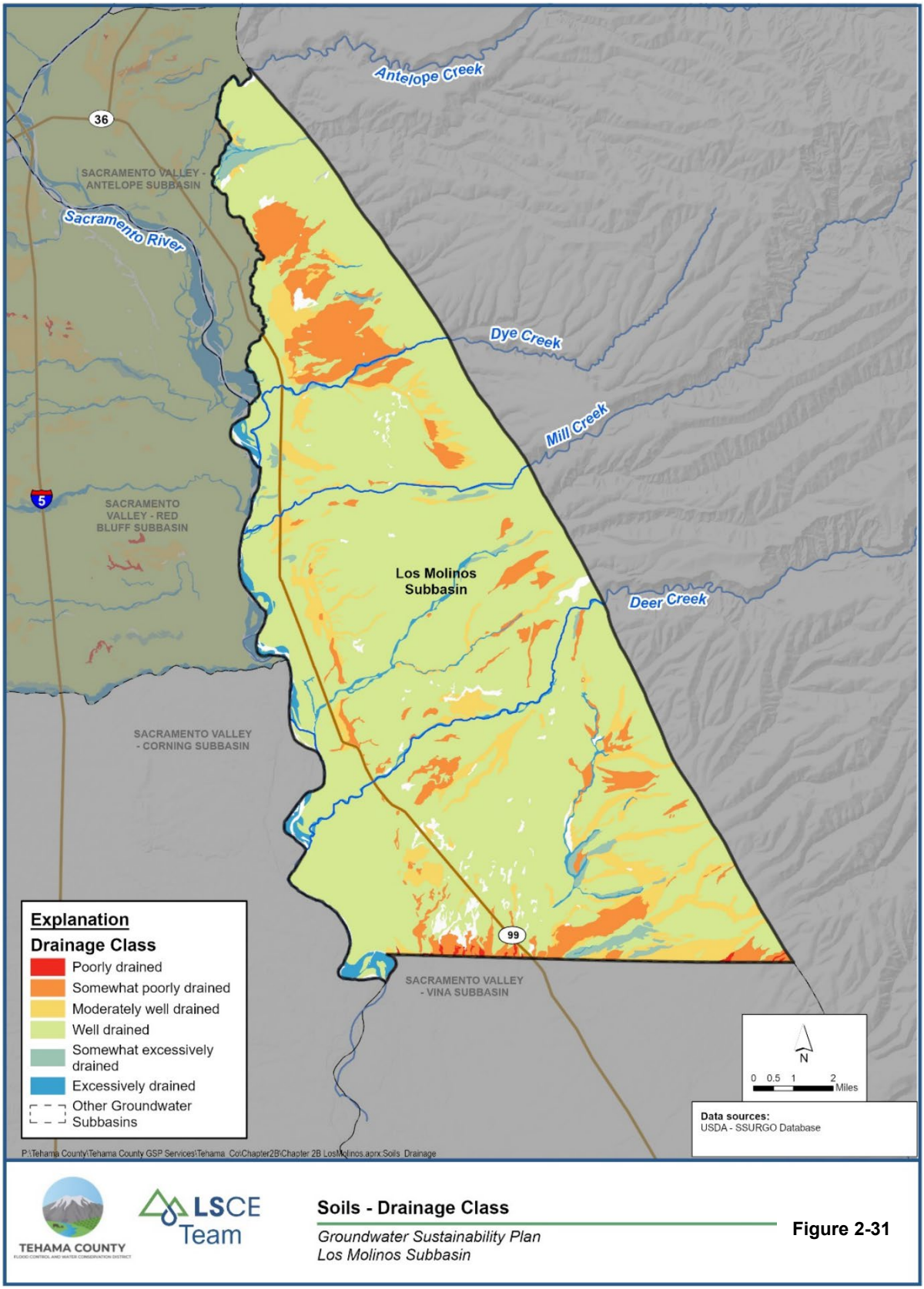
Soil drainage classes indicate the ability of a soil to drain water. Spatial distribution of soil drainage properties in the Los Molinos Subbasin closely resembles the distribution of saturated hydraulic conductivity and soil texture (**Figure 2-31**). More than 75% of the Subbasin area is categorized as well drained soils. Small patches of poorly drained and somewhat poorly drained soils, as well as moderately well drained soils mostly occur in the northern part and southern edge of the Subbasin. Excessively drained soils occur along and adjacent to drainage ways, where coarse soils are abundant.


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
5
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Los Molinos Subbasin
Deer Creek
SACRAMENTO VALLEY - CORNING SUBBASIN
99
SACRAMENTO VALLEY - VINA SUBBASIN
N
0 0.5 1 2
Miles
Data sources:
USDA - Soil Index
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B LosMolinos_aprx:Soils Units
TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT
LSCE Team
Soils - Type by Soil Series
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-28


Explanation
Soils Type
Soil Series
Alltamont
Anita
Anita-Galt
Anita-Keefers
Arbuckle
Arbuckle-Tehama
Berrendos
Bosquejo
Charger
Clear Lake
Columbia
Corning
Corning-Newville
Corning-Redding
Cortina
Doemill-Jokerst
Farwell
Gianella
Hillgate
Inks
Jokerst-Doemill-Typic
Keefers
Kimball
Langlier
Los Robles
Maywood
Millrace
Moda
Molinos
Munjar-Tuscan
Newville
Newville-Dibble
Orland
Perkins
Peters
Peters-Newville
Red Bluff
Redding
Redsluff
Redtough-Fallager-Anita
Redtough-Redswale
Riverwash
Supan
Tehama
Toomes
Toomes-Supan
Tuscan
Tuscan-Igo-Anita
Vina
Wafap-Hamslough
Wyo
Yolo
Zamora
Other Groundwater Subbasins
Data sources:
USDA - Soil Index
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B LosMolinos.aprx:Soils Units
TEHAMA COUNTY
LSCE Team
Soils - Type by Soil Series
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-28B


Antelope Creek
Sacramento River
Dye Creek
Mill Creek
Deer Creek
Los Molinos Subbasin
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
SACRAMENTO VALLEY - CORNING SUBBASIN
SACRAMENTO VALLEY - VINA SUBBASIN
36
5
99
Explanation
Soil Texture
Clay - gravelly
Clay
Clay - cobbly or stony
Loam
Loam - clay
Loam - shaly or silty
Loam - cobbly or stony
Loam - gravelly or sandy
Sand - loamy
Sand - gravelly
Other
Bedrock
Urban area
Water
Other Groundwater Subbasins
N
0 0.5 1 2 Miles
Data sources:
USDA - Soil Index
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B Los Molinos.aprx:Soils_Texture
TEHAMA COUNTY
LSCE Team
Soils - Texture
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-29


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
5
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Los Molinos Subbasin
Deer Creek
SACRAMENTO VALLEY - CORNING SUBBASIN
99
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
Average Saturated Hydraulic Conductivity (ft/day)
≤ 0.5
0.6 - 1.0
1.1 - 2.0
2.1 - 5.0
5.1 - 10.0
> 10.0
Other Groundwater Subbasins
N
0 0.5 1 2 Miles
Data sources:
DWR - subbasin boundaries;
USDA - SSURGO Database
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B Los Molinos.aprx:Soils_Ksat
TEHAMA COUNTY
LSCE Team
Soils - Saturated Hydraulic Conductivity
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-30

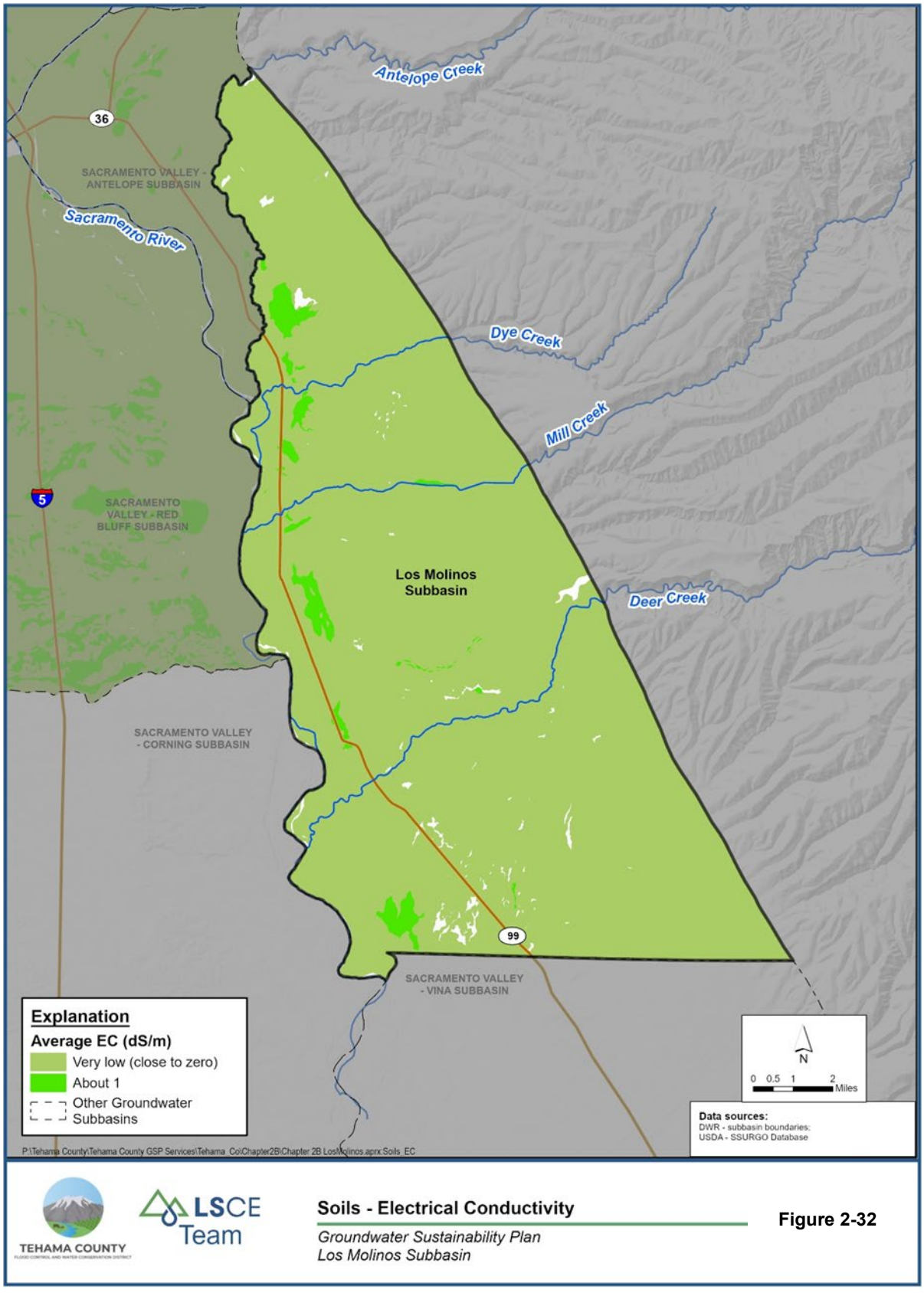

Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
5
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Los Molinos Subbasin
Deer Creek
SACRAMENTO VALLEY - CORNING SUBBASIN
99
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
Drainage Class
Poorly drained
Somewhat poorly drained
Moderately well drained
Well drained
Somewhat excessively drained
Excessively drained
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
USDA - SSURGO Database
P:\Tehama County\Tehama County GSP Services\Tehama Co\Chapter2B\Chapter 2B LosMolinos.aprx:Soils Drainage
TEHAMA COUNTY
LSCE Team
Soils - Drainage Class
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-31

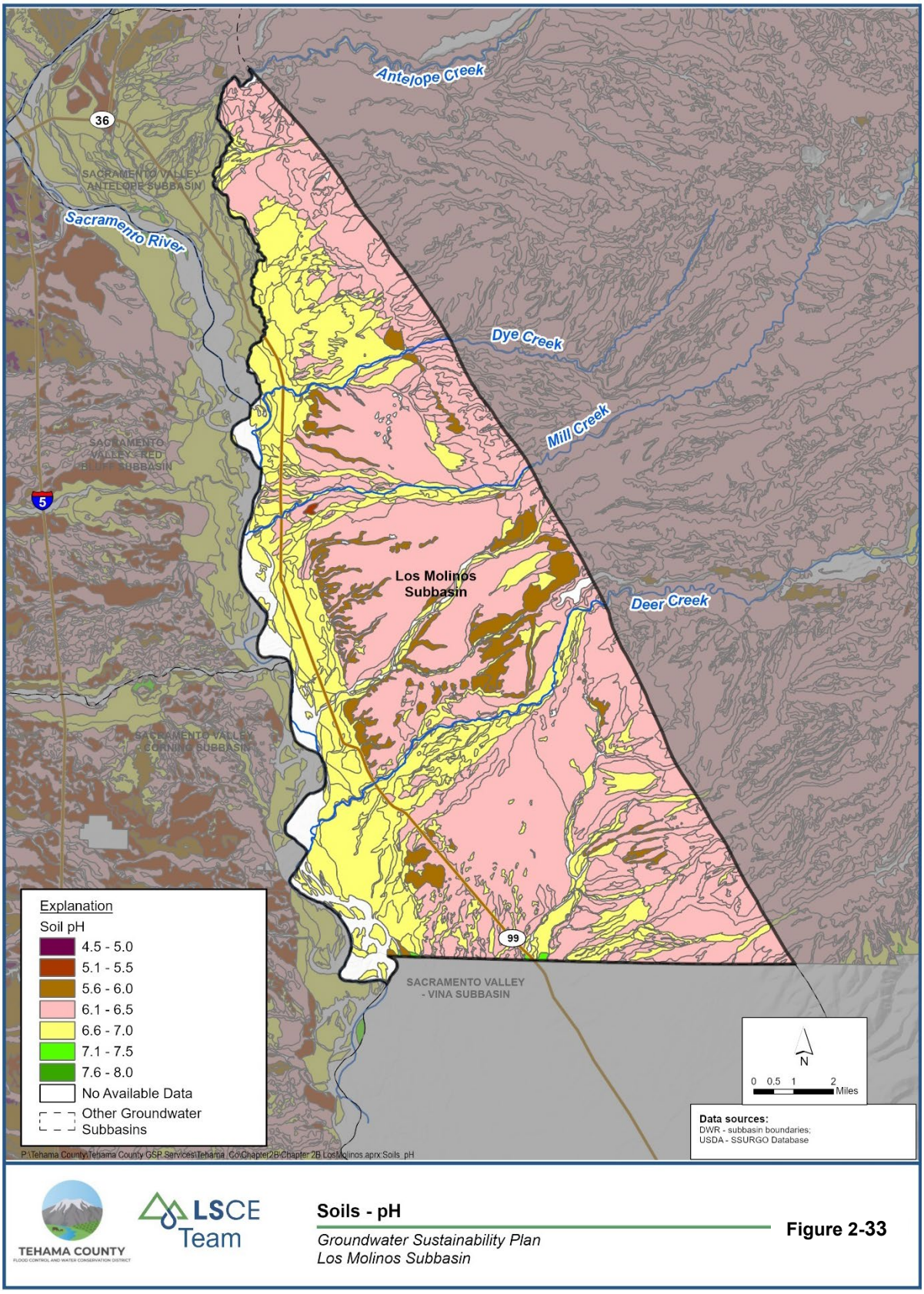
Electrical Conductivity

Electrical Conductivity (EC) of a soil is an indirect measure of the amount of salt present in that soil. Percolating water can leach and transport salts from saline soils to groundwater, resulting in an increase of the salinity of groundwater. All surficial soils in the Los Molinos Subbasin fall into non-saline class, where EC values are less than 2 decisiemens per meter (dS/m) (2,000 µmhos/cm). As per NRCS soil data, EC of surficial soils in more than 90% of the Subbasin is zero dS/m, while that of soils in the remaining areas is 1 dS/m (1,000 µmhos/cm) (**Figure 2-32**).

pH

Soil pH is a measure of the acidity or alkalinity of that soil, which influences chemical interactions between soil minerals and percolating water. A pH of 7 is considered neutral. Increasing pH values indicate more alkaline soil conditions and decreasing pH values indicate more acidic soil conditions. Soil pH in the Los Molinos Subbasin is slightly acidic. It ranges between 5.6 and 7.0 throughout the Subbasin (**Figure 2-33**). In general, solubility of minerals increases with acidity of the soil and water. Acidity of surficial soils in the Subbasin is not expected to adversely alter water quality.


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
5
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Los Molinos Subbasin
Deer Creek
SACRAMENTO VALLEY - CORNING SUBBASIN
99
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
Average EC (dS/m)
Very low (close to zero)
About 1
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR - subbasin boundaries;
USDA - SSURGO Database
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B Los Molinos.aprx:Soils_EC
TEHAMA COUNTY
LSCE Team
Soils - Electrical Conductivity
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-32



TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT

LSCE Team

Soils - pH

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-33

2.2.1.5 Identification/Differentiation of Principal Aquifers

Two principal aquifer units are defined in the Subbasin: Upper Aquifer and Lower Aquifer. The two-aquifer designation is based on an examination of time-series groundwater elevation hydrographs, electric resistivity data from geophysical logs, lithologic logs, well construction details, and review of previous studies in the Subbasin. The northern Sacramento Valley depositional environment is dominated by fluvial and alluvial deposition after the Eocene marine depositional environment transitioned to a subaerial one. The Pliocene depositional environment is similar to the current depositional conditions, with eastern depositional streams sourced from the Cascade Range and western depositional streams sourced from the Coast Ranges draining onto a central floodplain. This depositional environment resulted in a complex and varied series of water bearing sedimentary deposits and the Tuscan/Tehama Formations that collectively form a two-aquifer system in the Subbasin and beyond. Within singular water bearing formations there are areas where confined or unconfined conditions can be dominant. Generally, confined aquifer conditions are encountered at depth and unconfined conditions are seen in the shallower porous media. The complexity of the geologic materials and among the formations makes it difficult to define a singular widespread aquitard or distinctive change in geologic materials separating an upper and lower aquifer. To delineate between areas with a higher likelihood of confined conditions, well construction data throughout the Subbasin were examined. Most of the wells in the Subbasin are screened or completed above 400 feet below ground surface (ft bgs). The bottom of numerical model layer 5 best corresponds with this depth. The bottom of model layer 5 is used as the delineation between the Upper and the Lower Aquifer. This model layer boundary also generally corresponds to fine grained lithology from available well completion reports (**Figure 2-22** through **Figure 2-25**). Lastly, the degree of heterogeneity and anisotropy (directional preferable flow) is likely significant, but not easy to define based on current information.

Upper Aquifer

The Upper Aquifer is defined as the water bearing material from ground surface to the bottom of model layer 5 (approximately 350-450 ft bgs in the Subbasin). The aquifer has unconfined to semi-confined water conditions. Water bearing geologic units in the Upper Aquifer include the Quaternary formations and the upper portions of the Tehama and Tuscan Formations. Wells screened in the Upper Aquifer are used for agricultural and mainly domestic purposes. The depth to the bottom of the Upper Aquifer is approximately 350-450 ft bgs (**Figure 2-22 through Figure 2-25**). The storage capacity of the Los Molinos Subbasin Upper Aquifer is estimated to be approximately 400,000 acre-feet to a depth of 200 feet in the area between Mill Creek and Deer Creek (DWR, 2004).

Site-specific Aquifer properties obtained from aquifer tests were available for specific areas of the Subbasin, additional aquifer tests were also conducted in surrounding subbasins. In the Deer Creek area of the Subbasin, transmissivity (hydraulic conductivity multiplied by aquifer thickness) of the upper portion of the Tuscan Formation is estimated to be approximately 14,000 square feet per day (ft^2/d) to approximately 55,000 ft^2/d (DWR, 2003). These values were estimated based on aquifer tests conducted in a well screened from 70 ft bgs to 530 ft bgs (DWR, 2003). This depth interval covers a portion of the Lower Aquifer but is mostly within the Upper Aquifer.

Hydraulic conductivity (rate at which water moves through an aquifer) and storage coefficients (ability of the aquifer to store water, commonly expressed as specific yield for water table/unconfined aquifers and storativity for confined aquitards) have been estimated for the Tehama Formation in the neighboring Red Bluff Subbasin. The Tehama Formation has an average transmissivity of approximately 4,000 ft^2/d, an average storativity of 0.00089, and an average hydraulic conductivity of 120 feet per day (ft/d) based on a 1989 constant discharge aquifer test at the Rancho Tehama Reserve in the Red Bluff Subbasin (McManus, 1993; DWR, 2003).

Lower Aquifer

The Lower Aquifer is defined as the freshwater bearing geologic units throughout the Subbasin from the bottom of model layer 5 at approximately 350-450 ft bgs, to the bottom of the Subbasin. The aquifer has confined to semi-confined conditions. Water bearing geologic units include the lower portions of the Tehama and Tuscan Formations. Wells screened in the Lower Aquifer are largely for non-domestic purposes. Lack of a continuous confining layer in the Subbasin creates challenges for defining the top of the Lower Aquifer.

Transmissivity between 350 ft bgs and 600 ft bgs is approximately 5,600 ft^2/d to 17,000 ft^2/d in the Dye Creek area of the Subbasin (Harrison, 1989; Ely, 1994; DWR, 2003). In the same areas, average hydraulic conductivity ranges from approximately 40 ft/d to 60 ft/d, and the average storage coefficient is 0.0025 (Harrison, 1989; Ely, 1994; DWR, 2003).

The lower Tuscan Formation (Units A and B) has a hydraulic conductivity estimate (via an aquifer test south of Deer Creek and North of Little Chico Creek) of 41-88 ft/d (Brown and Caldwell, 2013). Transmissivity of the lower parts of the Tuscan Formation (340-920 ft bgs) ranges from 5,415 ft^2/d to 49,986 ft^2/d south in the Deer Creek area of the Subbasin (DWR, 2003). In the same areas, storativity is estimated to be 0.0025 and hydraulic conductivity is estimated to be 43 ft/d (DWR, 2003). The Tehama Formation has an average transmissivity of 4,341 ft^2/d, an average storativity of 0.00089, and an average hydraulic conductivity of 120 feet per day (ft/d) based on a 1989 constant discharge aquifer test at the Rancho Tehama Reserve in the Red Bluff Subbasin (McManus, 1993; DWR, 2003).

2.2.1.6 Definable Bottom of Basin

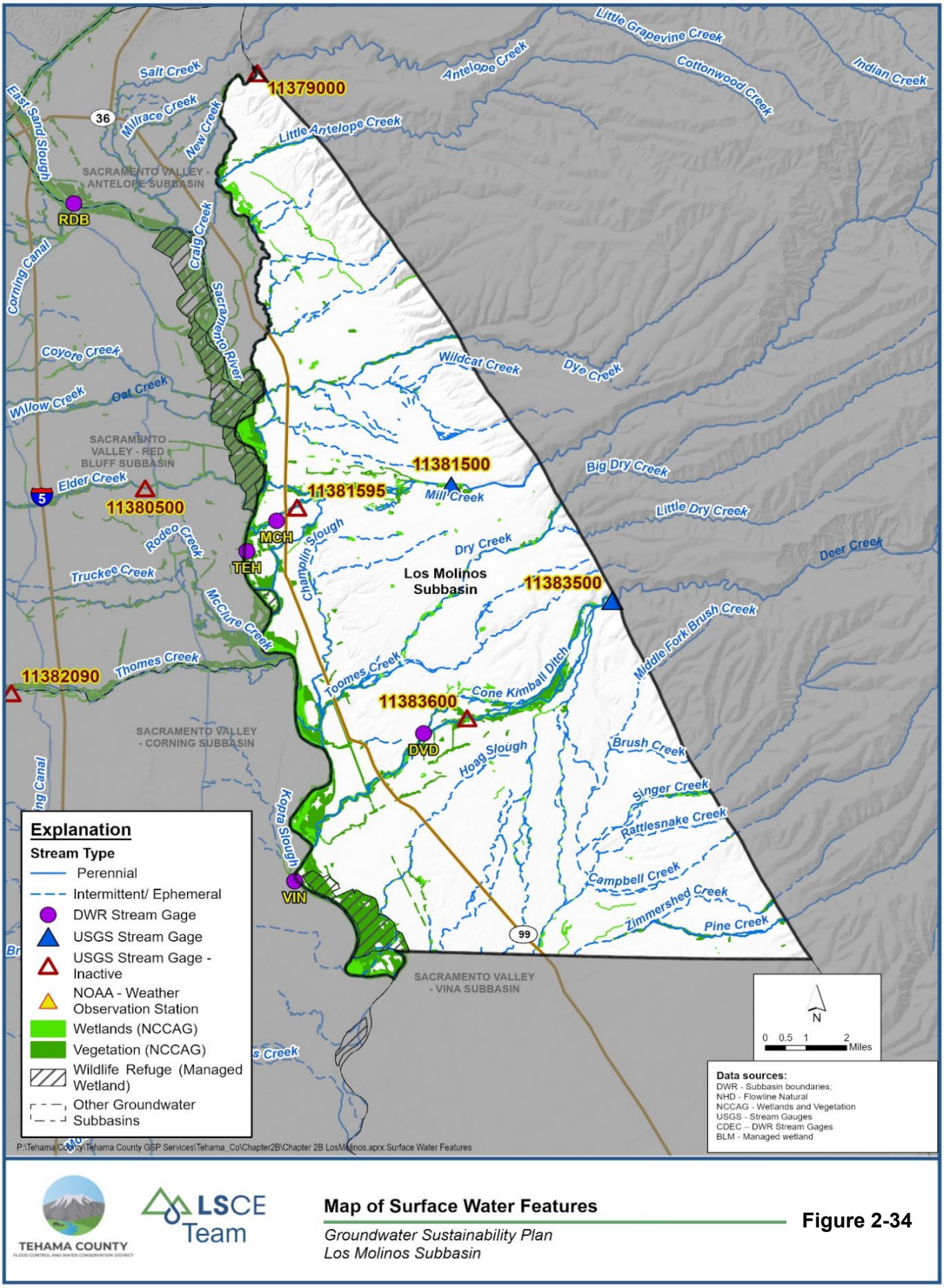
The base of the post-Eocene continental deposits is defined as the bottom of the basin. The post-Eocene deposits are the deepest locations where fresh water may exist. Contours of the base of post-Eocene deposits (**Figure 2-20)** are on the base of the Upper Princeton Valley Fill in the majority of the Subbasin. The Upper Princeton Valley Fill is a transitional formation from marine to terrestrial deposition. Interstitial fresh and brackish water is contained in the Upper Princeton Valley Fill and fresh water can intersect with the formation in places (USGS, 1974; Tehama County FCWCD, 2012). Fresh water is defined as having a maximum electrical conductivity of 3,000 micromhos per centimeter (µmhos/cm) (Berkstresser, 1973). The base of fresh water in the Subbasin is shallowest in the east and southeast at elevations shallower than -1,200 ft, mean sea level (msl) and deepest in the west at elevations deeper than -2,000 ft, msl (**Figure 2-15;** Berkstresser, 1973). The elevation of the base of fresh water as depicted by the equal elevation contour lines is interrupted in the northeast where the Chico Monocline possibly affects the depth to fresh water. Fresh water depth based on electrical conductivity is corroborated by studies by DWR (2014).

2.2.1.7 Surface Water Features and Areas of Recharge

The primary surface water features in the Subbasin are the Sacramento River, Dye Creek, Mill Creek, Deer Creek, Little Antelope Creek, and Antelope Creek (**Figure 2-34**). Flow of all these waterways occur throughout the year (perennial). The Sacramento River flows southward along the western boundary of the Subbasin, while Antelope Creek flows southward along the northwestern boundary. Wildcat Creek and Little Wildcat Creek in the northern part of the Subbasin contribute to the flow of Dye Creek, which enters the Sacramento River approximately 1.5 miles downstream from where Antelope Creek enters the Sacramento River. Mill Creek enters the Sacramento River slightly downstream of where Dye Creek enters the Sacramento River. Deer Creek enters the Sacramento River in the southern portion of the Subbasin approximately 4 miles upstream from the southern boundary of the Subbasin. Little Antelope Creek flows through the northern area of the Subbasin where it flows into Antelope Creek approximately 5 miles north of the Sacramento River. There are several intermittent or ephemeral streams within the Subbasin, including Champlin Slough, Delaney Slough, Wildcat Creek and Brush Creek. These streams are tributaries of the Sacramento River and have a general flow direction of northeast to southwest. Several small seasonal ponds (surface area less than 10 acres) occur along streams, but there are no natural lakes or reservoirs within the Subbasin.

Groundwater recharge of the Subbasin primarily occurs from the flow of the Sacramento River and the other streams and tributaries in the Subbasin. Some recharge likely occurs to the east of the Subbasin boundary (DWR, 2004). Some of the groundwater recharge contributions from smaller streams and tributaries likely support low flow conditions in the Sacramento River as baseflow. Relatively high hydraulic conductivity of streambeds and soils located adjacent to these streams create favorable conditions for percolation of surface water (**Figure 2-30**). However, the Soil Agricultural Groundwater Banking Index (SAGBI; O'Geen et al., 2015), which indicates the suitability of land for groundwater recharge by flooding, gives “poor” deep percolation rating to many areas of flood plains and natural levees of streams despite the presence of highly conductive surficial soils (**Figure 2-35**). The poor rating in these areas can be attributed to the presence of low-permeable soil layers and a relatively shallow groundwater table, which are unfavorable for groundwater banking operations or managed aquifer recharge. Lastly, recharge likely also occurs along 1) the hill front due to runoff and groundwater movement down into the valley, 2) disperse aerial recharge from natural precipitation, and 3) irrigation water.

Seasonal wetlands exist adjacent to many streams, and most notably along the Sacramento River (**Figure 2-36**). A portion of the Sacramento River National Wildlife Refuge, a managed wetland, also exists at the southern part of the Subbasin (**Figure 2-34**). These wetlands may indicate the seasonal occurrence of groundwater discharge when the groundwater table rises to the land surface. However, data are not available to distinguish between wetlands fed by groundwater and those fed by surface water (from streams and precipitation run-off). A direct source of recharge to deeper geologic formations like Tuscan Unit B occurs where the formations outcrop on the eastern edge of the Subbasin (DWR, 2003).



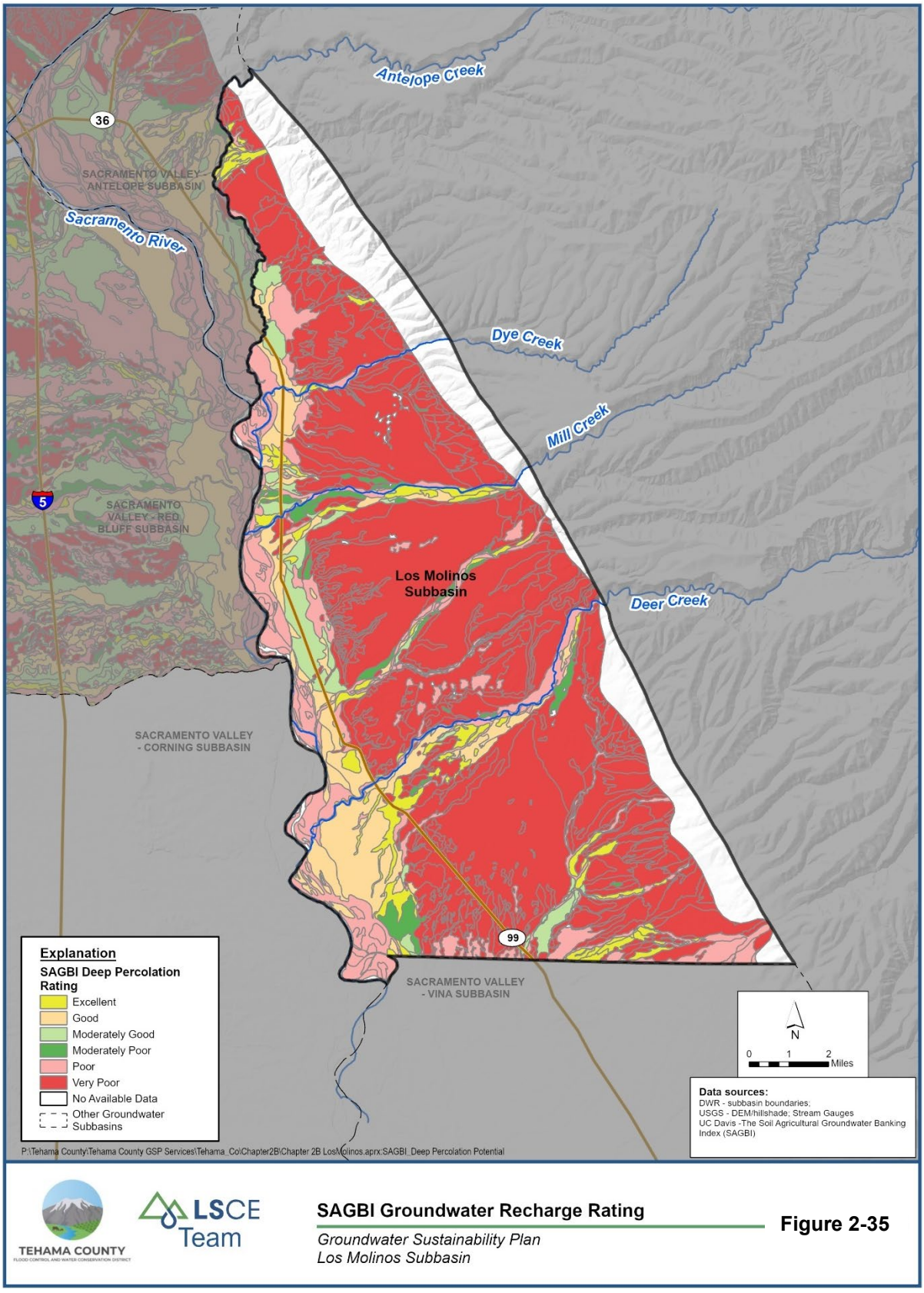
TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT

LSCE Team

Map of Surface Water Features

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-34



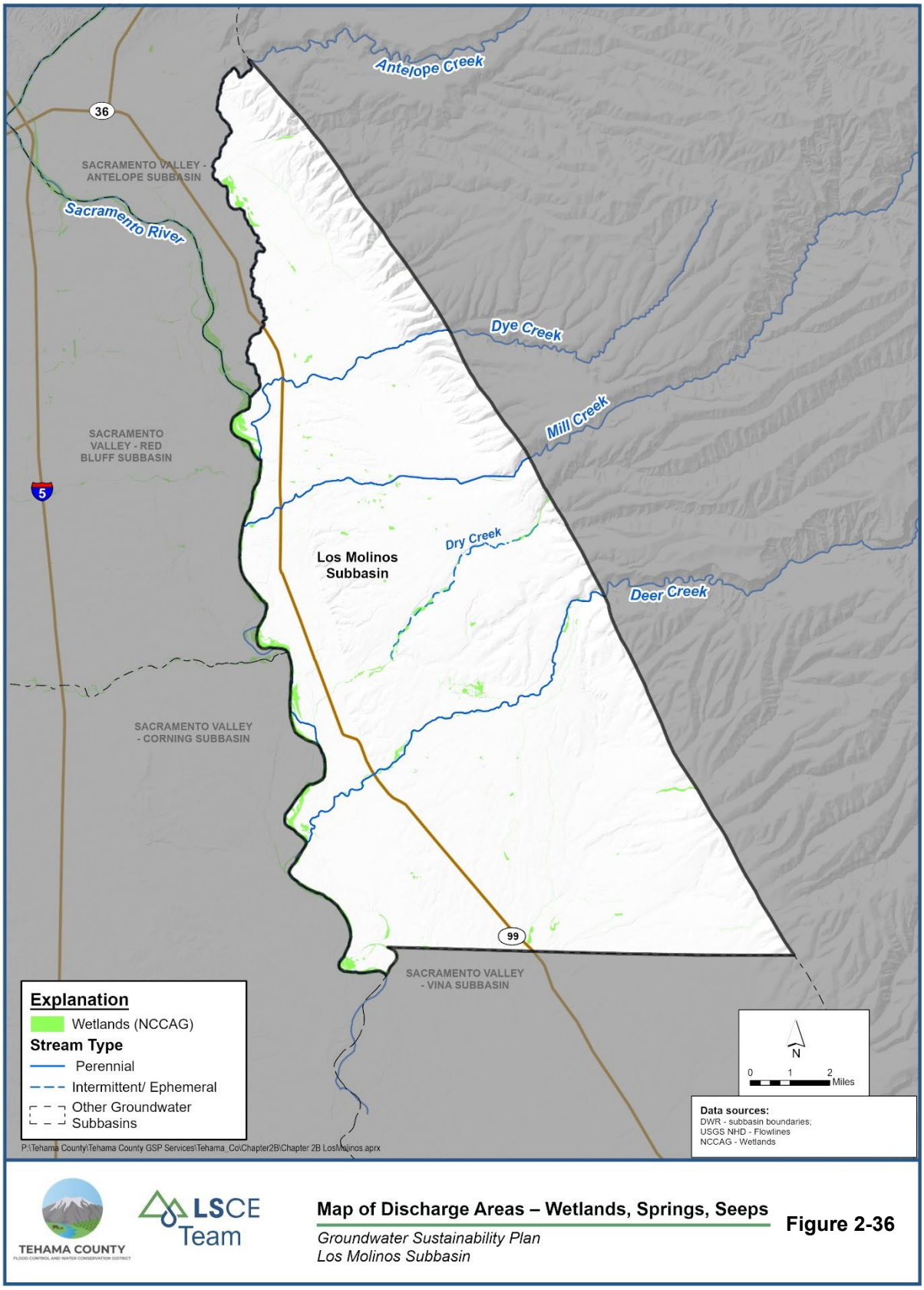
TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT

LSCE Team

SAGBI Groundwater Recharge Rating

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-35


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
Dry Creek
Los Molinos Subbasin
Deer Creek
SACRAMENTO VALLEY - CORNING SUBBASIN
99
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
Wetlands (NCCAG)
Stream Type
Perennial
Intermittent/ Ephemeral
Other Groundwater Subbasins
N
0 1 2 Miles
Data sources:
DWR - subbasin boundaries;
USGS NHD - Flowlines
NCCAG - Wetlands
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B LosMolinos.aprx
TEHAMA COUNTY
LSCE Team
Map of Discharge Areas – Wetlands, Springs, Seeps
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-36

2.2.1.8 Data Gaps and Uncertainty

Stratigraphy

The general stratigraphy of the subsurface within the Subbasin is characterized based on past studies and LSCE's interpretation of well completion reports and geophysical logs, however, specific thicknesses and lateral extent of formations is poorly understood. The western extent of the Tuscan Formation in the vicinity of the Sacramento River is poorly defined and the extent of the interfingering between the Tuscan and Tehama Formations in the subsurface is not known. The Hydrogeologic properties differ between the two formations, and it would be beneficial to know where the properties change so aquifer zones could be better constrained and future wells could be screened in targeted intervals.

Hydrogeologic Parameters

Estimates of hydrogeologic parameters are available for site-specific areas in the Subbasin and parameters have been estimated for geologic formations outside of the Subbasin; however, the formations vary with extent and may be different in other areas of the Subbasin. Parameters like storativity, transmissivity, and hydraulic conductivity can be estimated based on geology however, without field and lab measurements the range of values is significant. Future pump tests and testing of soil collected from drilling will help characterize the parameters specific to the Subbasin.

Surface Water and Recharge

Surface water and groundwater interconnectivity is based on observable relationships between streams and shallow groundwater. There is a lack of shallow wells near active stream gages, a condition needed to establish the relationship. Future frequent monitoring from the existing- and from new- stream gauges along the major waterways and new proximal shallow monitoring wells would help to describe interaction between surface water and groundwater.

2.2.2 Current and Historical Groundwater Conditions

An understanding of groundwater levels and the direction of flow is essential to sustainable groundwater management. This includes both the spatial and temporal variation of groundwater levels which are a function of geology, groundwater management, land use, and climatic conditions. Historical and current groundwater levels of the Subbasin were evaluated using data obtained from public databases (DWR, SWRCB, and USGS) and information available in the literature. LSCE performed a quality assurance/quality control (QA/QC) process on compiled data, which included evaluation of data for completeness and duplication, as well as identification of questionable data.

2.2.2.1 Groundwater Levels and Flow Direction

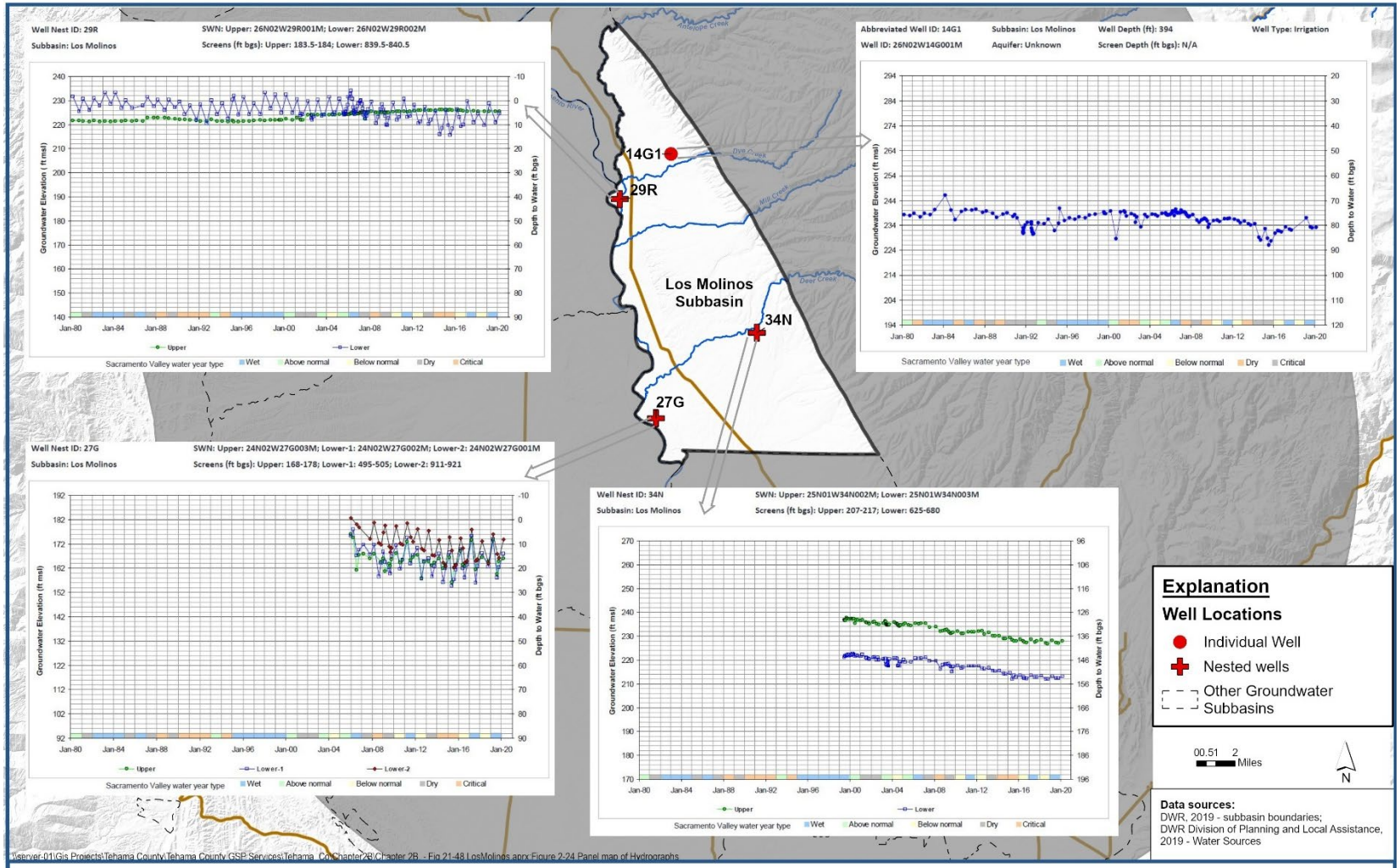
2.2.2.1.1 *Groundwater Levels*

To gain a historical perspective of trends in groundwater levels, hydrographs were generated for wells with historical time series data of sufficient period of record. Representative hydrographs and the locations of corresponding wells are shown in **Figure 2-37**, while all hydrographs used for the groundwater level evaluation are in **Appendix 2-F**. A graphical illustration that describes information shown on a

hydrograph is also included in **Appendix 2-F**. Trends of groundwater levels can be observed over various time periods when data is available. The time-series data also show seasonal variations and changes that correspond to wet and dry periods of the Subbasin. The total annual precipitation measured at the Red Bluff Municipal Airport (RBF) and Orland (ORL) show strong positive correlations with the Sacramento Valley Water Year Index (Pearson's correlation coefficients of 0.72 and 0.73, respectively). **Figure 2-34** shows the locations of the rain gages, and **Figure 2-38** shows the annual precipitation and cumulative departure curve of precipitation at Orland. Sacramento Valley hydrology between water years of 1990 and 2018 (representative base period of this GSP which represents long-term average annual hydrologic conditions), indicate multi-year wet periods occurred in 1995-1999, while multi-year dry periods occurred in 1990-1992 (started in 1987), 2007-2009 and 2013-2015 (**Table 2-9**).

Upper Aquifer

Seasonal high-water levels in the Upper Aquifer (in winter/spring seasons) during wet periods range between a few feet below ground surface and about 90 ft bgs. Depth to water is shallower in the valley floor of the western part of the Subbasin (less than 40 ft bgs) compared to that in the eastern hillslopes. Groundwater levels decreased during dry periods likely due to the combined effect of increased withdrawal from wells and reduction in recharge. The lowest groundwater levels in recent history (since 1980) occurred during the 2013-2015 drought. During that period, seasonal high-water levels decreased by up to about 5 ft in most areas, but the decrease was up to 10 ft at some locations compared to previous wet periods. Recent data indicate that the groundwater levels partially or completely recovered to pre-drought levels since then. Seasonal water level fluctuations of most wells during a water year are less than five feet, but fluctuations up to about 10 ft occur at some wells depending on well location, construction, and local water use.



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Panel Map of Selected Groundwater Elevation Hydrographs

Figure 2-37

Groundwater Sustainability Plan
Los Molinos Subbasin

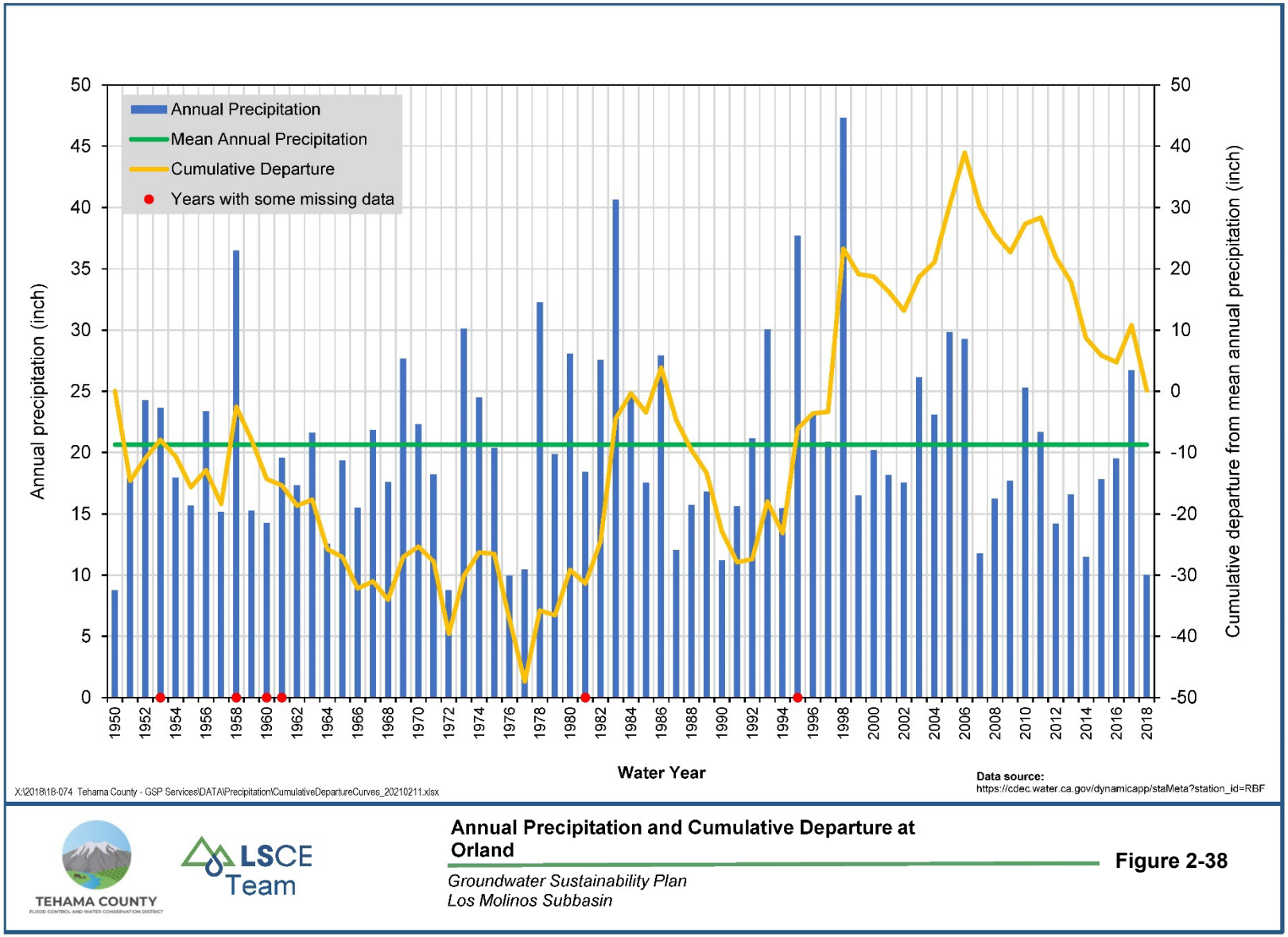

Annual Precipitation
Mean Annual Precipitation
Cumulative Departure
Years with some missing data
Annual precipitation (inch)
Cumulative departure from mean annual precipitation (inch)
Water Year
X:\2018\18-074 Tehama County - GSP Services\DATA\Precipitation\CumulativeDepartureCurves_20210211.xlsx
Data source:
https://cdec.water.ca.gov/dynamicapp/staMeta?station_id=RBF
TEHAMA COUNTY
LSCE Team
Annual Precipitation and Cumulative Departure at Orland
Figure 2-38
Groundwater Sustainability Plan
Los Molinos Subbasin

Table 2-9. Sacramento Valley Water Year Types Since 1980

WATER YEAR	WATER YEAR INDEX	WATER YEAR TYPE
1980	9.04	Above Normal
1981	6.21	Dry
1982	12.76	Wet
1983	15.29	Wet
1984	10.00	Wet
1985	6.47	Dry
1986	9.96	Wet
1987	5.86	Dry
1988	4.65	Critical
1989	6.13	Dry
1990	4.81	Critical
1991	4.21	Critical
1992	4.06	Critical
1993	8.54	Above Normal
1994	5.02	Critical
1995	12.89	Wet
1996	10.26	Wet
1997	10.82	Wet
1998	13.31	Wet
1999	9.80	Wet
2000	8.94	Above Normal
2001	5.76	Dry
2002	6.35	Dry
2003	8.21	Above Normal
2004	7.51	Below Normal
2005	8.49	Above Normal
2006	13.20	Wet
2007	6.19	Dry
2008	5.16	Critical
2009	5.78	Dry
2010	7.08	Below Normal
2011	10.54	Wet
2012	6.89	Below Normal
2013	5.83	Dry
2014	4.07	Critical
2015	4.00	Critical
2016	6.71	Below Normal
2017	14.14	Wet
2018	7.14	Below Normal
2019	10.34	Wet

Source - https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST
Accessed in January 2021

Lower Aquifer

Depth to water in the Lower Aquifer ranges from less than one foot (i.e., close to the ground surface) to about 10 ft bgs close to the western boundary of the Subbasin, and it gradually increases towards the eastern boundary up to about 150 ft bgs. Seasonal fluctuations, as well as fluctuations that correspond to wet and dry climatic conditions, are less than five feet in most areas. However, range of these fluctuations can be up to 10 ft close to the western boundary of the Subbasin.

Trends in Groundwater Levels

Statistical analysis was conducted on data from eight wells, which have data that span the entirety of the 1990 through 2018 hydrologic base period. Stable groundwater levels are observed both in the northern and southern areas of the Subbasin. Five of these eight wells are screened in the Upper Aquifer, two are screened only in the Lower Aquifer and the other well is likely a composite well (screen depths are unknown, but the well penetrates both aquifers). Seasonal high-water levels of seven wells show small declines (between two feet to seven feet during 1990-2018 period at rates between 0.1 to 0.25 ft/year). The other well, an Upper Aquifer well close to the Sacramento River and Dye Creek, shows a slight increasing trend of seasonal high elevations (about five feet during 1990-2018 period). Results of the groundwater level trend analysis, which used both parametric (Ordinary least squares regression) and nonparametric (Mann-Kendall and Theil–Sen) methods, are included in **Appendix 2-F**. The slightly decreasing trend of groundwater levels is not an indication of overdraft, but likely due to removal of temporary surplus of groundwater. Temporary surplus removal is the extraction of a volume of aquifer storage to enable the capture of recharge and reduction in subsurface outflow from the Subbasin without impacting beneficial users of groundwater to an unreasonable degree.

A factor in trends observed in groundwater elevation change is the potential gradual increase of groundwater withdrawal. Even though the actual amount of extracted groundwater from wells is not metered or directly measured, changes in land use and the number of wells constructed over time could be used to indicate an increase in groundwater withdrawal in the Subbasin. Well completion reports obtained from DWR show that approximately 770 new wells (all types, domestic, irrigation and public supply) were constructed from 1970 to 1999. Construction continued into the last two decades, 2000-2009 and 2010-2019, with about 160 and 100 new wells, respectively. The increase of total wells in the Subbasin suggests increased total pumping (withdrawal) contributing to observed slightly declining groundwater level trends. Land use details are presented in Section 2.2.2.1, and water budgets are discussed in detail in Section 2.3.

2.2.2.1.2 *Groundwater Elevation Contours and Flow Directions (§354.16(a)(1))*

Groundwater elevation contour maps were created to evaluate general groundwater flow directions in both aquifers. Seasonal high and seasonal low water elevations of Upper Aquifer wells (wells screened only within the Upper Aquifer) and Lower Aquifer wells (wells screened only within the Lower Aquifer) were used to develop contours of equal groundwater elevation (“Contours”). Water levels of wells that are entirely screened within the top 50 ft bgs were excluded from contouring of Upper Aquifer groundwater elevations, since these wells are likely not representative of the areas of the aquifer where groundwater pumping occurs. Also, wells screened both in the Upper and Lower Aquifers (composite

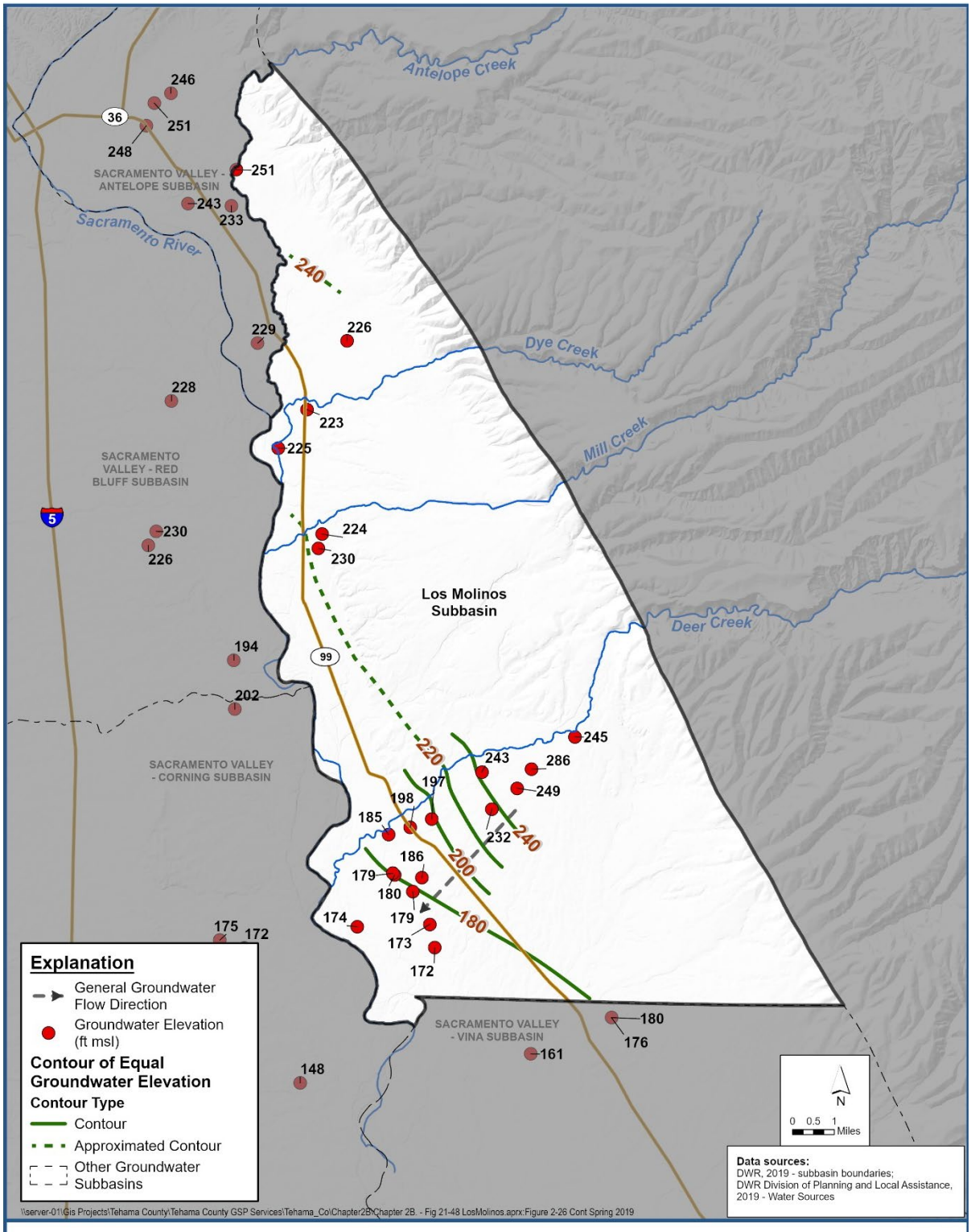
wells), and wells without construction details were excluded from contouring because these wells may not represent aquifer-specific groundwater elevations. Contours were initially developed using spatial analyst tools in ArcGIS software, and then modified based on professional judgement.

Contour maps were created to evaluate seasonal high and seasonal low groundwater conditions in multiple years that included wet, dry, and critical water year types between 1990 and 2019. Contours of current groundwater conditions are represented using the groundwater elevations of water year 2019. After evaluation of groundwater level hydrographs with long-term data and the Sacramento Valley water year type record (**Table 2-9**), water years 2017, 2013, and 2015 were considered to represent groundwater conditions in wet, dry, and critical years, respectively.

Upper Aquifer

Upper Aquifer wells with water level data are common in the valley floor close to the Deer Creek, Mill Creek and Dye Creek, but sparse in other areas of the Subbasin. Therefore, contours were not developed for areas in the eastern hillslopes and southeastern portion of the Subbasin where data was lacking. Groundwater elevations generally increase towards eastern and northern areas of the Subbasin. The lowest groundwater elevations occur in the southwestern portion (west of State Highway 99E and south of Deer Creek).

Upper Aquifer contour maps show that the water level fluctuations between winter/spring and fall seasons, as well as between different water year types are relatively small (less than five feet in most areas). Groundwater elevations in 2019 ranged from about 170 to 250 ft msl during seasonal high conditions (**Figure 2-39**), and the elevations decreased by five feet to 10 ft at different locations of the Subbasin during seasonal low conditions (**Figure 2-40**). Nearly similar seasonal elevations were present in the representative wet year (**Figures 2-41** and **2-42**). Compared to the wet year, seasonal high elevations in the dry year are about three feet to 10 ft deeper in areas south of the Mill Creek, but less than five feet deeper in the northern areas (**Figure 2-43**). However, seasonal low elevations of a dry year (**Figure 2-44**) and that of a wet year are nearly similar. Groundwater elevations in a critical year remains nearly similar to the elevations of a dry year (**Figure 2-45** and **Figure 2-46**), except a decrease of up to five feet in seasonal low elevations in areas south of Deer Creek.



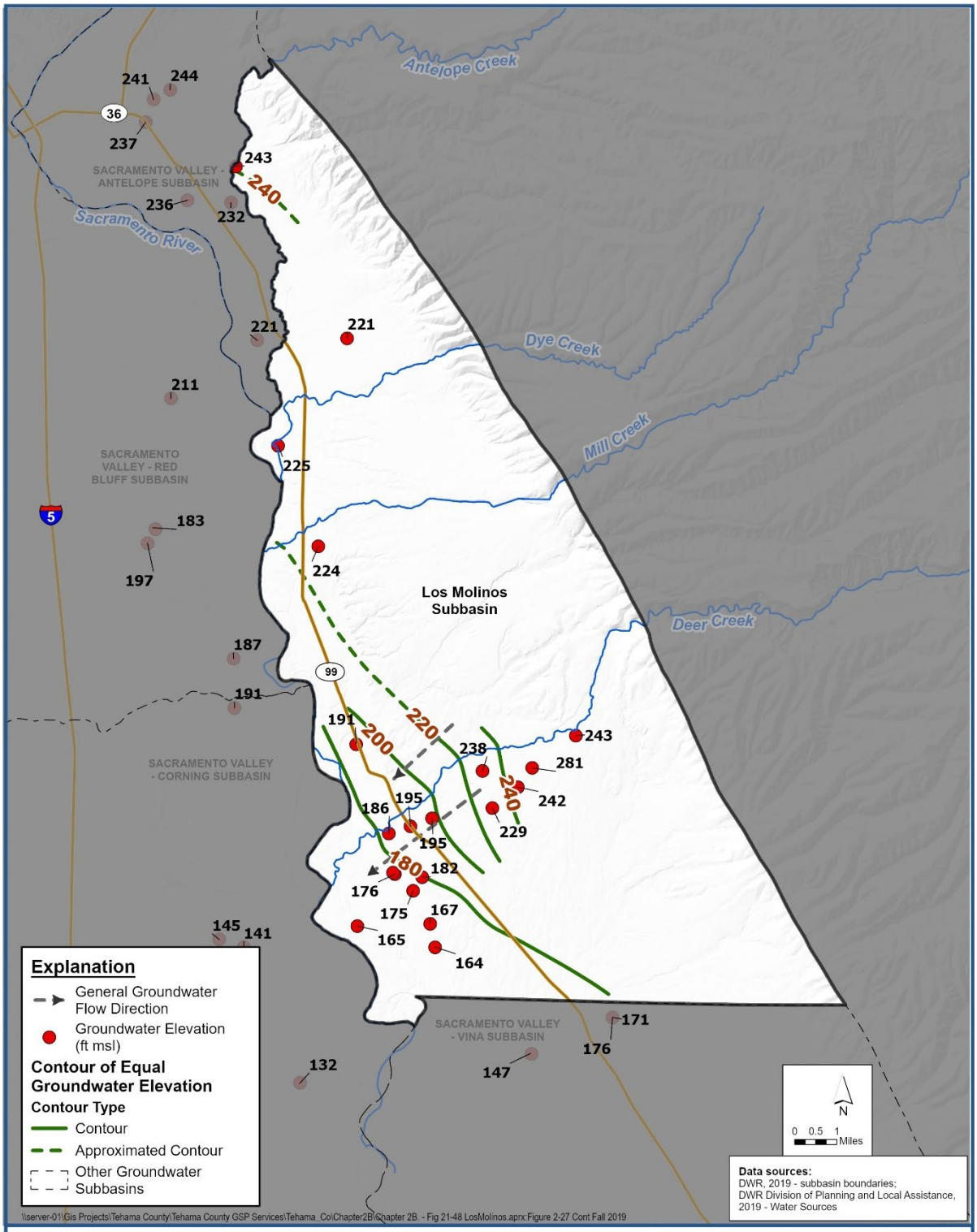
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Contours of Equal Groundwater Elevation
Upper Aquifer – Seasonal High of 2019

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-39



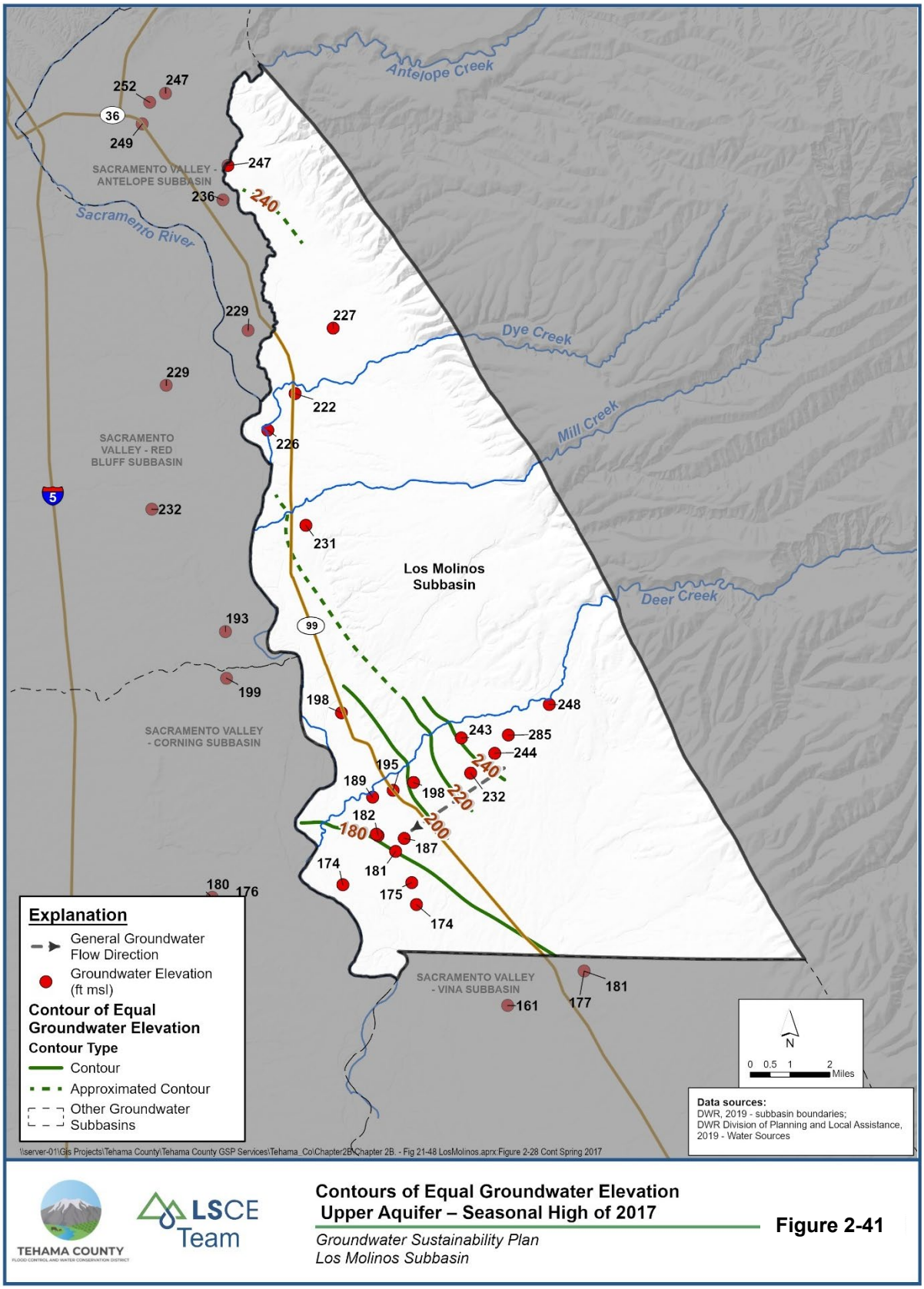
TEHAMA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT

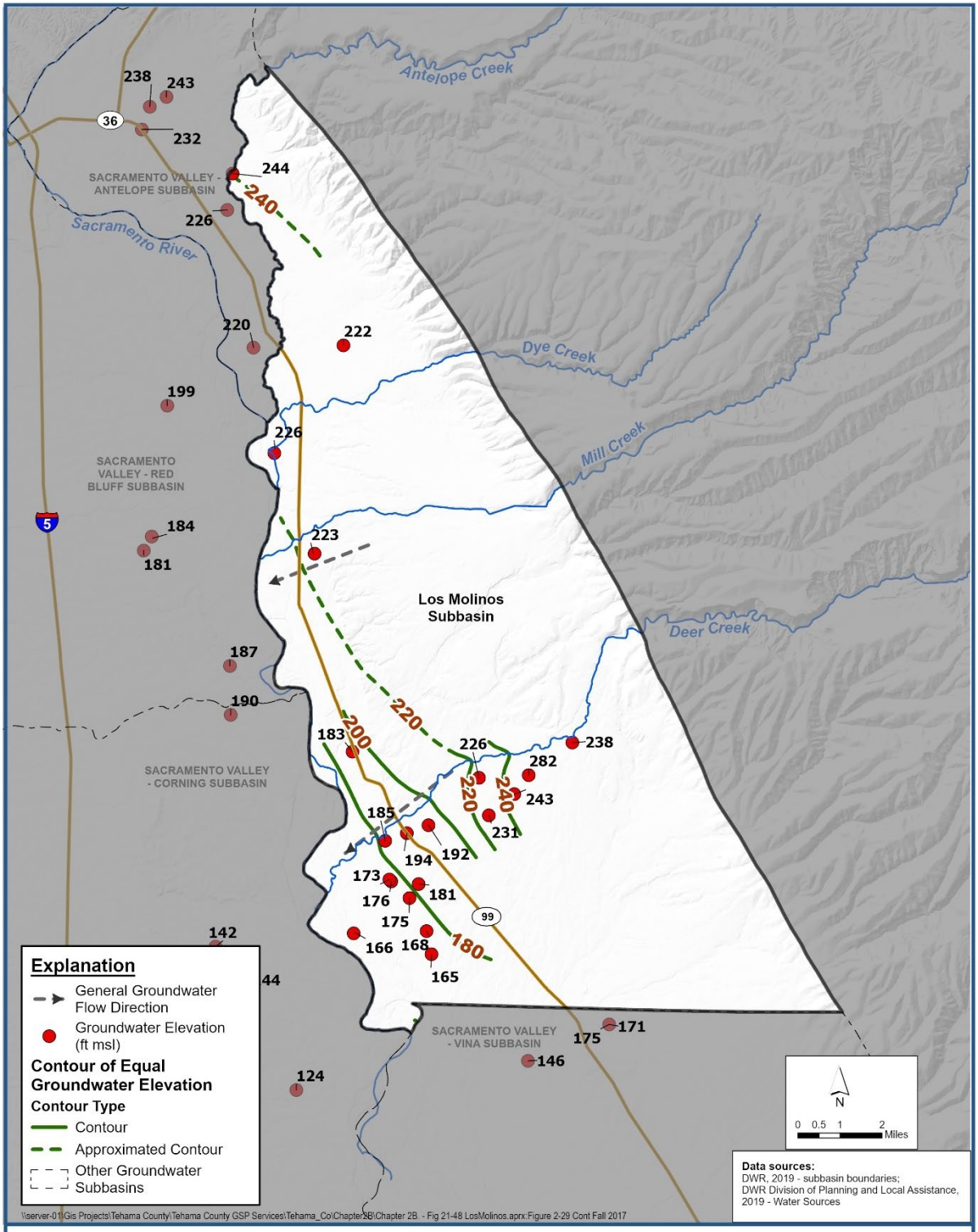
LSCE Team

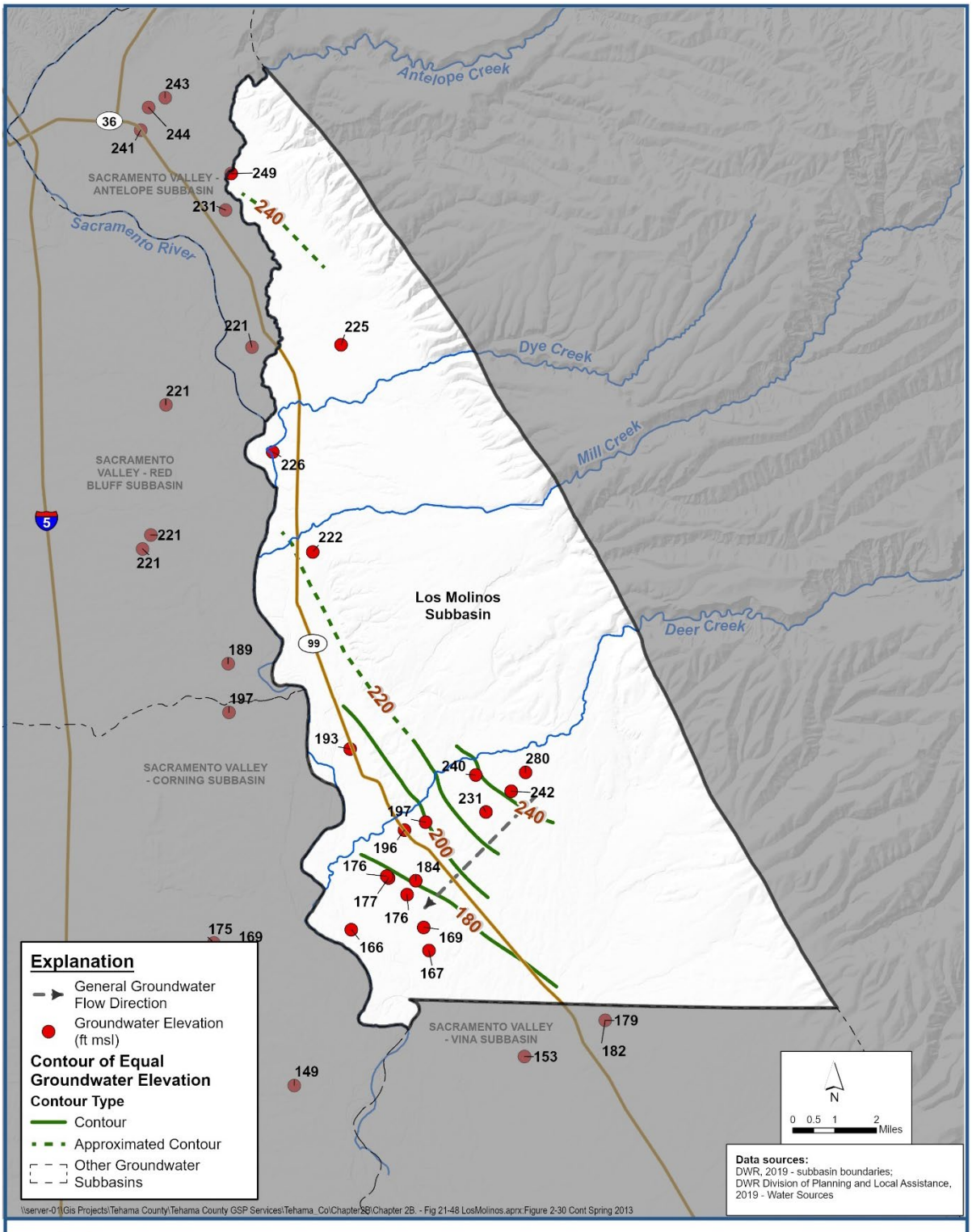
Contours of Equal Groundwater Elevation
Upper Aquifer – Seasonal Low of 2019

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-40


Antelope Creek
Dye Creek
Mill Creek
Deer Creek
Sacramento River
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
SACRAMENTO VALLEY - CORNING SUBBASIN
SACRAMENTO VALLEY - VINA SUBBASIN
Los Molinos Subbasin
252
247
249
247
236
240
229
227
229
222
226
232
231
193
199
198
248
243
285
244
240
195
189
198
220
232
182
180
200
187
174
181
175
174
180
176
181
177
161
36
5
99
Explanation
General Groundwater Flow Direction
Groundwater Elevation (ft msl)
Contour of Equal Groundwater Elevation
Contour Type
Contour
Approximated Contour
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
\\server-01\Gis Projects\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B. - Fig 21-48 LosMolinos.aprx:Figure 2-28 Cont Spring 2017
TEHAMA COUNTY
LSCE Team
Contours of Equal Groundwater Elevation
Upper Aquifer – Seasonal High of 2017
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-41


Antelope Creek
Dye Creek
Mill Creek
Deer Creek
Sacramento River
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
SACRAMENTO VALLEY - CORNING SUBBASIN
SACRAMENTO VALLEY - VINA SUBBASIN
Los Molinos Subbasin
238
243
232
244
226
220
222
199
226
184
181
223
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190
183
226
238
282
243
231
185
194
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168
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5
99
Explanation
General Groundwater Flow Direction
Groundwater Elevation (ft msl)
Contour of Equal Groundwater Elevation
Contour Type
Contour
Approximated Contour
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
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TEHAMA COUNTY
LSCE Team
Contours of Equal Groundwater Elevation
Upper Aquifer – Seasonal Low of 2017
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-42



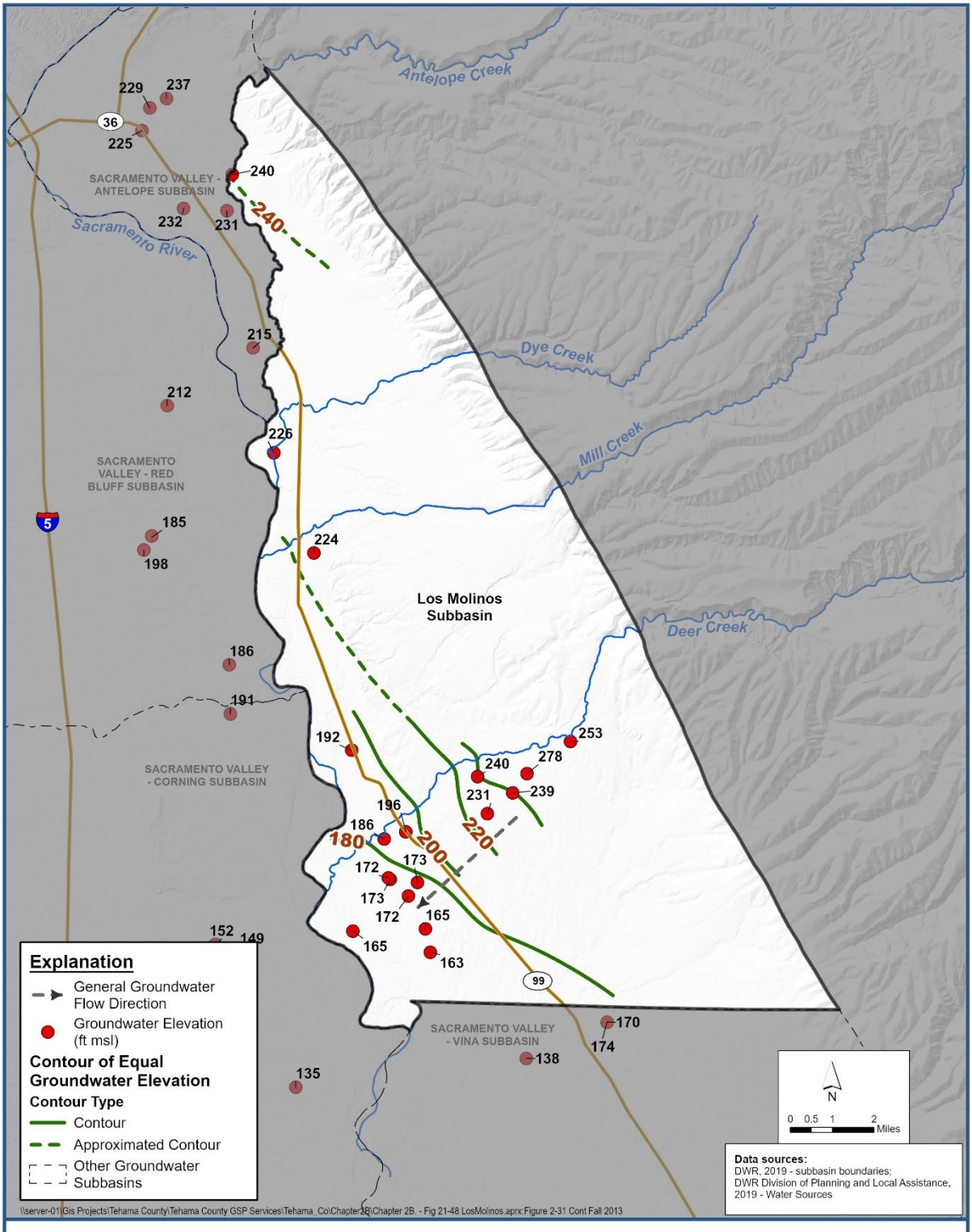
TEHAMA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT

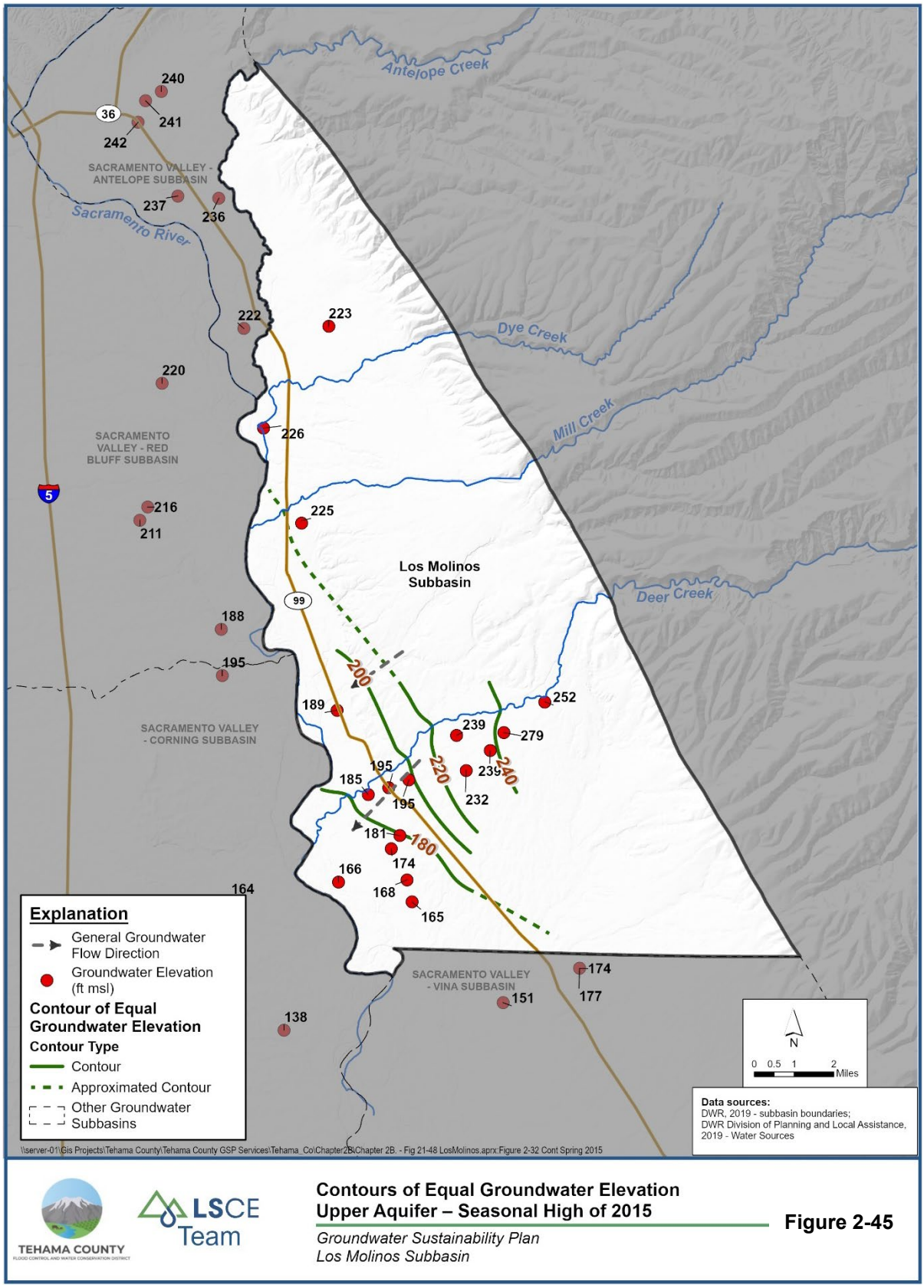
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Contours of Equal Groundwater Elevation
Upper Aquifer – Seasonal High of 2013

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-43


Antelope Creek
Dye Creek
Mill Creek
Deer Creek
Sacramento River
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
SACRAMENTO VALLEY - CORNING SUBBASIN
SACRAMENTO VALLEY - VINA SUBBASIN
Los Molinos Subbasin
229
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138
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99
36
5
Explanation
General Groundwater Flow Direction
Groundwater Elevation (ft msl)
Contour of Equal Groundwater Elevation
Contour Type
Contour
Approximated Contour
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
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TEHAMA COUNTY
LSCE Team
Contours of Equal Groundwater Elevation
Upper Aquifer – Seasonal Low of 2013
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-44



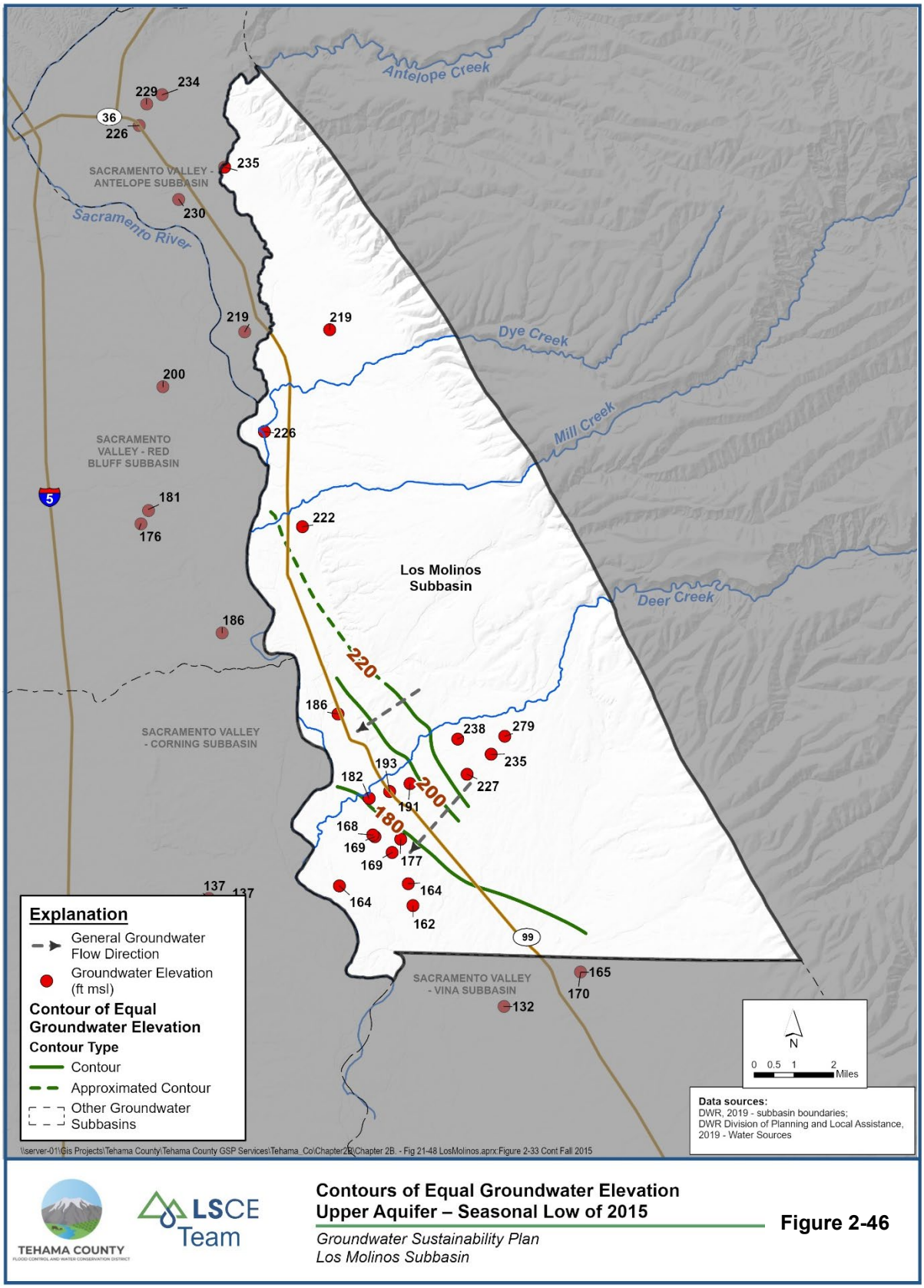
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Contours of Equal Groundwater Elevation
Upper Aquifer – Seasonal High of 2015

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-45



TEHAMA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT

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Contours of Equal Groundwater Elevation
Upper Aquifer – Seasonal Low of 2015

Groundwater Sustainability Plan
Los Molinos Subbasin

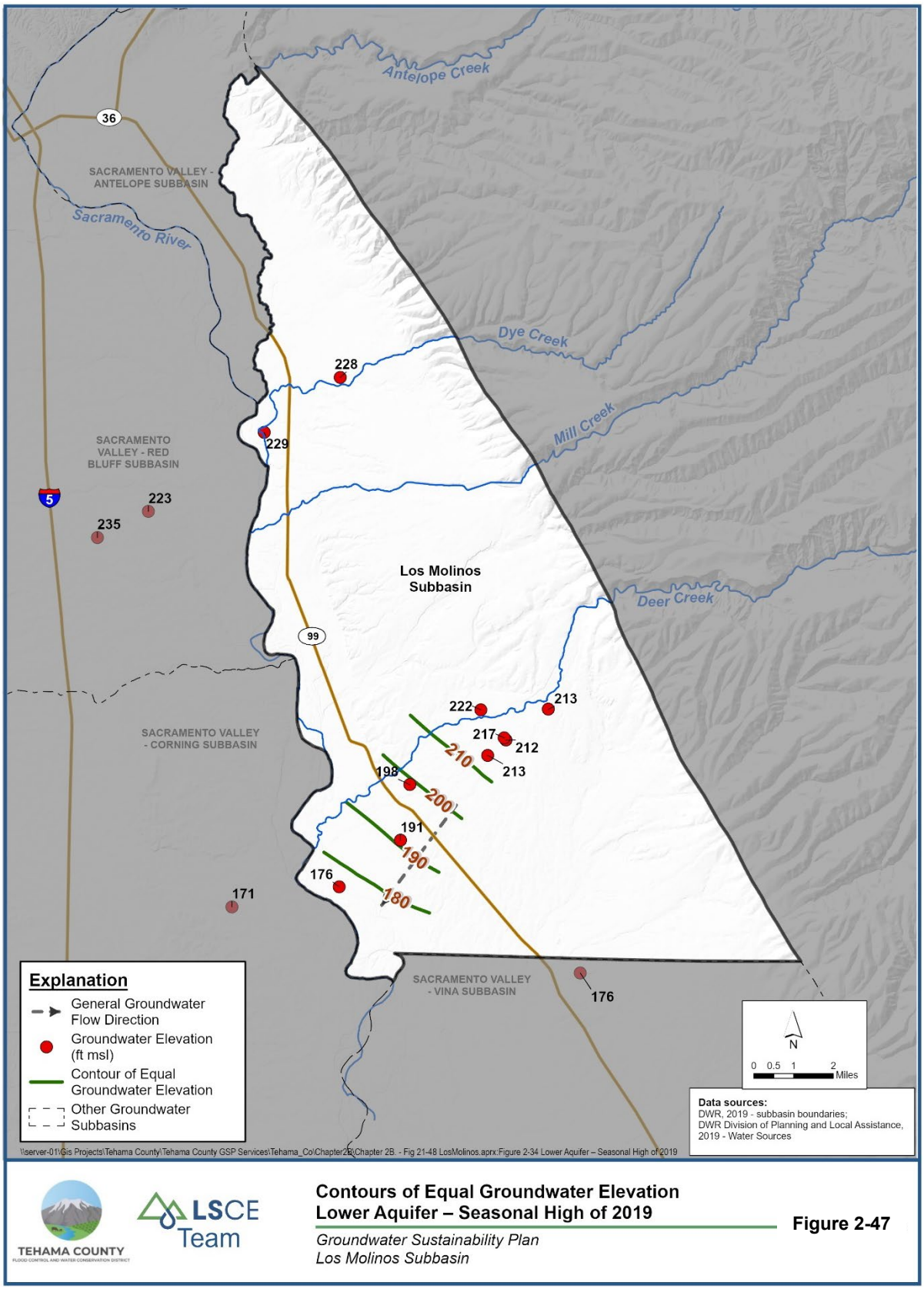
Figure 2-46

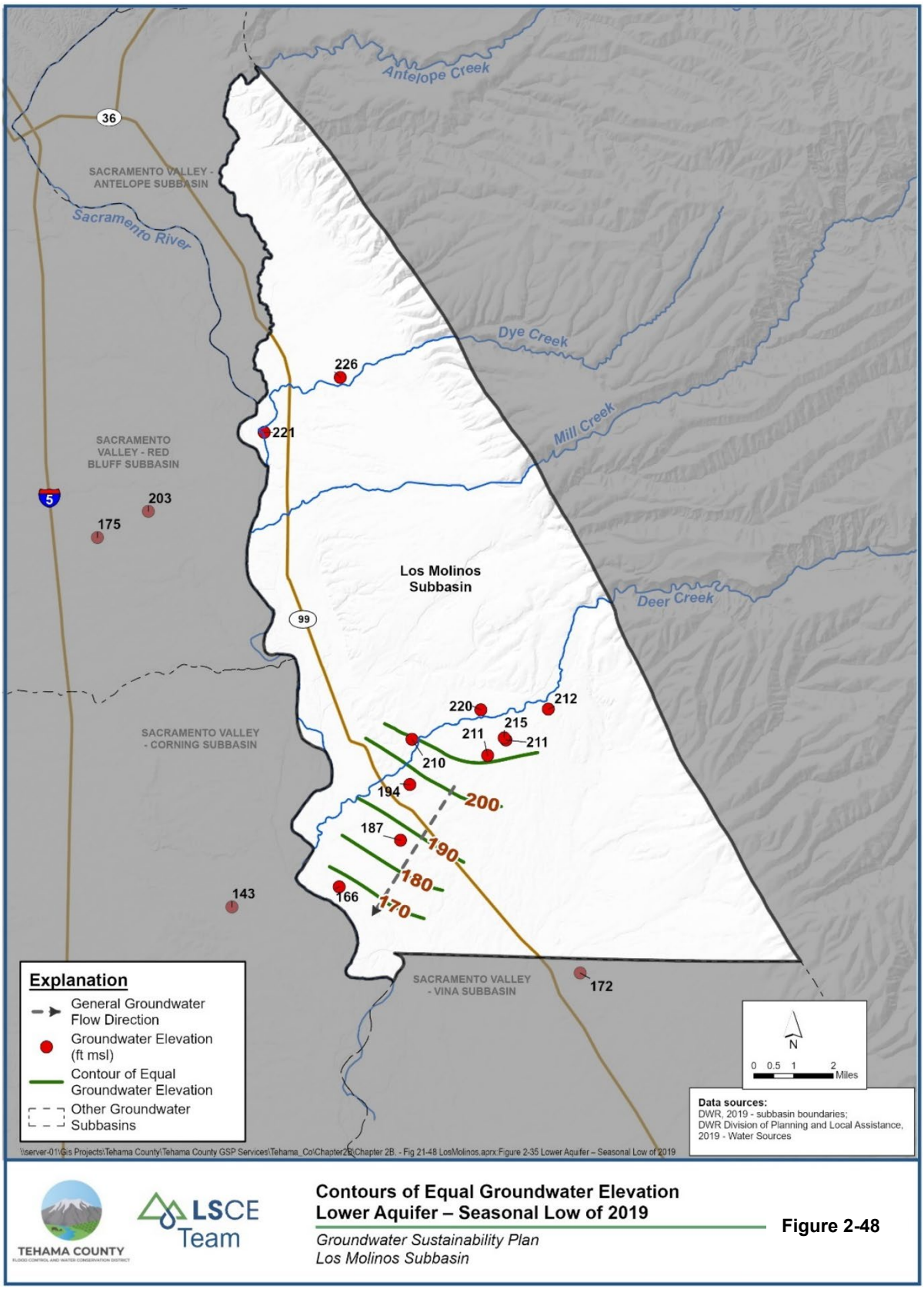
Groundwater contour maps of the Upper Aquifer indicate a westerly/southwesterly general flow from the elevated areas of the valley towards the Sacramento River in the valley floor. General groundwater flow directions in the Subbasin are primarily determined by the topography and influenced by local-scale groundwater withdrawal and recharge. Groundwater contour maps also show that the general horizontal hydraulic gradient in the southwestern portion of the Subbasin (south of Deer Creek) remains at about 20 feet per mile (ft/mile) during the winter/spring of all water year types, and the fall of wet years. The lateral gradient slightly increases to about 23 ft/mile during the fall of dry and critical water years. Historical water level data indicate a consistent, vertically downward hydraulic gradient in the Upper Aquifer. However, accurate quantification of vertical gradients is difficult because of lack of data from nested monitoring wells screened at different depths in the Upper Aquifer.

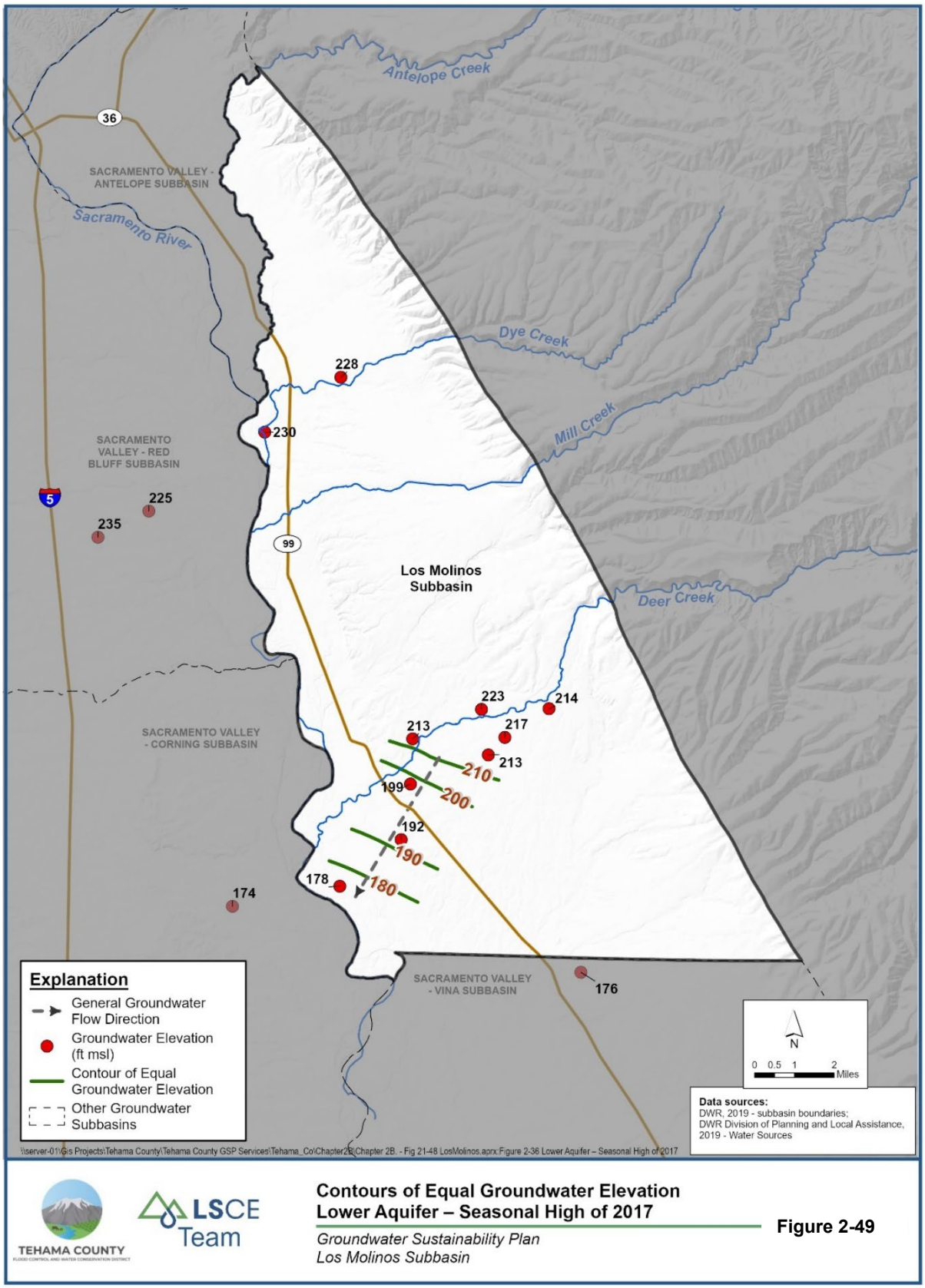
Vertical hydraulic gradient was evaluated using pairs of closely located (distance less than 1,000 ft) individual wells screened at different depths. Water level data of wells 24N01W05Q002M and 24N01W05Q003M indicate that the downward gradient in an area about three miles northeast of the town of Vina is approximately 0.10 with slight seasonal and annual fluctuations. However, water levels of wells 25N01W33J001M and 25N01W34N002M indicate that the downward gradient in an area about two miles further northeast (close to foothills) fluctuate between 0.20 and 0.40 without identifiable trends. Hydrographs of nested wells screened in the Upper Aquifer and Lower Aquifer show vertically downward hydraulic gradients of 0.01 to 0.02 between the two aquifers in most areas of the Subbasin. However, the gradient can increase up to about 0.04 in eastern foothills. Water levels of two nested wells (26N02W29R001M and 26N02W29R0012) close to the Sacramento River and Dye Creek (northwestern part of the Subbasin) show the historical occurrence of vertically upward gradients between the Upper and Lower Aquifer. Upward gradients of up to 0.02 were consistently observed during seasonal high conditions since the 1960s, until vertically downward gradients started to occur predominantly during dry conditions since 2011. During seasonal low conditions, upward gradients of up to 0.01 were observed in most years from the 1960s until 2005. Since then, the gradient remained vertically downward with magnitudes up to 0.02. Water level hydrographs and a location map of above-mentioned wells are given in **Appendix 2-F**.

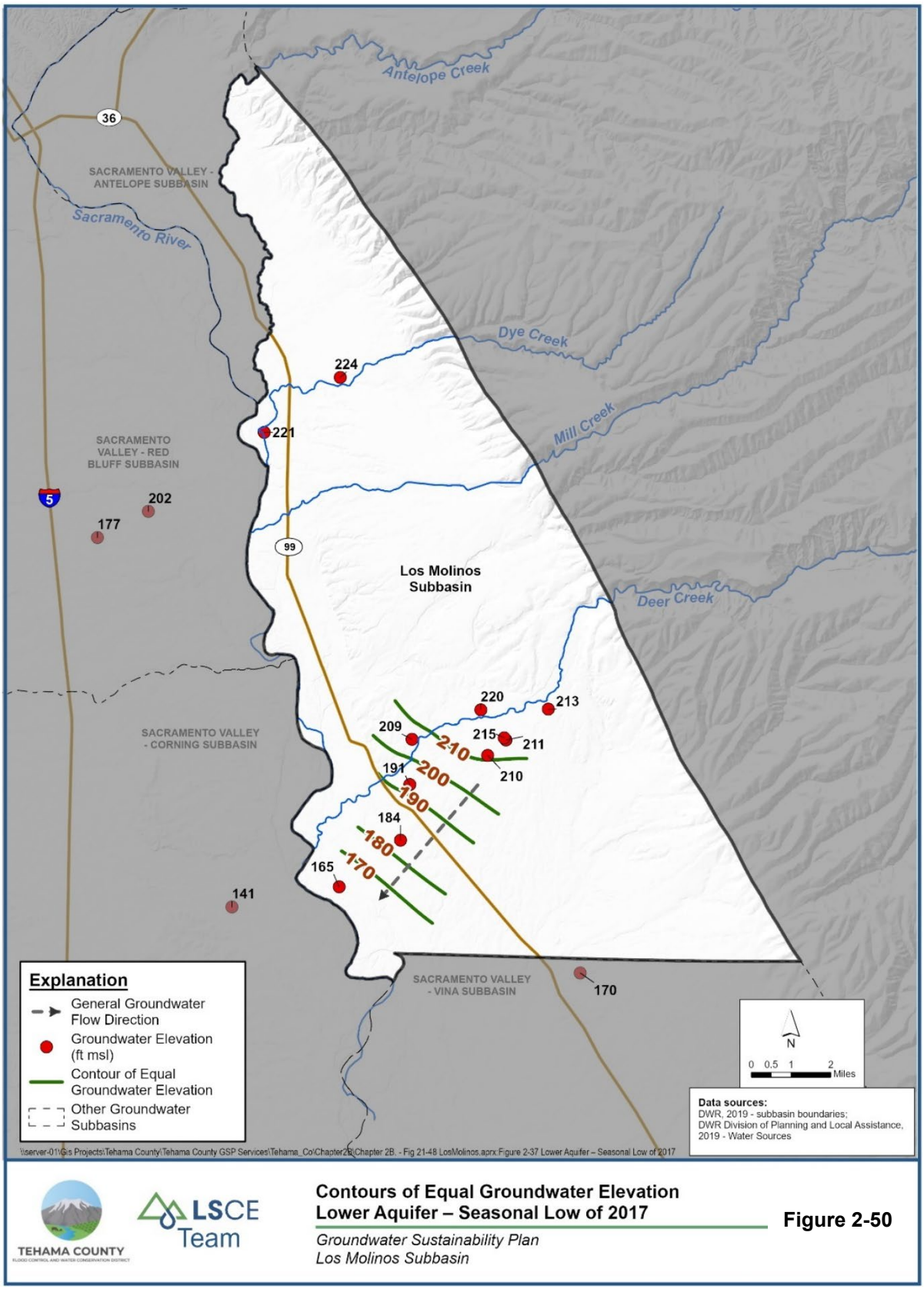
Lower Aquifer

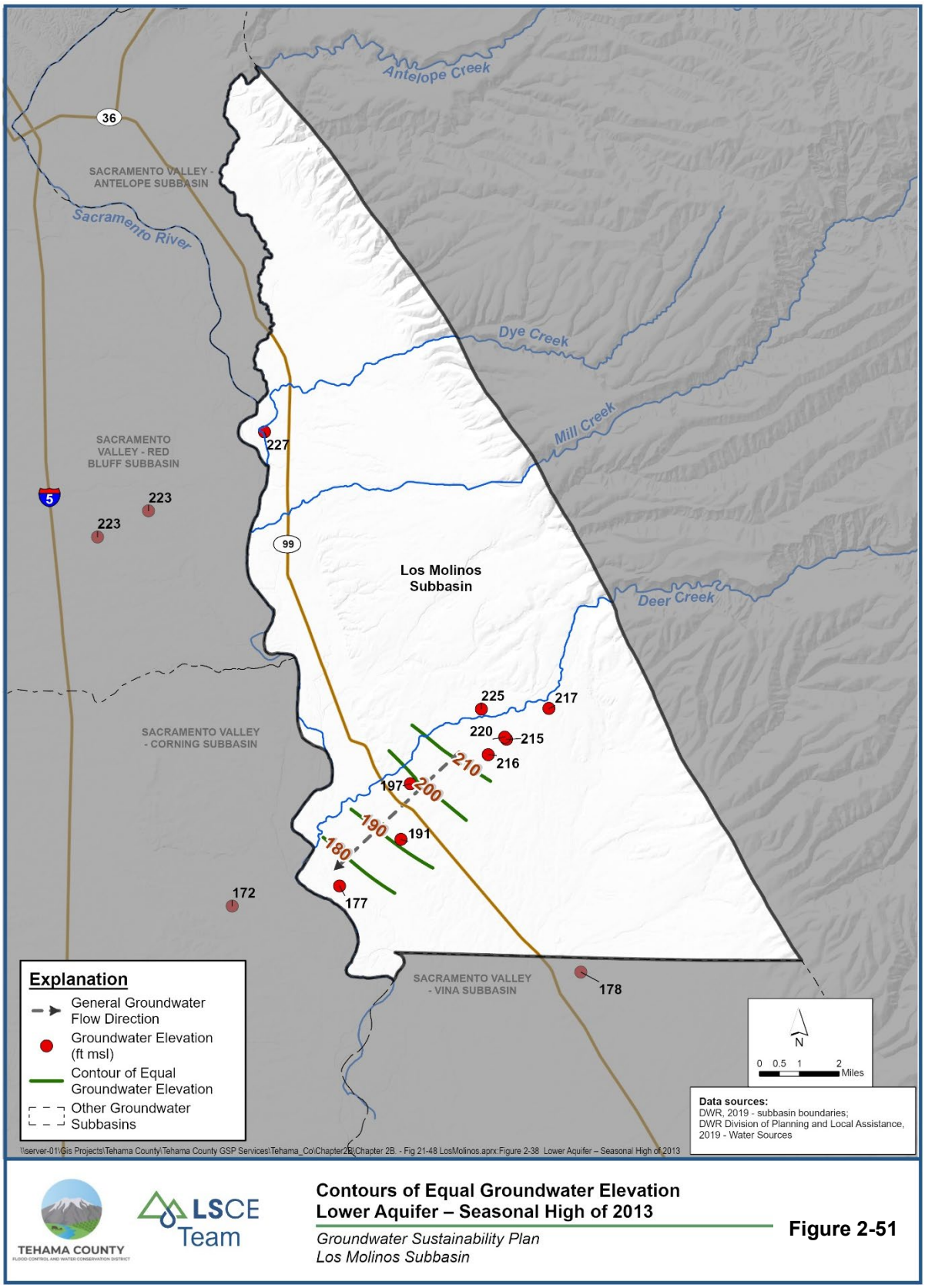
Groundwater elevations in the Lower Aquifer also increase towards eastern and northern areas of the Subbasin. Similar to groundwater elevations in the Upper Aquifer, the lowest groundwater elevations of the Lower Aquifer also occur in the southwestern portion of the Subbasin (west of State Highway 99E and south of Deer Creek). Also, groundwater level fluctuations in the Lower Aquifer between winter/spring and fall seasons, as well as between different water year types are relatively small (less than 10 ft in most areas). Groundwater elevations of 2019 ranged from about 175 to 230 ft msl during seasonal high conditions (**Figure 2-47**). During seasonal low conditions, the elevations decreased by few feet in most areas of the Subbasin, but the decreases of up to 10 ft were observed in areas west of State Highway 99E (**Figure 2-48**). Nearly similar seasonal elevations were present in the representative wet year (**Figures 2-49** and **2-50**). Compared to the wet year, seasonal elevations in the dry year (**Figures 2-51** and **2-52**) decreased by less than five feet most areas. In the critical year, seasonal high elevations (**Figure 2-53**) were nearly similar to that of the dry year, however seasonal low elevations (**Figure 2-54**) decreased by up to six feet in most areas of the Subbasin.


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
228
Mill Creek
229
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
223
235
Los Molinos Subbasin
Deer Creek
99
222
213
217
212
213
210
198
200
191
190
176
180
171
SACRAMENTO VALLEY - CORNING SUBBASIN
SACRAMENTO VALLEY - VINA SUBBASIN
176
Explanation
General Groundwater Flow Direction
Groundwater Elevation (ft msl)
Contour of Equal Groundwater Elevation
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
\\server-01\Gis Projects\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B. - Fig 21-48 LosMolinos.aprx:Figure 2-34 Lower Aquifer – Seasonal High of 2019
TEHAMA COUNTY
LSCE Team
Contours of Equal Groundwater Elevation
Lower Aquifer – Seasonal High of 2019
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-47


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
226
221
Mill Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
203
175
Los Molinos Subbasin
Deer Creek
99
220
212
215
211
211
210
194
200
187
190
180
170
143
166
SACRAMENTO VALLEY - CORNING SUBBASIN
SACRAMENTO VALLEY - VINA SUBBASIN
172
Explanation
General Groundwater Flow Direction
Groundwater Elevation (ft msl)
Contour of Equal Groundwater Elevation
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
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TEHAMA COUNTY
LSCE Team
Contours of Equal Groundwater Elevation
Lower Aquifer – Seasonal Low of 2019
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-48


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
228
230
Mill Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
225
235
99
Los Molinos Subbasin
Deer Creek
223
214
213
217
213
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199
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174
SACRAMENTO VALLEY - CORNING SUBBASIN
SACRAMENTO VALLEY - VINA SUBBASIN
176
Explanation
General Groundwater Flow Direction
Groundwater Elevation (ft msl)
Contour of Equal Groundwater Elevation
Other Groundwater Subbasins
N
0 0.5 1 2 Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
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TEHAMA COUNTY
LSCE Team
Contours of Equal Groundwater Elevation
Lower Aquifer – Seasonal High of 2017
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-49

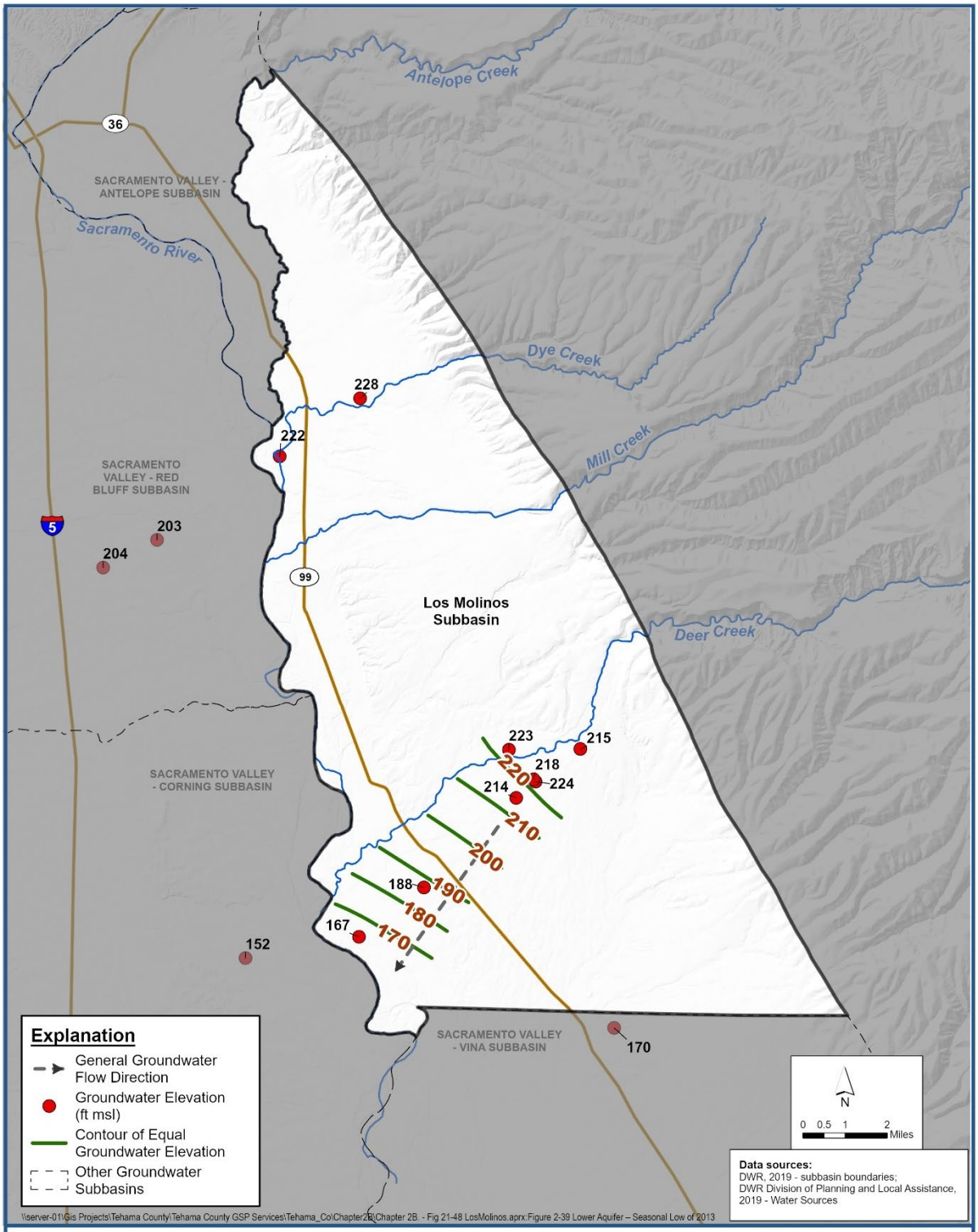

Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
224
221
Mill Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
202
177
99
Los Molinos Subbasin
Deer Creek
220
213
209
215
211
210
191
184
165
141
SACRAMENTO VALLEY - CORNING SUBBASIN
210
200
190
180
170
SACRAMENTO VALLEY - VINA SUBBASIN
170
Explanation
General Groundwater Flow Direction
Groundwater Elevation (ft msl)
Contour of Equal Groundwater Elevation
Other Groundwater Subbasins
N
0 0.5 1 2 Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
\\server-01\Gis Projects\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B. - Fig 21-48 LosMolinos.aprx:Figure 2-37 Lower Aquifer – Seasonal Low of 2017
TEHAMA COUNTY
LSCE Team
Contours of Equal Groundwater Elevation
Lower Aquifer – Seasonal Low of 2017
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-50

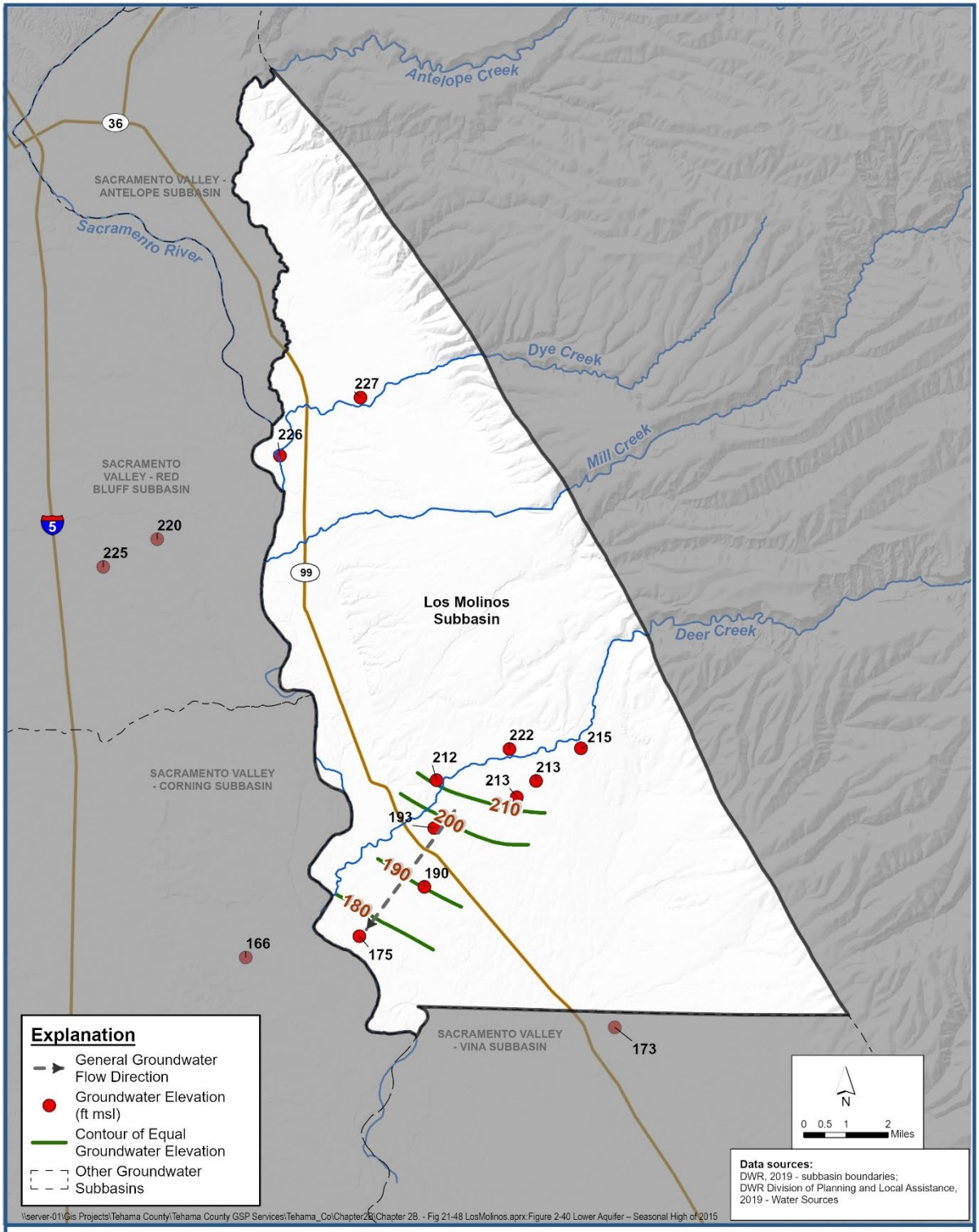


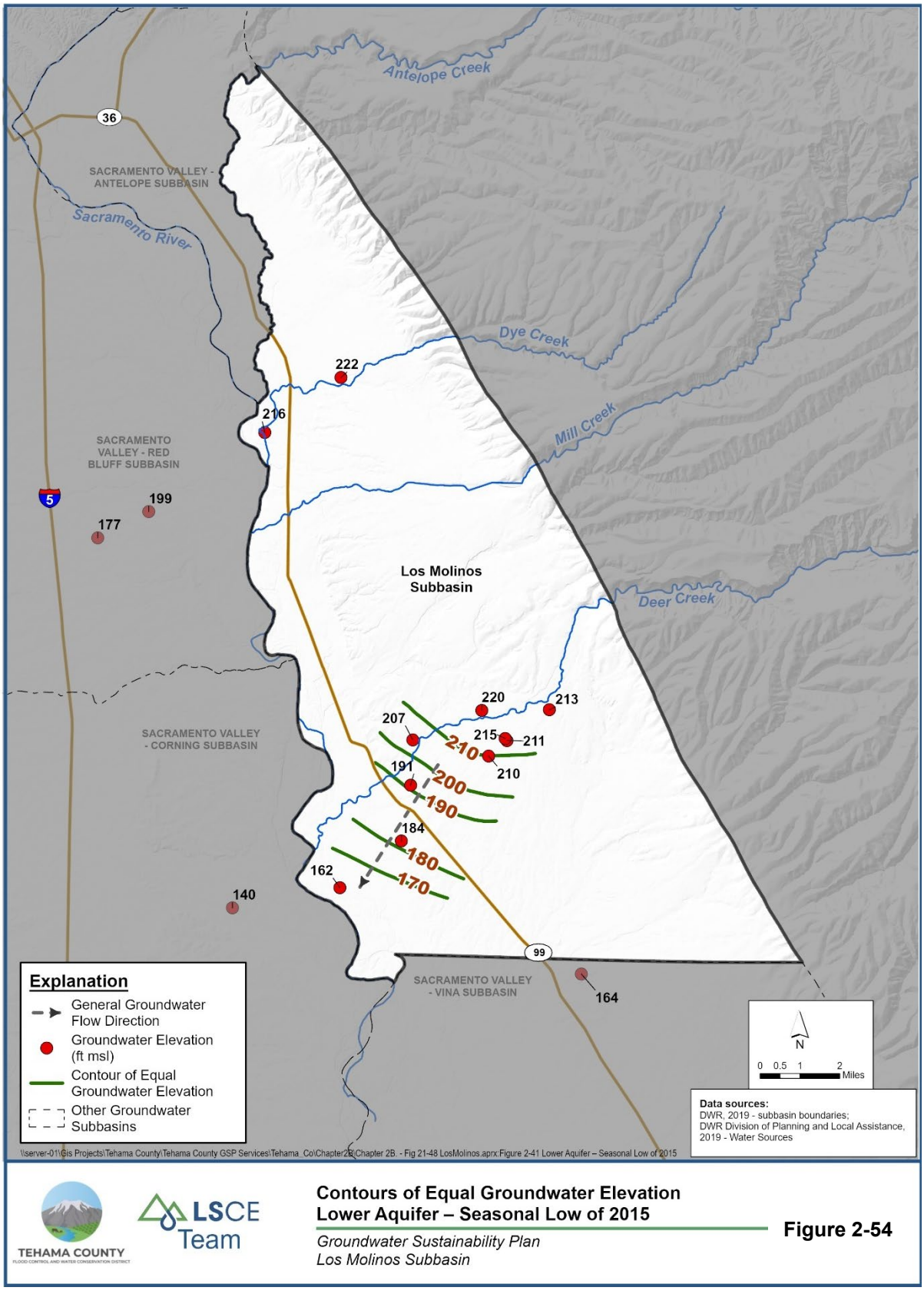
Contours of Equal Groundwater Elevation
Lower Aquifer – Seasonal High of 2013

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-51


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
228
222
Mill Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
203
204
99
Los Molinos Subbasin
Deer Creek
223
215
218
224
214
220
210
200
188
190
180
167
170
152
SACRAMENTO VALLEY - CORNING SUBBASIN
SACRAMENTO VALLEY - VINA SUBBASIN
170
Explanation
General Groundwater Flow Direction
Groundwater Elevation (ft msl)
Contour of Equal Groundwater Elevation
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
\\server-01\Gis Projects\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B. - Fig 21-48 LosMolinos.aprx:Figure 2-39 Lower Aquifer – Seasonal Low of 2013
TEHAMA COUNTY
LSCE Team
Contours of Equal Groundwater Elevation
Lower Aquifer – Seasonal Low of 2013
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-52


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
227
226
Mill Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
220
225
99
Los Molinos Subbasin
Deer Creek
222
215
212
213
213
210
193
200
190
190
180
175
166
SACRAMENTO VALLEY - CORNING SUBBASIN
SACRAMENTO VALLEY - VINA SUBBASIN
173
Explanation
General Groundwater Flow Direction
Groundwater Elevation (ft msl)
Contour of Equal Groundwater Elevation
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
\\server-01\Gis Projects\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B. - Fig 21-48 LosMolinos.aprx:Figure 2-40 Lower Aquifer – Seasonal High of 2015
TEHAMA COUNTY
LSCE Team
Contours of Equal Groundwater Elevation
Lower Aquifer – Seasonal High of 2015
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-53



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Contours of Equal Groundwater Elevation
Lower Aquifer – Seasonal Low of 2015

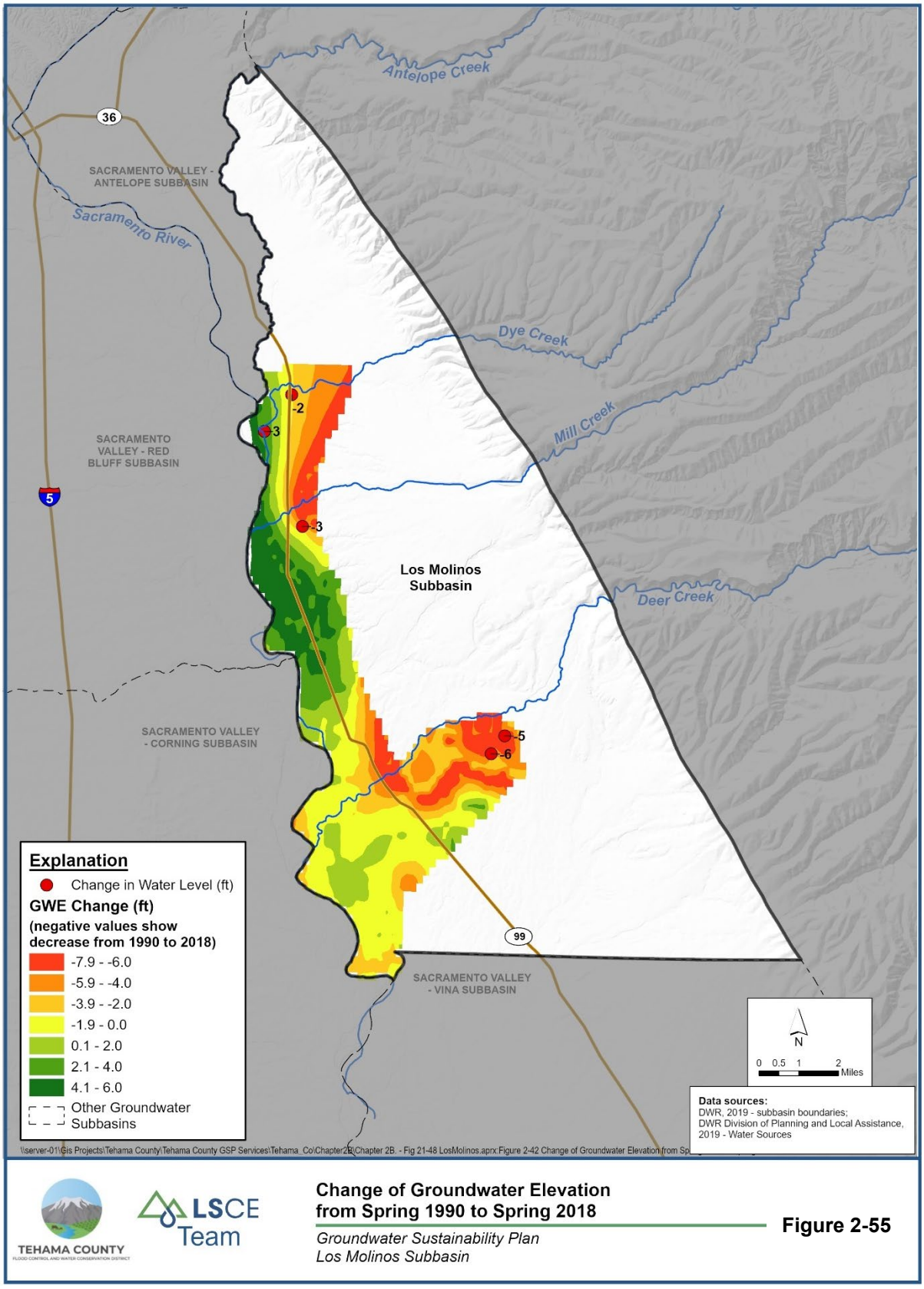
Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-54

Groundwater elevation contours of the Lower Aquifer were developed only for a narrow area that extends about two miles south along Deer Creek because of the lack of data in other areas of the Subbasin. These contour maps indicate a southwesterly general flow in the Lower Aquifer similar to flow in the Upper Aquifer in this portion of the Subbasin. The general horizontal hydraulic gradient in the southwestern areas of the Subbasin (south of Deer Creek) during the winter/spring is approximately 8 ft/mile in a wet year, but it increases to about 10 ft/mile in dry and critical years. During the fall of all water year types, the horizontal gradient is approximately 11 ft/mile. Hydrographs of nested wells in the southwestern part of the Subbasin (south/southwest of the town of Vina) show a vertically upward hydraulic gradients of about 0.01 – 0.02 within the Lower Aquifer. These gradients do not systematically fluctuate between seasons or wet and dry periods. The upward gradient can extend into the Upper Aquifer in some areas as indicated by hydrographs of nested wells located south of the Town of Vina (hydrographs are in **Appendix 2-F**).

2.2.2.2 Change in Groundwater Levels and Storage

Change in seasonal high groundwater elevations (spring to spring) from 1990 to 2018 was estimated to evaluate changes in groundwater storage in the Upper Aquifer during the hydrologic base period. Groundwater elevation surfaces for 1990 and 2018 were separately created by interpolating available water levels in each year, and then the difference between these two surfaces (**Figure 2-55)**, which encompasses a volume of both water and porous media, was calculated. Sufficient water level data were available to evaluate groundwater level changes only in a western portion of the Subbasin south of Dye Creek as shown in **Figure 2-55**. Between springs of 1990 and 2018, groundwater elevations in some parts of this area increased by up to five feet, while elevations in some other parts decreased by up to eight feet. The area where groundwater elevation change was estimated is approximately 24,100 acres, which is about 25% of the Subbasin area. However, this area includes about 64% of all irrigated lands in the Subbasin (2018 land use data). The change of groundwater elevations corresponds to a decrease of approximately 1,400 acre-feet of groundwater in the Upper Aquifer of this area, using the volume between the two groundwater surfaces and a specific yield of 0.06 (DWR, 2004). Groundwater storage change in the Lower Aquifer was not estimated because of lack of data. However, we can expect that volumetric change in the Lower Aquifer to be smaller than the change in the Upper Aquifer because of relatively small changes in groundwater elevations (shown in hydrographs) and smaller storage coefficients due to confined/semi-confined aquifer. The specific year-to-year historical groundwater storage changes are also estimated using a surface water-groundwater flow model discussed in the section 2.3.


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
-2
-3
-3
Los Molinos Subbasin
Deer Creek
SACRAMENTO VALLEY - CORNING SUBBASIN
-5
-6
99
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
Change in Water Level (ft)
GWE Change (ft)
(negative values show decrease from 1990 to 2018)
-7.9 - -6.0
-5.9 - -4.0
-3.9 - -2.0
-1.9 - 0.0
0.1 - 2.0
2.1 - 4.0
4.1 - 6.0
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
\\server-01\Gis Projects\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B. - Fig 21-48 LosMolinos.aprx:Figure 2-42 Change of Groundwater Elevation from Sp
TEHAMA COUNTY
LSCE Team
Change of Groundwater Elevation from Spring 1990 to Spring 2018
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-55

2.2.2.3 Groundwater Quality

The evaluation of groundwater quality in the Subbasin included a literature review (e.g., Bennett et al., 2011; DWR, 2009; DWR, 2020; SWRCB, 2009 and Tehama County FCWCD, 2012) and evaluation of groundwater quality data collected from SWRCB GeoTracker and GeoTracker GAMA databases. Widespread presence of contaminants at undesirable levels is not a groundwater quality concern in the Subbasin at present. Previous studies documented occurrences of chemicals in groundwater samples at concentrations above the primary or secondary maximum contaminant levels. Also, occurrence of synthetic organic compounds and volatile organic compounds associated with industrial products and pesticides at concentrations higher than their Maximum Contaminant Levels (MCL) have been reported in the Subbasins. These contaminants are listed in Chapter 2.1. Currently all groundwater clean-up sites (including leaking underground storage tanks) within the Subbasin are closed or inactive. The following discussion focuses on total dissolved solid (TDS), nitrate, arsenic, and coliform bacteria concentrations in groundwater.

Total Dissolved Solid (TDS)

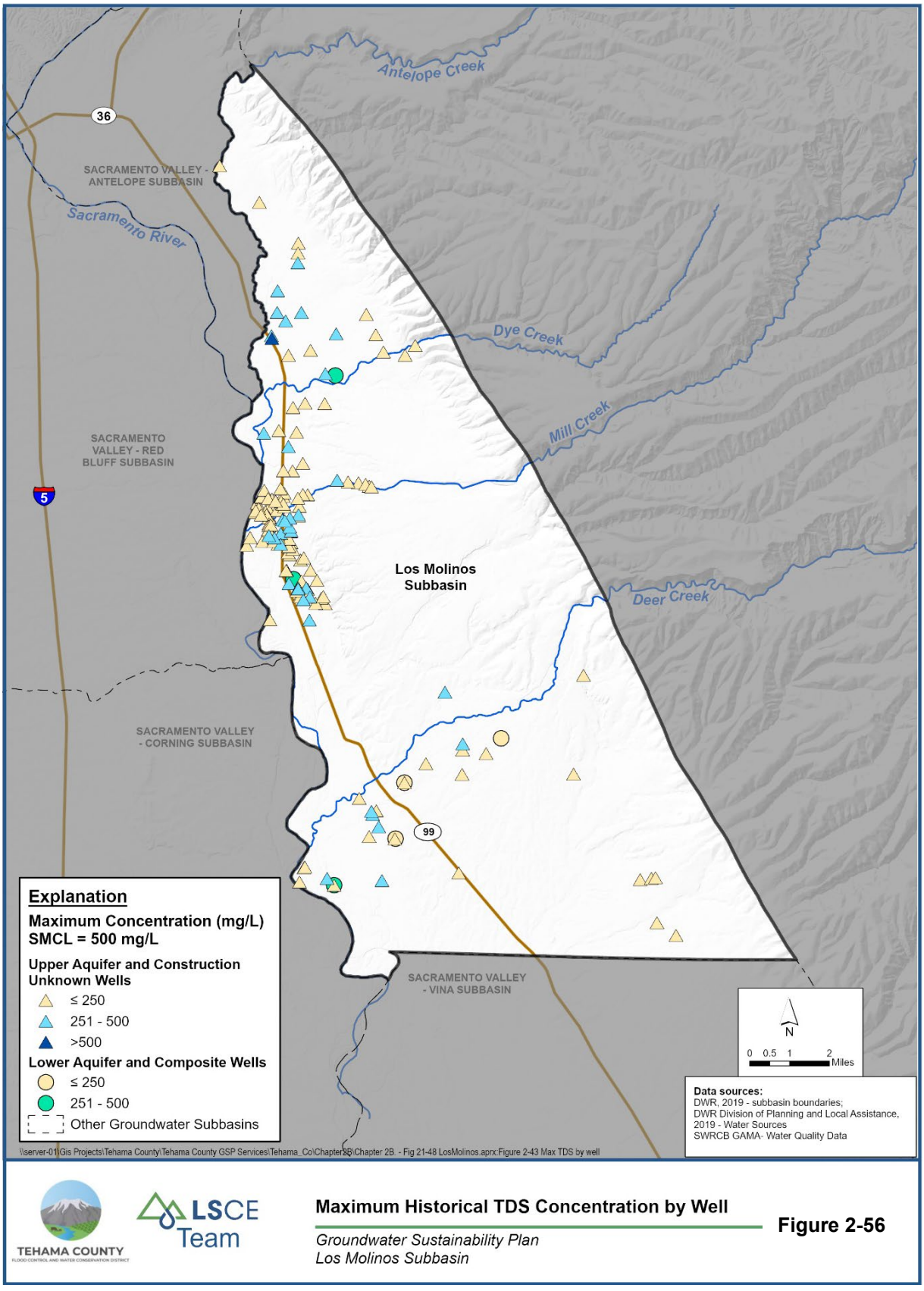
The occurrence of Total Dissolved Solids (TDS) at undesirable concentrations is not a concern at present. A total of 315 groundwater samples were tested for TDS since 1958, and results of only one sample exceeded the Secondary Maximum Contaminant Level of 500 mg/L (a concentration of 530 mg/L in 1995). The maximum TDS results collected from 163 of 167 tested wells (37 Upper Aquifer wells, eight Lower Aquifer wells and 122 composite or construction details unknown wells) are less than 400 mg/L (**Figure 2-56**).

Nitrate

The occurrence of nitrate at undesirable concentrations is not a concern in the Subbasin, because nitrate (nitrate, expressed as nitrogen) concentrations of all 644 samples tested since 1956 were below the Maximum Contaminant Level (MCL) of 10 mg/L. Only seven of 177 sampled wells resulted in test results above 7 mg/L (**Figure 2-57**). The highest historical nitrate concentration in the Subbasin, 9.61 mg/L, was from a sample collected from a municipal well near the Town of Los Molinos (well 5201068-001) in 2017. All test results from all other wells are less than 7 mg/L. Nitrate concentration timeseries graphs and location maps of two municipal wells that have long-term data (well 5201068-001 and 5200653-001) are in **Appendix 2-G**. Potential sources of nitrate in the Subbasin include sewage disposal systems and fertilizer used in agriculture.

Arsenic

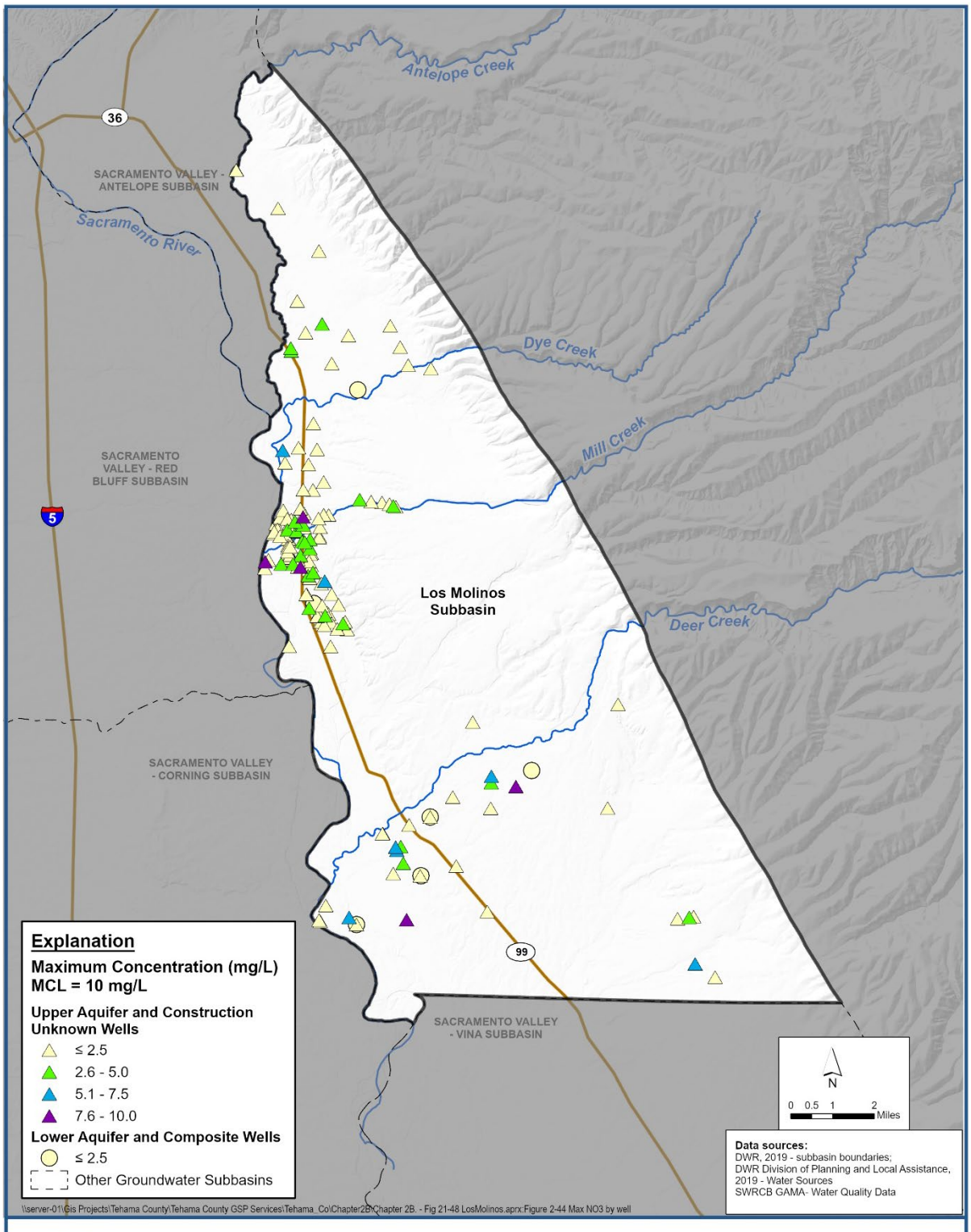
The occurrence of arsenic at concentrations exceeding the MCL of 10 micrograms per liter (µg/L) is a groundwater quality concern in some areas in the Subbasin. Results of 47% of samples tested since 1959 (189 of 404 tested samples) exceeded the MCL. Results exceeding the MCL at least once are associated with 26% of tested wells in the Subbasin (35 of 134 tested wells since 1959). The highest historical arsenic concentration in the Subbasin, 28 µg/L, was from a sample collected from a municipal well near the Town of Los Molinos (well 5200550-001) in 2015. Most wells with above-MCL test results are in areas around the Town of Los Molinos (west of State Highway 99E and south of Mill Creek; **Figure 2-58**). Sufficient data are not available to evaluate variability of arsenic concentration with depth, and timeseries data do not show an identifiable temporal trend at any well (**Appendix 2-G**). Arsenic is a naturally occurring chemical that originates from volcanic rocks of the Tuscan formation (Tehama County FCWCD, 2012).



Maximum Historical TDS Concentration by Well

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-56

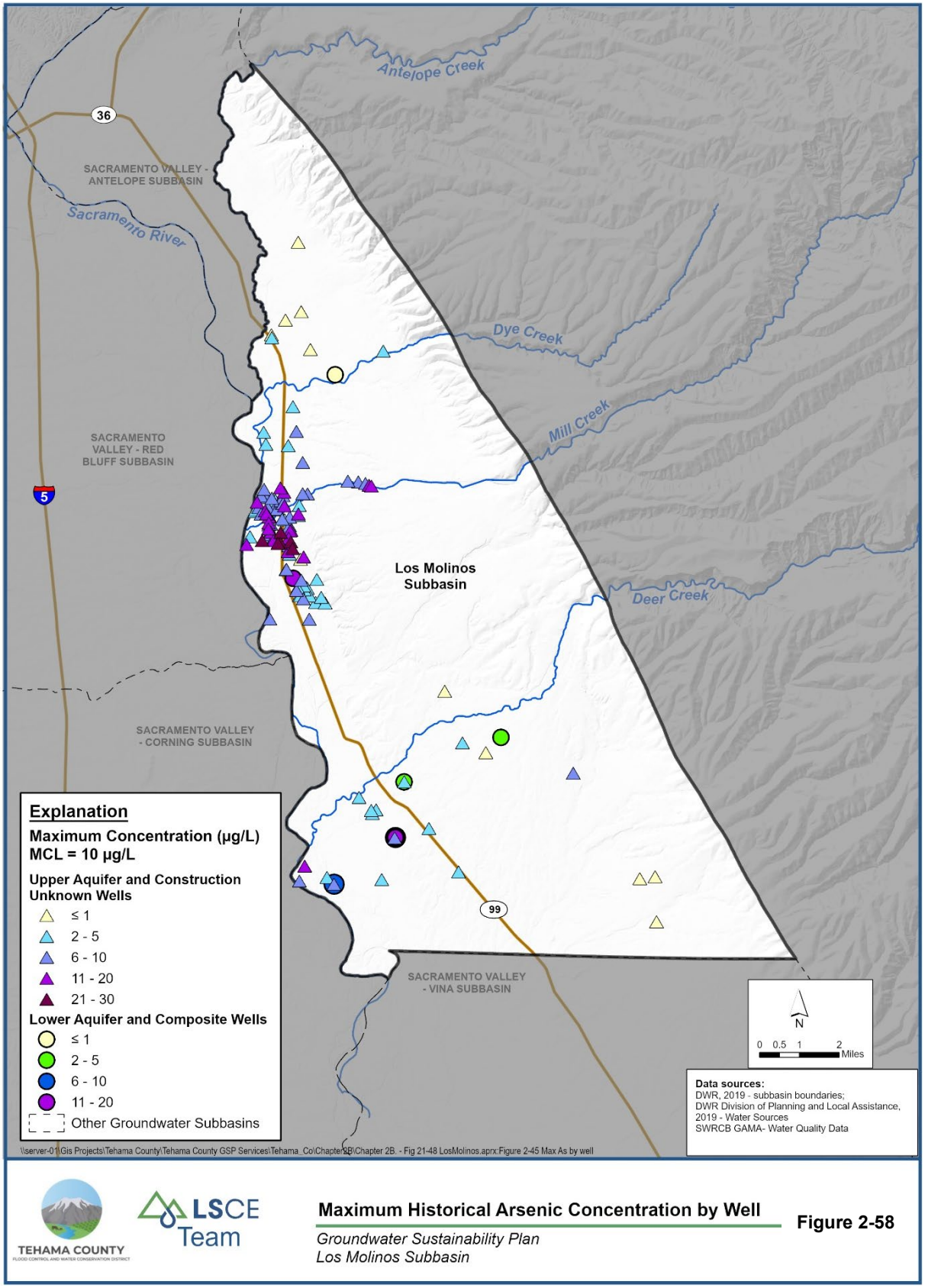


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Maximum Historical Nitrate Concentration by Well **Figure 2-57**

Groundwater Sustainability Plan
Los Molinos Subbasin


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
Los Molinos Subbasin
Deer Creek
SACRAMENTO VALLEY - CORNING SUBBASIN
99
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
Maximum Concentration (µg/L)
MCL = 10 µg/L
Upper Aquifer and Construction Unknown Wells
≤ 1
2 - 5
6 - 10
11 - 20
21 - 30
Lower Aquifer and Composite Wells
≤ 1
2 - 5
6 - 10
11 - 20
Other Groundwater Subbasins
N
0 0.5 1 2
Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR Division of Planning and Local Assistance, 2019 - Water Sources
SWRCB GAMA- Water Quality Data
\\server-01\Gis Projects\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter 2B\Chapter 2B. - Fig 21-48 LosMolinos.aprx:Figure 2-45 Max As by well
TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT
LSCE Team
Maximum Historical Arsenic Concentration by Well
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-58

2.2.2.4 Seawater Intrusion

Seawater intrusion is not an applicable sustainability indicator for the Los Molinos Subbasin because it is not likely to occur in the Subbasin due to its distance from the Pacific Ocean (about 90 miles).

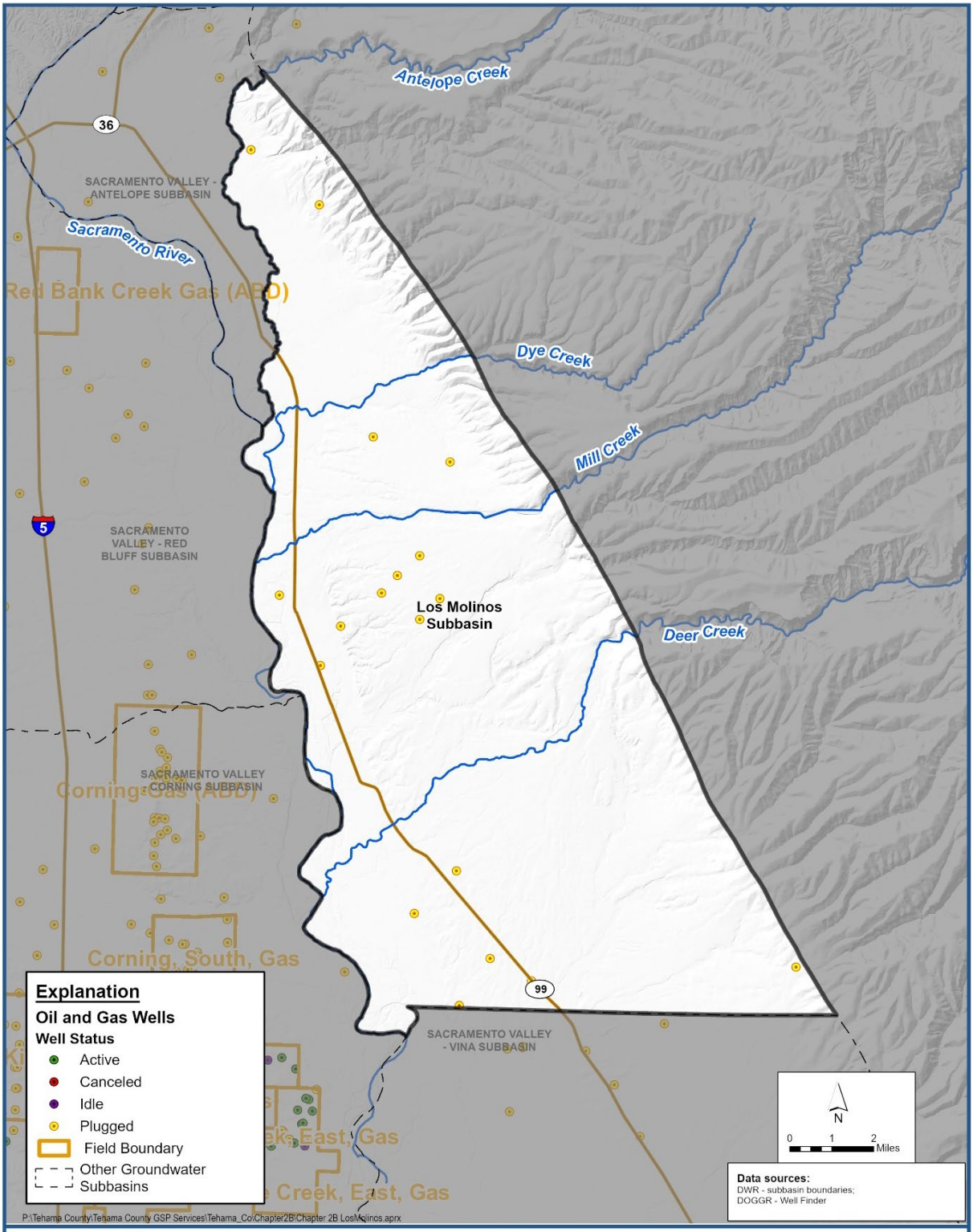
2.2.2.5 Subsurface Compaction and Land Subsidence

Los Molinos Subbasin has little to no reported evidence of subsidence. Subsidence occurs when groundwater is extracted from the pore spaces in the geologic material leading to compaction. The compaction causes the ground surface elevation to drop. In addition to groundwater extraction, oil and gas extraction can lead to subsidence. There are no active oil or gas wells in the Subbasin (**Figure 2-59**). Subsidence monitoring in the Subbasin is available from three main surveys conducted by DWR and UNAVCO. The subsidence measured in these studies is likely elastic, meaning the land surface can recover (rise) if groundwater is recharged and again fills the pore spaces. Negative subsidence measurements indicate a downward vertical movement of the land surface and positive values indicate an upward movement.

In 2018 DWR released a report on land subsidence from 2008-2017 using Global Positioning Systems (GPS) survey methods. In 2008, DWR contracted the installation of a series of survey monuments across 11 counties; four survey monuments are within the Subbasin boundaries (**Figure 2-60**). These monuments were surveyed to establish a baseline elevation and then resurveyed in 2017. Results from 2008 and 2017 were compared to establish an average change in ground surface elevation over the almost ten-year study period. The GPS survey method has an error of uncertainty of 0.17 ft. Therefore, measurements less than 0.17 ft are not statistically significant and are uncertain (DWR, 2018). In the Subbasin, measured ground surface elevation ranged from an increase of 0.001 ft to 0.041 ft (**Figure 2-60**). On average, ground surface elevation in the Subbasin increased 0.002 feet per year over the duration of the study.

In 2015 DWR began reporting Interferometric Synthetic Aperture Radar (InSAR) surveys to assist with subsidence studies related to SGMA. Vertical measurements are collected by the European Space Agency (ESA) Sentinal-1A satellite and compared to previous measurements to establish a change in surface elevation. The vertical measurements are collected as point data sets that represent 100-meter by 100-meter areas and are used to interpolate GIS rasters (**Figure 2-61**). Maximum vertical displacement measured using the InSAR approach from July 2015 to June 2019 was -0.05 to 0.01 ft in the Subbasin (**Figure 2-61**). On average, subsidence in the Subbasin was approximately -0.01 feet per year to -0.003 feet per year from January 2015 to September 2019. The subsidence is likely elastic, meaning the land surface can recover (rise) if groundwater is recharged and again fills the pore spaces.

Between 2003 and 2008, UNAVCO installed GPS survey stations to record lateral and vertical land surface movement as part of their Plate Boundary Observatory (PBO) project. The GPS stations for the PBO record movement on a centimeter to millimeter scale. There is one PBO monitoring station within the Subbasin (P344) near Deer Creek (**Figure 2-62**). Since recording at P344 began in 2006, there has been an overall decrease in ground surface elevation of approximately 0.05 ft. On average, in the last 14 years, ground surface decreased 0.013 ft/yr. This station recorded large fluctuations (>-0.2 ft) in 2016 and 2018. These measurements are questionable and likely not representative of subsidence in those years.



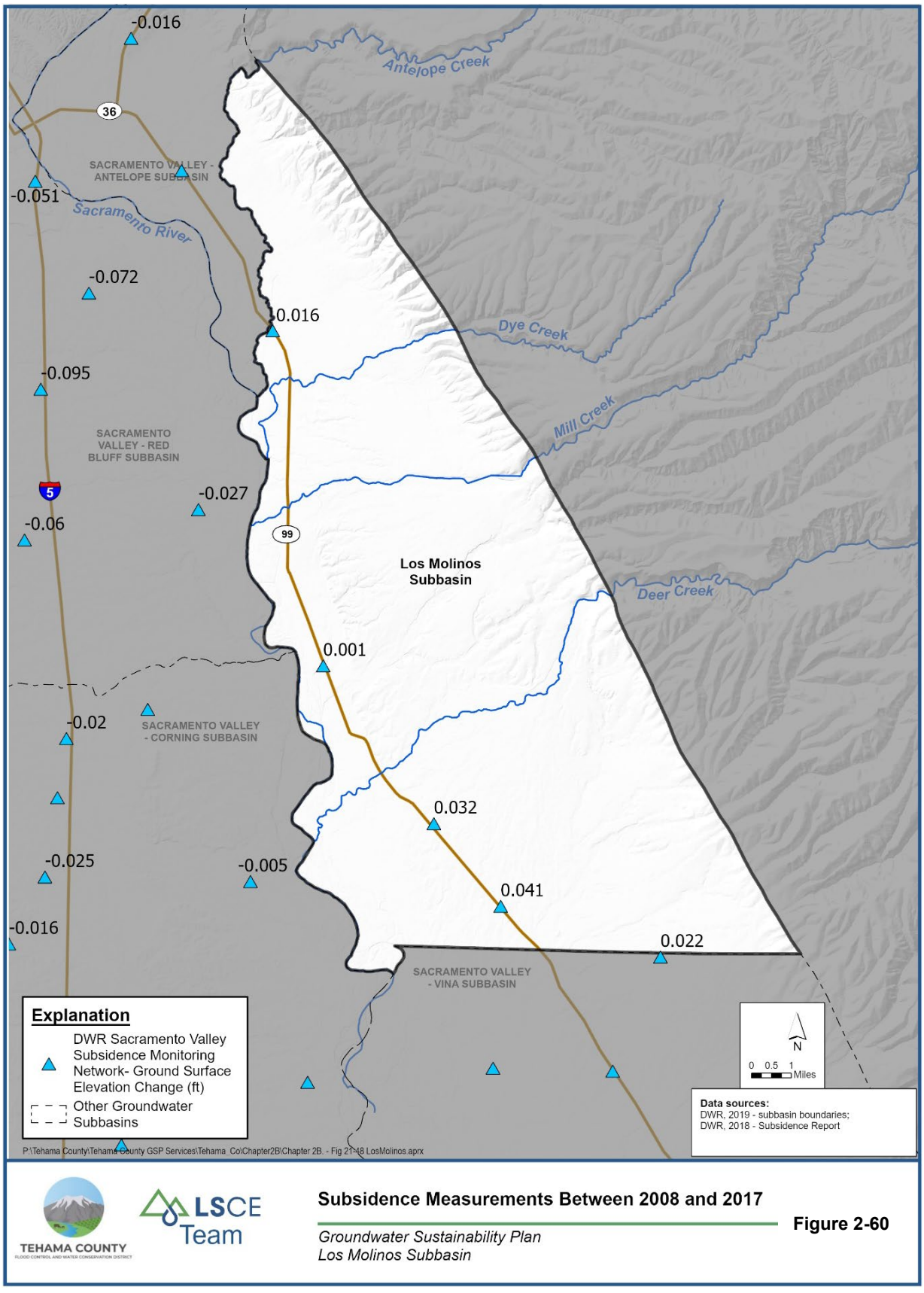
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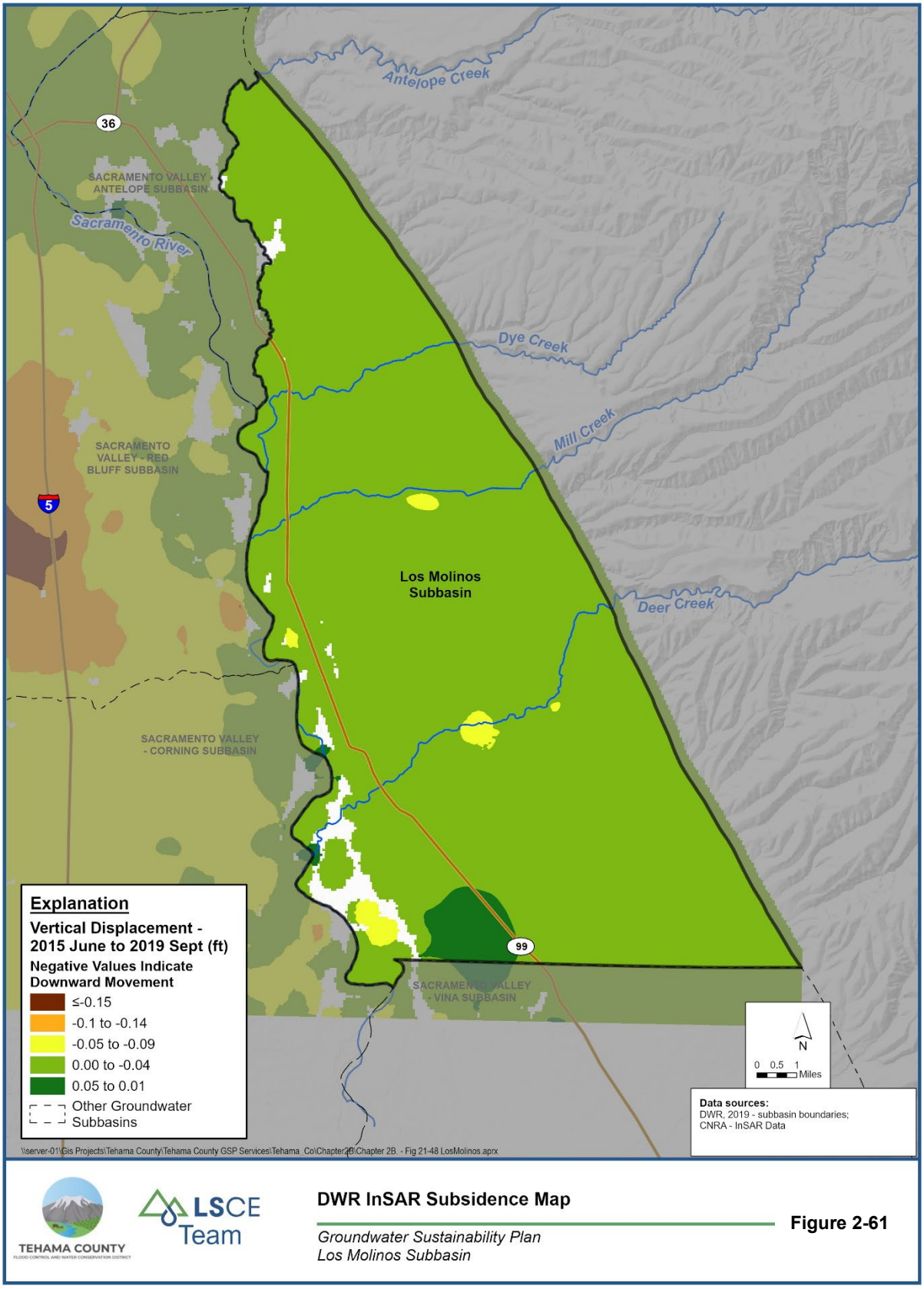
LSCE Team

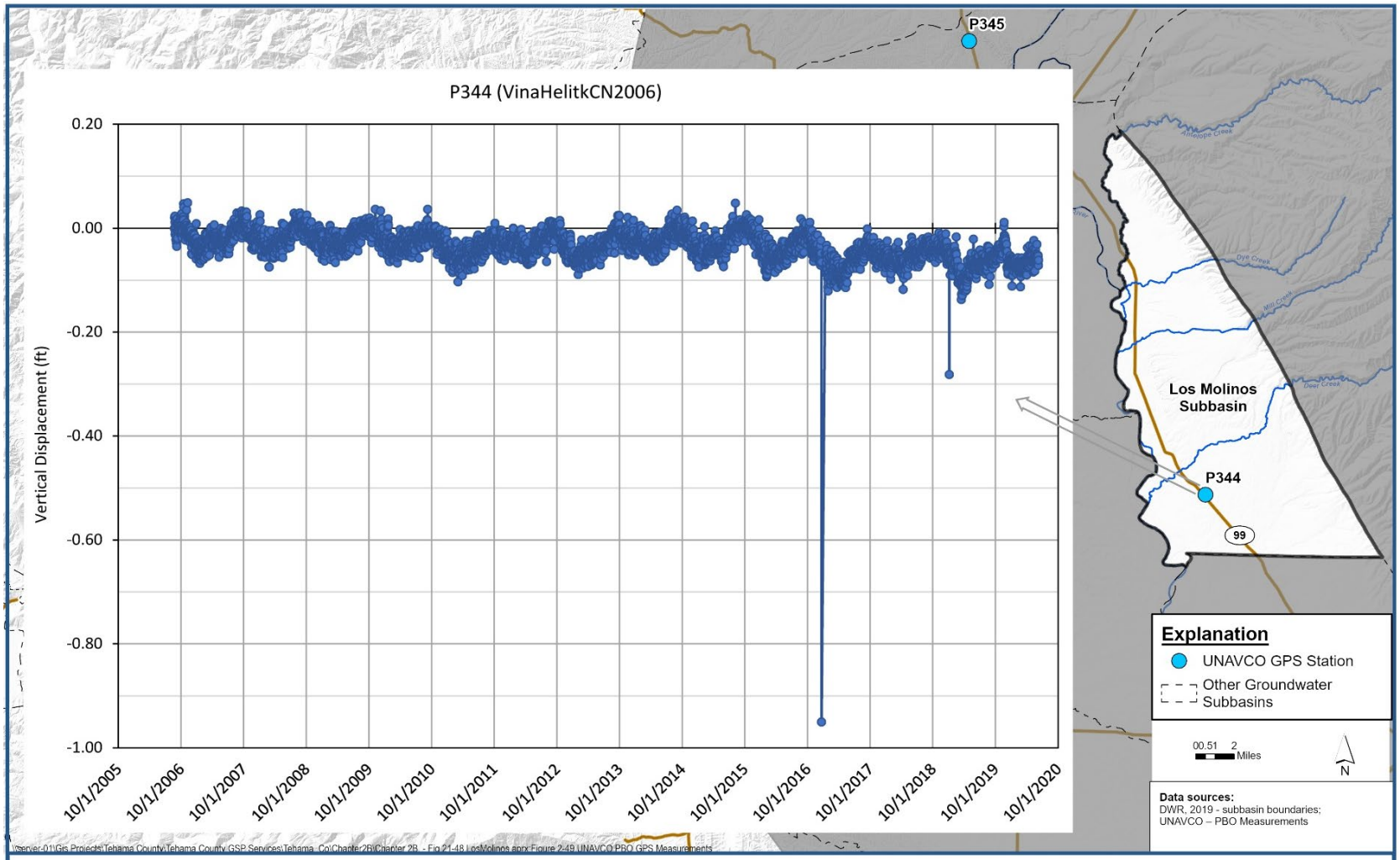
Map of Oil and Gas Fields and Wells

Groundwater Sustainability Plan
Los Molinos Subbasin

Figure 2-59


-0.016
Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
-0.051
Sacramento River
-0.072
0.016
Dye Creek
-0.095
Mill Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
-0.027
-0.06
99
Los Molinos Subbasin
Deer Creek
0.001
-0.02
SACRAMENTO VALLEY - CORNING SUBBASIN
0.032
-0.025
-0.005
0.041
-0.016
0.022
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
DWR Sacramento Valley Subsidence Monitoring Network- Ground Surface Elevation Change (ft)
Other Groundwater Subbasins
N
0 0.5 1 Miles
Data sources:
DWR, 2019 - subbasin boundaries;
DWR, 2018 - Subsidence Report
P:\Tehama County\Tehama County GSP Services\Tehama Co\Chapter2B\Chapter 2B. - Fig 21-48 LosMolinos.aprx
TEHAMA COUNTY
LSCE Team
Subsidence Measurements Between 2008 and 2017
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-60


Antelope Creek
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
Dye Creek
Mill Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
5
Los Molinos Subbasin
Deer Creek
SACRAMENTO VALLEY - CORNING SUBBASIN
99
SACRAMENTO VALLEY - VINA SUBBASIN
Explanation
Vertical Displacement - 2015 June to 2019 Sept (ft)
Negative Values Indicate Downward Movement
≤-0.15
-0.1 to -0.14
-0.05 to -0.09
0.00 to -0.04
0.05 to 0.01
Other Groundwater Subbasins
N
0 0.5 1 Miles
Data sources:
DWR, 2019 - subbasin boundaries;
CNRA - InSAR Data
\\server-01\Gis Projects\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B. - Fig 21-48 LosMolinos.aprx
TEHAMA COUNTY
LSCE Team
DWR InSAR Subsidence Map
Figure 2-61
Groundwater Sustainability Plan
Los Molinos Subbasin


P345
P344 (VinaHelitkCN2006)
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
Vertical Displacement (ft)
10/1/2005
10/1/2006
10/1/2007
10/1/2008
10/1/2009
10/1/2010
10/1/2011
10/1/2012
10/1/2013
10/1/2014
10/1/2015
10/1/2016
10/1/2017
10/1/2018
10/1/2019
10/1/2020
Los Molinos Subbasin
P344
99
Explanation
UNAVCO GPS Station
Other Groundwater Subbasins
0 0.5 1 2
Miles
N
Data sources:
DWR, 2019 - subbasin boundaries;
UNAVCO – PBO Measurements
TEHAMA COUNTY
LSCE Team
UNAVCO PBO GPS Measurements
Groundwater Sustainability Plan
Los Molinos Subbasin
Figure 2-62

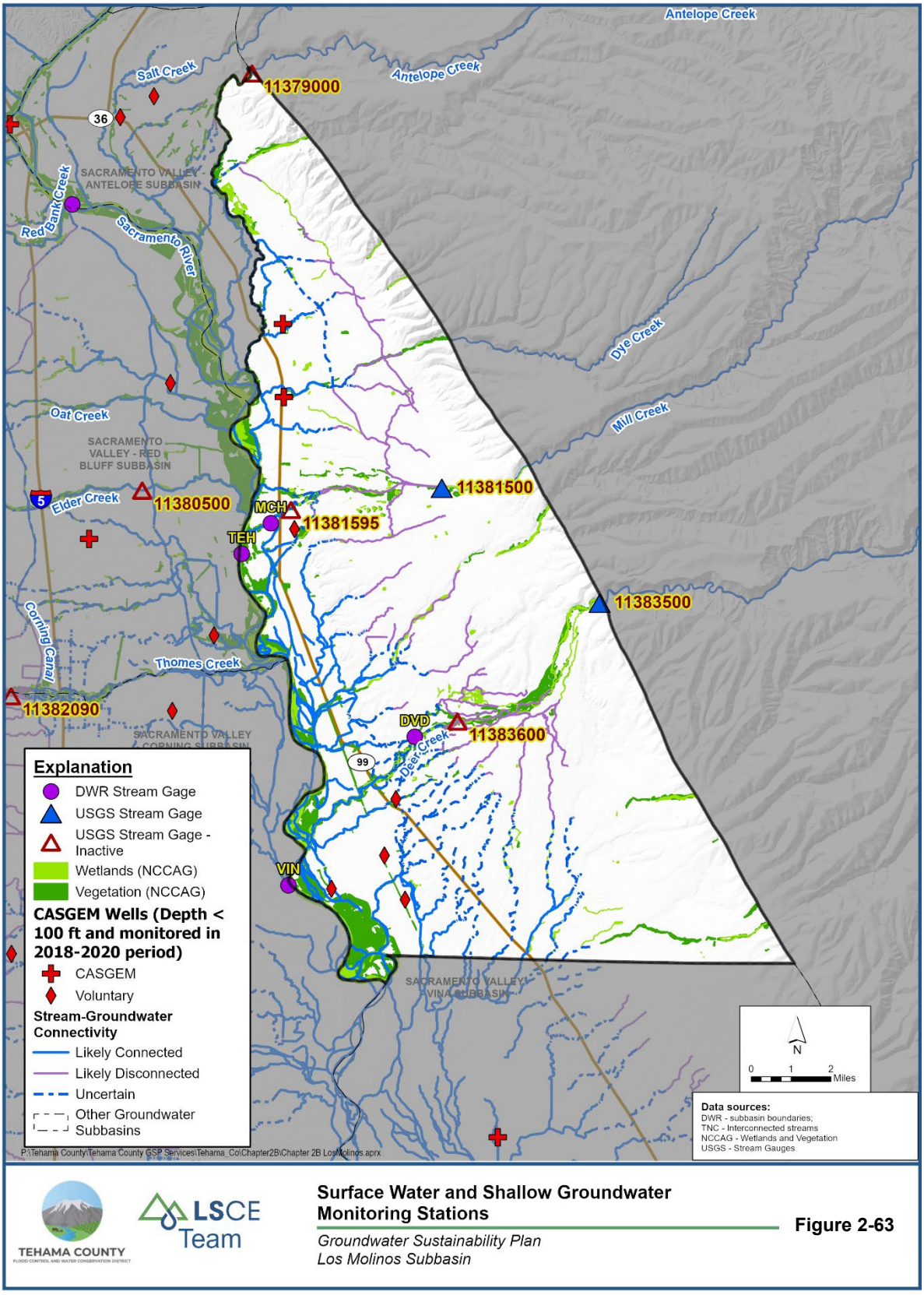
2.2.2.6 Surface Water Conditions

Historic and current surface water flow data is limited in the Subbasin. As discussed in Section 2.2.1.7, the Sacramento River, Antelope Creek, Little Antelope Creek, Dye Creek, Mill Creek, and Deer Creek are the main surface water features in the Subbasin and are all perennial. Champlin Slough, Delaney Slough, Wildcat Creek, Brush Creek, and other smaller streams also flow through the Subbasin. Only the Sacramento River, Deer Creek, and Mill Creek, have historic or current flow data.

The Sacramento River has three currently active gaging stations within the Subbasin; DWR station at Tehama Bridge (TEH), DWR station at Vina Bridge (VIN), and DWR station at Vina East Bank (VNO). Station TEH is located at the western boundary of the Subbasin about four miles downstream from the Antelope Subbasin (**Figure 2-63**). Station TEH is only equipped with stage sensors and only directly measures stage; however, CDEC's website presents some flow data (assumed to be calculated from stage). Station VIN is located about 3.5 miles upstream from the southern boundary of the Subbasin with a daily record since 1984. Historical data from VIN shows a mean annual flow rate of about 12,300 cubic feet per second (CFS) with highest flows from January through March (historical mean over 18,600 CFS), and lowest flows in October (historical mean about 7,000 CFS) (USGS NWIS stream flow data). Station VNO is in the same location as VIN, however, no data is available from the DWR CDEC database.

Mill Creek is currently measured in the Subbasin by two active monitoring stations: USGS station #11381500 (MLM) close to the eastern boundary of the Subbasin and DWR station Mill Creek Below HWY 99 (MCH) near the western border of the Subbasin (**Figure 2-63**). Station MLM has annual flow data since 1929 with an average annual flow of 303 CFS. In general, the flow is highest in February and March (mean of over 469 CFS), and lowest in August and September (mean of about 112 CFS) (USGS NWIS stream flow data). DWR station MCH has flow data dating back to 1999. In general, the flow is highest in February and March (mean of over 375 CFS), and lowest in August and September (mean of about 13 CFS).

Deer Creek is currently measured in the Subbasin by two active monitoring stations: USGS station #11383500 (DCV) close to the eastern boundary of the Subbasin and DWR station Deer Creek Below Stanford Vina Dam (DVD) near the western border of the Subbasin (**Figure 2-63**). Station DCV has annual flow data since 1912 with an average annual flow of 321 CFS. In general, the flow is highest in February and March (mean of over 610 CFS), and lowest in August and September (mean of about 96 CFS) (USGS NWIS stream flow data). DWR station DVD has flow data dating back to 1997. In general, the flow is highest in January through March (mean of over 325 CFS), and lowest in August and September (mean of about 20 CFS).



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Surface Water and Shallow Groundwater Monitoring Stations

Figure 2-63

Groundwater Sustainability Plan
Los Molinos Subbasin

2.2.2.6.1 *Interconnected Surface Water Systems*

Characterizing the connectivity of the surface water systems in the Subbasin is challenging due to the limited data. Modeling surface water and groundwater interaction will also be a means to address the connectivity and is discussed in section 2.3. When a stream stage is higher than that of the groundwater table the stream will lose water to the ground via infiltration of water through the streambed (losing conditions). If losing conditions are present but the depth of the water table is too deep, the stream is considered losing and disconnected. Losing conditions with groundwater just below the stream are connected. When the water table elevation is higher than the stream stage, groundwater will infiltrate into the stream causing the stream to gain water (gaining conditions). Groundwater and surface water are always connected under gaining conditions. Stream data like flow magnitude or stage height, coupled with shallow groundwater elevation or flow direction, is needed to establish the connectivity of streams and groundwater.

The Subbasin does not contain active stream gages near shallow monitoring wells needed to accurately define interconnectivity of surface water and groundwater (**Figure 2-63**). As discussed in section 2.2.2.6, there are multiple currently active sources of stream stage data in the Subbasin. There are seven currently monitored shallow CASGEM wells in the Subbasin. The closest CASGEM well to a stream stage station is 0.6 miles away from station MCH. This well is closer to another stream (ungaged) and is not representative of connectivity between Mill Creek and the shallow groundwater based on examination of available data. Another station DVD is on Deer Creek and is 0.8 miles from a monitoring well however this well is closer to Delaney Slough and likewise is not representative of connectivity between Deer Creek and the shallow. Installation of shallow monitoring wells near currently active stream gages would help to characterize the interconnectivity of the streams and the groundwater in the Subbasin.

Figure 2-63 shows likely interconnected, likely disconnected and interconnectivity uncertain stream reaches based on a dataset developed by The Nature Conservancy (TNC, 2021). This dataset categorizes the likelihood of the interconnectivity based on approximated streambed elevation at a selected point and the minimum depth to groundwater at a nearby well recorded between 2011 and 2018. A stream segment that was hydraulically connected to groundwater at any time during that period is categorized as likely interconnected. Therefore, a large uncertainty exists about the seasonal and year-to -year variability of interconnectivity of streams. Losing and gaining stream segments categorized using the calibrated Tehama Integrated Hydrologic Model are included in **Sub-appendix G** of **Appendix 2-J**.

2.2.2.7 Identification of Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) are defined in the GSP regulations as, “ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface” (23 CCR § 351(m)). Freshwater species in Los Molinos Subbasin are listed in **Appendix 2-H**. These species were geographically selected from the California Freshwater Species Database (CDFW, 2015). The approach used to both identify and prioritize GDE’s was modified from the guidance document *Groundwater Dependent Ecosystems under the Sustainable Groundwater Management Act – Guidance for Preparing Groundwater Sustainability Plans* (The Nature Conservancy, 2018. The guidance document was produced by The Nature Conservancy (TNC), an environmental

stakeholder who has been actively involved in GSP development and review throughout the State. The dataset of Natural Communities Commonly Associated with Groundwater (NCCAG) provides indicators of potential groundwater dependent ecosystems (iGDEs). This dataset, provided by DWR, is a compilation of 48 publicly available state and federal agency datasets that map vegetation, wetlands, springs, and seeps in California (Klausmeyer et al., 2018). NCCAG data show the occurrence of iGDEs adjacent to perennial and intermittent streams, as well as seasonally flooded wetlands in the Subbasin (**Figure 2-63**). The process used to identify potential GDEs in the Subbasin was accomplished by:

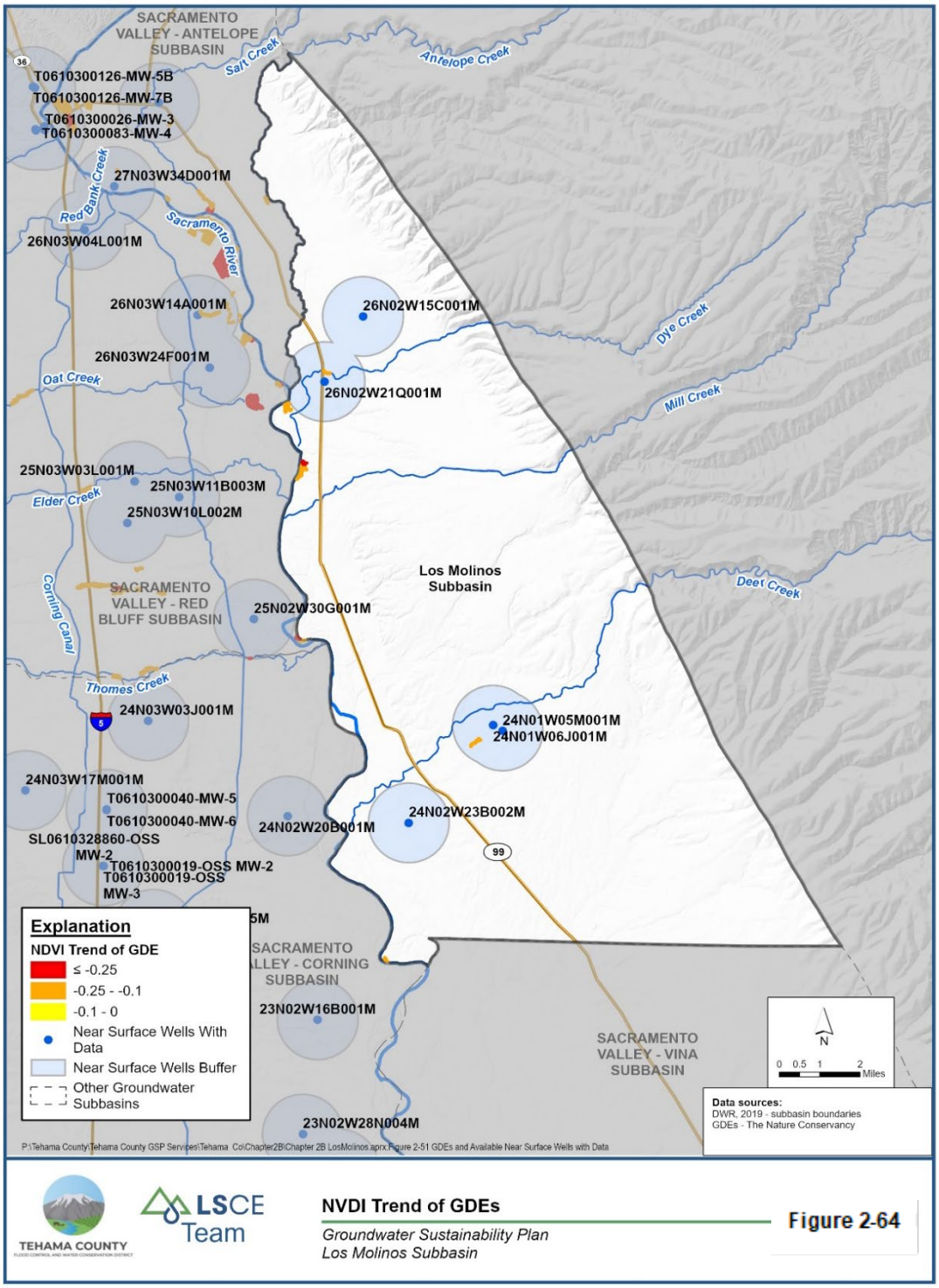
- a comparison of iGDEs with recent land cover data to update the map of iGDEs. This step is required because some iGDEs given in the NCCAG dataset are sourced from datasets mapped many years before 2015, which is the baseline year of SGMA. IGDEs found to exist within developed or irrigated lands were excluded during this step.
- an evaluation of groundwater conditions that can support GDEs. GDEs are likely to exist in areas where the seasonal high groundwater levels do not fall deeper than 30 ft bgs (TNC, 2019). Therefore, identifying areas with shallow groundwater that can support GDEs is important to identify GDEs. IGDEs within 1 mile of wells and with 2015-seasonal-high water deeper than 30 ft were excluded in this step.

A detailed description of methodology of GDE identification and prioritization is presented in a separate Technical Memorandum in **Appendix 2-ISurface Water Depletion and GDE Methodology and Analysis**. The steps above reduce the original NCCAG dataset of iGDEs from an area of 4,824 acres to 4,306 acres of GDEs, a reduction of 11%.

Identified GDEs were then prioritized for future monitoring using two Vegetation Metrics available at the GDE Pulse web application developed by TNC; Normalized Derived Vegetation Index (NDVI) that indicates vegetation greenness and Normalized Derived Moisture Index (NDMI) that indicates vegetation moisture (Klausmeyer et al., 2019). An annual NDVI value based on summer conditions was assigned to each individual GDE. Then a linear regression was performed to determine the trend of NDVI values between 1990 and 2018 (representative base period of this GSP). A negative trend of NDVI indicates a decrease in vegetation greenness during this period. GDEs with negative NDVI trends were classified as high priority (trend less than -0.1) and low priority (trend between -0.1 and zero) for future monitoring. High priority GDEs cover an area of about 36 acres within the Subbasin (**Figure 2-64**). In the future, low priority GDEs will be observed outside of the established monitoring program and may be reclassified as high priority depending on future conditions.

High priority GDEs were further evaluated to determine if temporal changes of vegetation metrics and local groundwater levels were correlated. Identifying such correlations would be useful to establish groundwater levels that can sustain GDEs. Only wells that were perforated within the top 100 feet below ground surface (near surface wells) and located within approximately one mile from the GDEs were included in this analysis. Vegetation metrics of high priority GDEs and groundwater levels of three wells that met above criteria (**Figure 2-64**) were analyzed, but two of these wells did not have sufficient water level data to identify correlations. Water levels of the other well (24N01W06J001M in **Figure 2-64**) and vegetation metrics of an adjacent GDE had a moderate

correlation (**Figure 2-65**). Depth to water at this well has been deeper than 30 ft bgs since 2012. It indicates that historical water levels at this location (shallower than 30 ft bgs) may have sustained GDEs before 2012, however current and future water levels may be too deep to support GDEs. Considering the lack of groundwater level monitoring close to high priority GDEs at present, installation of shallow groundwater monitoring wells near or within these GDEs is recommended.



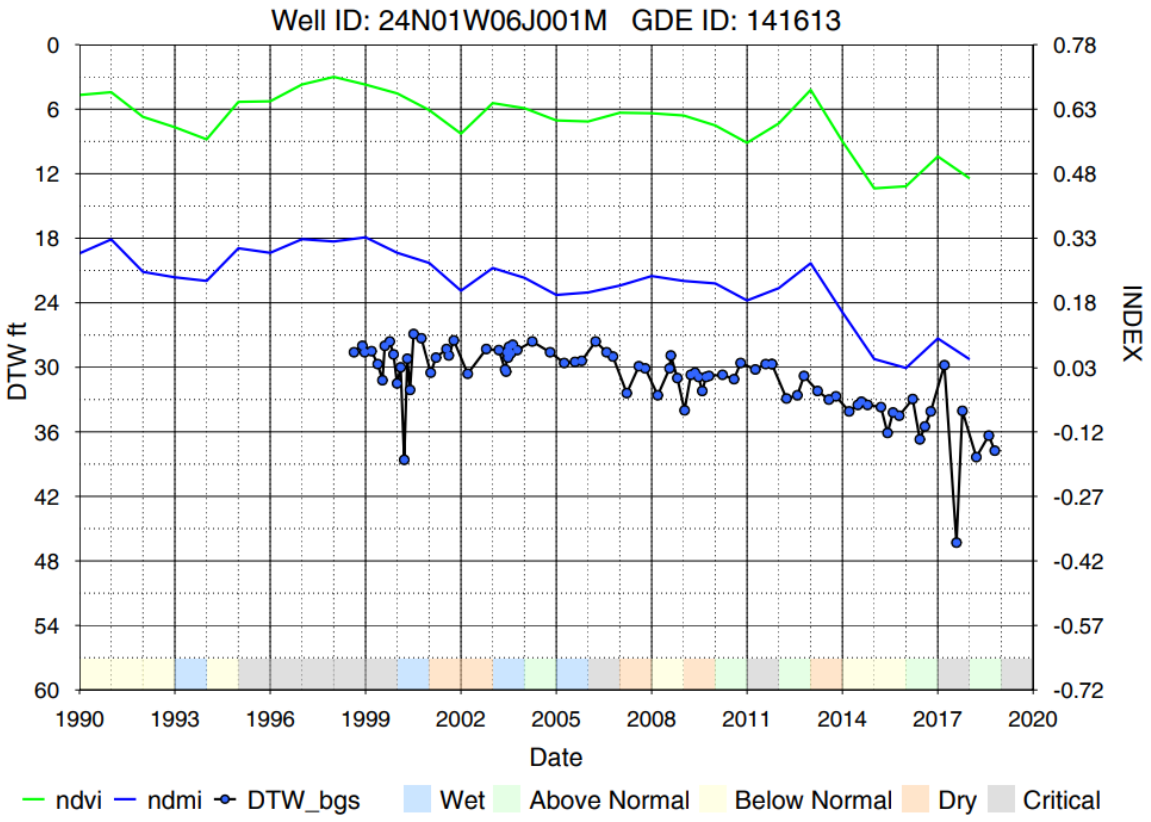


Figure 2-65. Timeseries Graph of NDVI and NDMI of a GDE and Depth to Water at an Adjacent Well

2.2.3 Basin Setting Summary

In the Los Molinos Subbasin, water generally flows in a west to southwestern direction with downward vertical movement in the Upper Aquifer driven by natural recharge. Water typically follows topography flowing from high elevation areas in the east toward low elevations near Sacramento River in the west. Recharge contributions to the deeper geologic formations occurs on the eastern side of the Subbasin where the formations outcrop at the surface. Aquifer recharge also generally occurs along the Sacramento River and perennial streams where saturated hydraulic conductivity of soils is high. Proximal to these surface water features groundwater likely flows outward when groundwater elevations are lower (losing conditions). Discharge from the groundwater also occurs in these areas when the water table rises to the ground surface elevation (gaining conditions). The larger source of discharge is likely from production of water wells. A portion of applied water (irrigation) also contributes to recharge.

There is a two-aquifer system in the Subbasin with unconfined to semi-confined conditions in the Upper Aquifer and semi-confined to confined conditions in the Lower Aquifer. At present there are no widespread groundwater quality concerns in the Subbasin. However, about 26% of tested wells in the Subbasin (35 of 134 tested wells since 1959) have exceeded the arsenic Maximum Contaminant Level of arsenic (10 µg/L) at least once.

The concepts discussed in Section 2.2 will be further discussed and refined in Chapter 2.3, the Water Budget. Section 2.2 provided basic concepts needed to understand the geometry of the Subbasin, distribution and character of water bearing material, distribution and movement of groundwater and surface water, and historic and current groundwater conditions including water quality. Basic physical Properties of the Subbasin include:

- The Los Molinos Subbasin is bounded to the north by the Antelope Subbasin separated by Antelope Creek, to the west by the Sacramento River, to the south by the Tehama County boundary, and to the east by the Chico Monocline.
- Fresh water occurs as groundwater to a maximum depth of over -2,000 ft msl in the northwest portion of the Subbasin.
- The bottom of the Subbasin is defined as the base of the post-Eocene continental deposits.
- The more recent geologic history is dominated by fluvial and alluvial deposition.
- The major water bearing formations are the Tuscan and Tehama Formations with some contribution from the shallower Quaternary sedimentary deposits.
- The ground surface generally slopes from the east to west with steeper slopes in the east of the Subbasin.
- Los Molinos Subbasin has little to no reported evidence of subsidence, with recent rates of -0.013 feet/year or less.

Based on available data, a two-aquifer system is defined in the Subbasin. Groundwater conditions in the Subbasin include:

- The Upper Aquifer is defined as model layers 1-5 (approximately 350-450 ft bgs) and the Lower Aquifer is defined as model layers 6-9. The model layers will be further discussed in section 2.3.
- Recharge of the Subbasin primarily occurs from the flow of the Sacramento River, Deer Creek, Dye Creek, and other streams.
- Subsurface geologic formations can be recharged directly where they outcrop in the east.
- At different locations of the Subbasin, seasonal high water levels range between about 10 and 90 ft bgs in the Upper Aquifer, and from less than 1 ft to about 150 ft bgs in the Lower Aquifer.
- Water level fluctuations of up to about 10 ft occur between seasons, and between wet and dry climatic conditions in both aquifers.
- Groundwater contour maps of the Upper Aquifer and Lower Aquifer indicate westerly/ southwesterly general flow from the elevated areas of the valley towards the Sacramento River in the valley floor.

- Horizontal hydraulic gradients in the Upper Aquifer and Lower Aquifer are approximately 20 ft/mile and 10 ft/mile, respectively with small seasonal and annual fluctuations.
- Vertical hydraulic gradient in the Upper Aquifer is consistently downward (0.1 to 0.4), and that in the Lower Aquifer is vertically upward (0.01 – 0.02).
- Vertical gradient between the Upper Aquifer and Lower Aquifer can be upward or downward depending on the season, climatic conditions, and the location within the Subbasin.
- Long-term water levels in the Subbasin are stable, and some wells with long-term water level data (1990 to 2018) showing small decreasing trends of about 0.1 to 0.25 ft/year.
- At present, groundwater quality is good with few exceptions most notably undesirable concentrations of arsenic in some areas of the Subbasin.

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