FINAL REPORT

Bowman Subbasin

Sustainable Groundwater Management Act

Groundwater Sustainability Plan
Chapter 2B Basin Setting

January 2022

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Tehama County Flood Control and Water Conservation District

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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	Deci-siemens 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

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

2.1 Description of Plan Area

2.2 Basin Setting

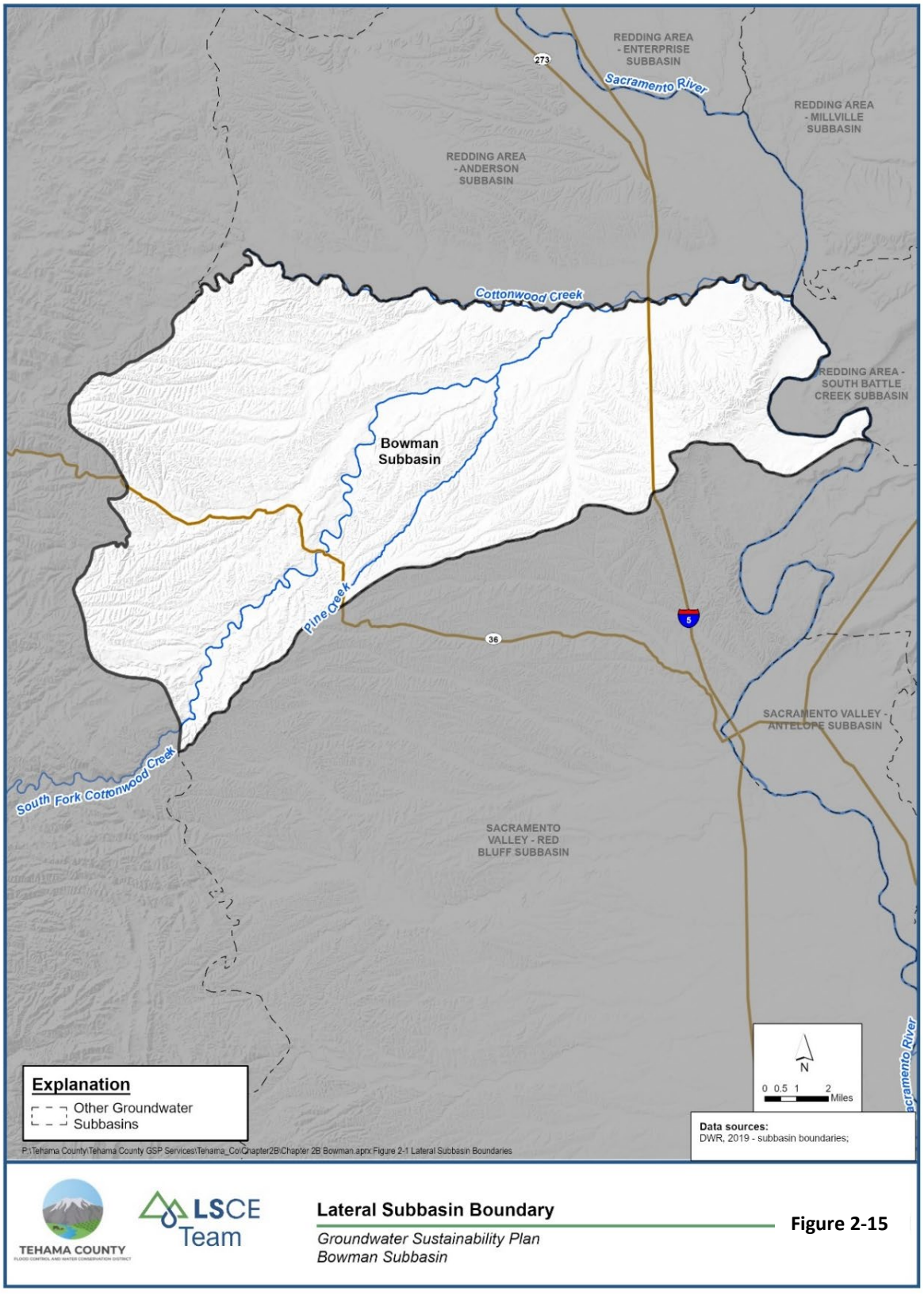
The Basin Setting section is a description of available information used as a background to develop the sustainability criteria for the Subbasin. It includes a detailed review of studies and historic groundwater conditions in the Subbasin. This information provides context about the quantity and movement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

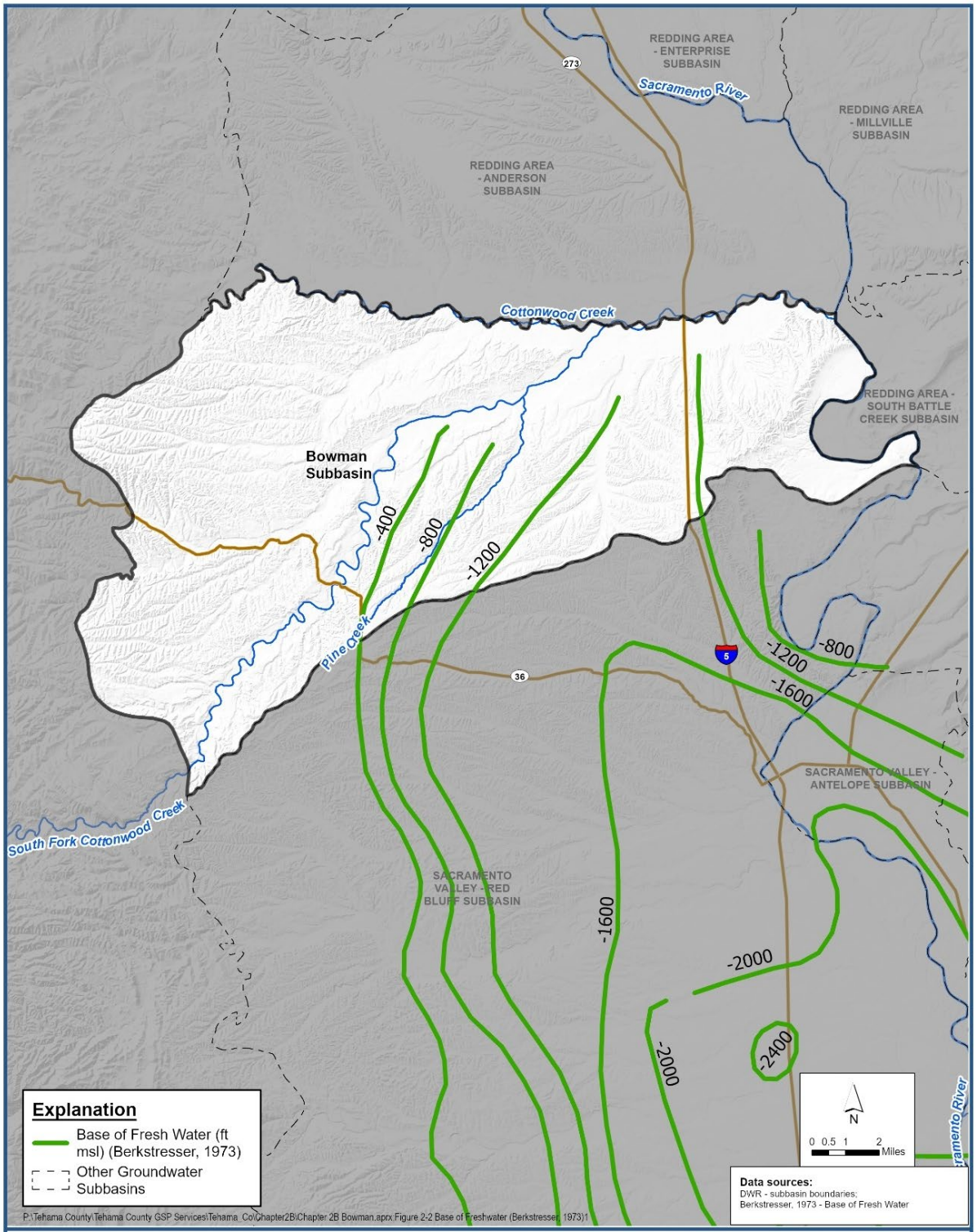
2.2.1 Hydrogeologic Conceptual Model

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 Bowman 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 Bowman 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 Bowman Subbasin boundary descriptions were updated to incorporate the preexisting Rosewood Subbasin in the 2018 Bulletin 118 update. 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 by Cottonwood Creek (county border). The western boundary is defined as the Coast Ranges and the eastern boundary is defined as the Sacramento River (DWR, 2004). The Red Bluff Arch separates the Subbasin from the Red Bluff Subbasin to the south (DWR, 2004). 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 2-15** and the bottom of the basin is discussed further in section 2.2.1.6 and presented in **Figure 2-16** and **Figure 2-17**.


REDDING AREA - ENTERPRISE SUBBASIN
Sacramento River
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
Cottonwood Creek
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
Bowman Subbasin
Pine Creek
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
South Fork Cottonwood Creek
SACRAMENTO VALLEY - RED BLUFF 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 Bowman.aprx Figure 2-1 Lateral Subbasin Boundaries
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Lateral Subbasin Boundary
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-15



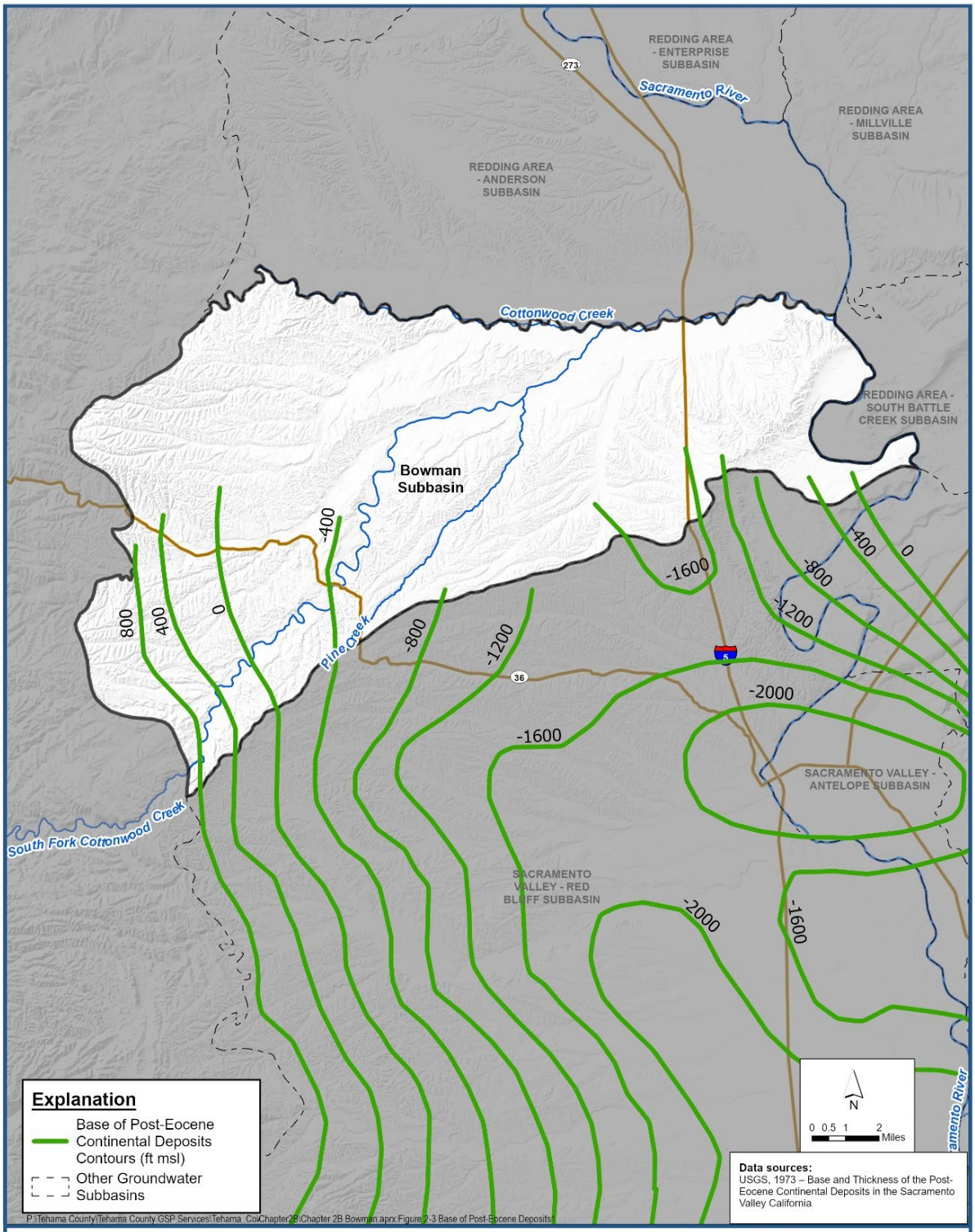
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Contours of Equal Groundwater Elevation, Base of Freshwater

Figure 2-16

Groundwater Sustainability Plan
Bowman Subbasin



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Contours of Equal Elevation, Base of Post-Eocene Deposits

Figure 2-17

Groundwater Sustainability Plan
Bowman Subbasin

2.2.1.2 Topographic Information

The Bowman Subbasin is characterized by a relatively sloped topographic setting along the western side of the Redding Area groundwater basin. Topography is highest along the western border of the Subbasin where the Coast Ranges foothills transition to the valley floor. The topographic slope is steep in the west (10% - >50%) and is generally shallow in the northern and eastern areas of the Subbasin (<2%) (**Figure 2-18**). The ground surface elevation ranges from over 1,000 feet above mean sea level (ft msl) in the west and southwest parts of the Subbasin to less than 400 ft msl in the majority of the Subbasin (**Figure 2-19**).

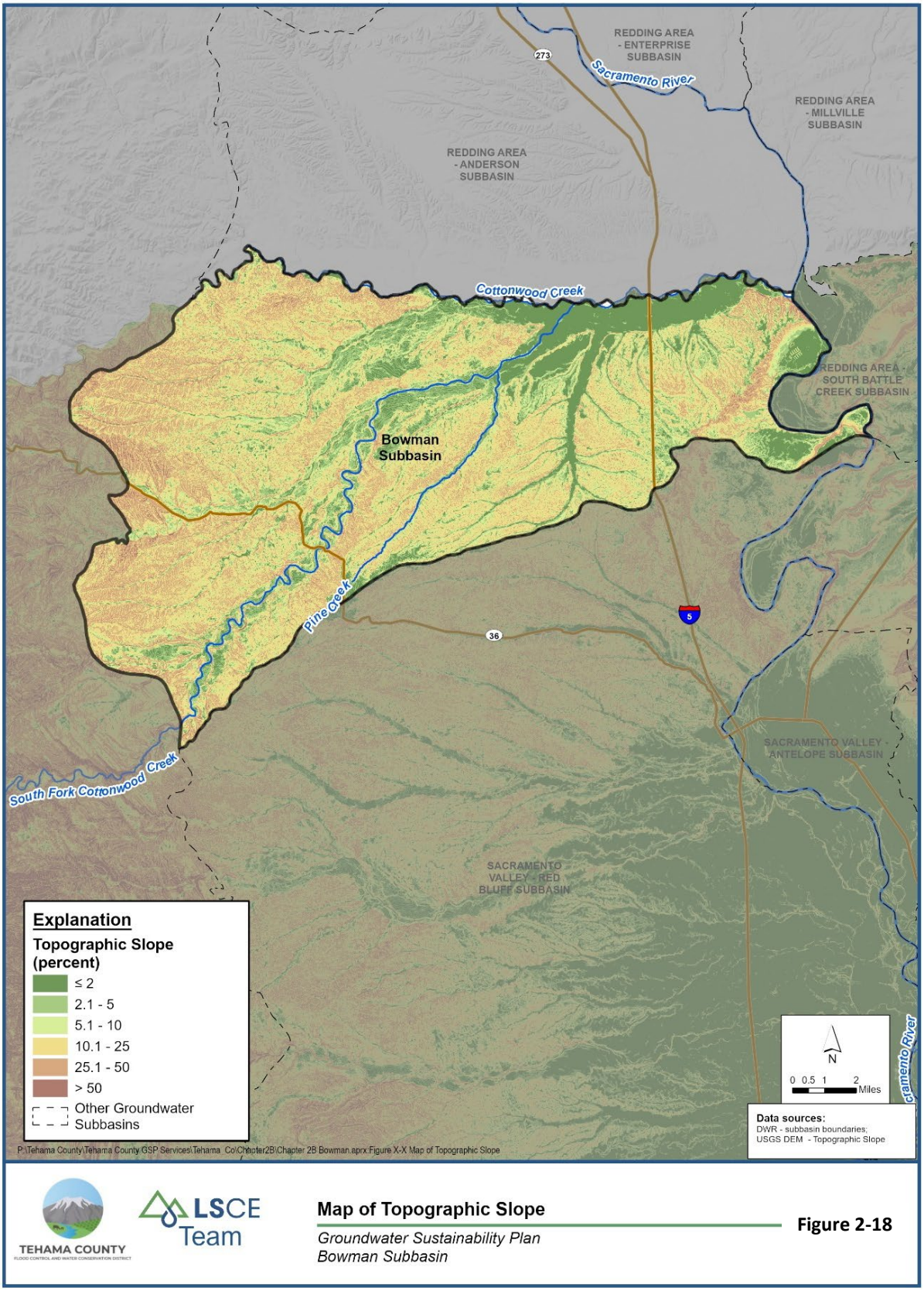
2.2.1.3 Geologic Setting

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).



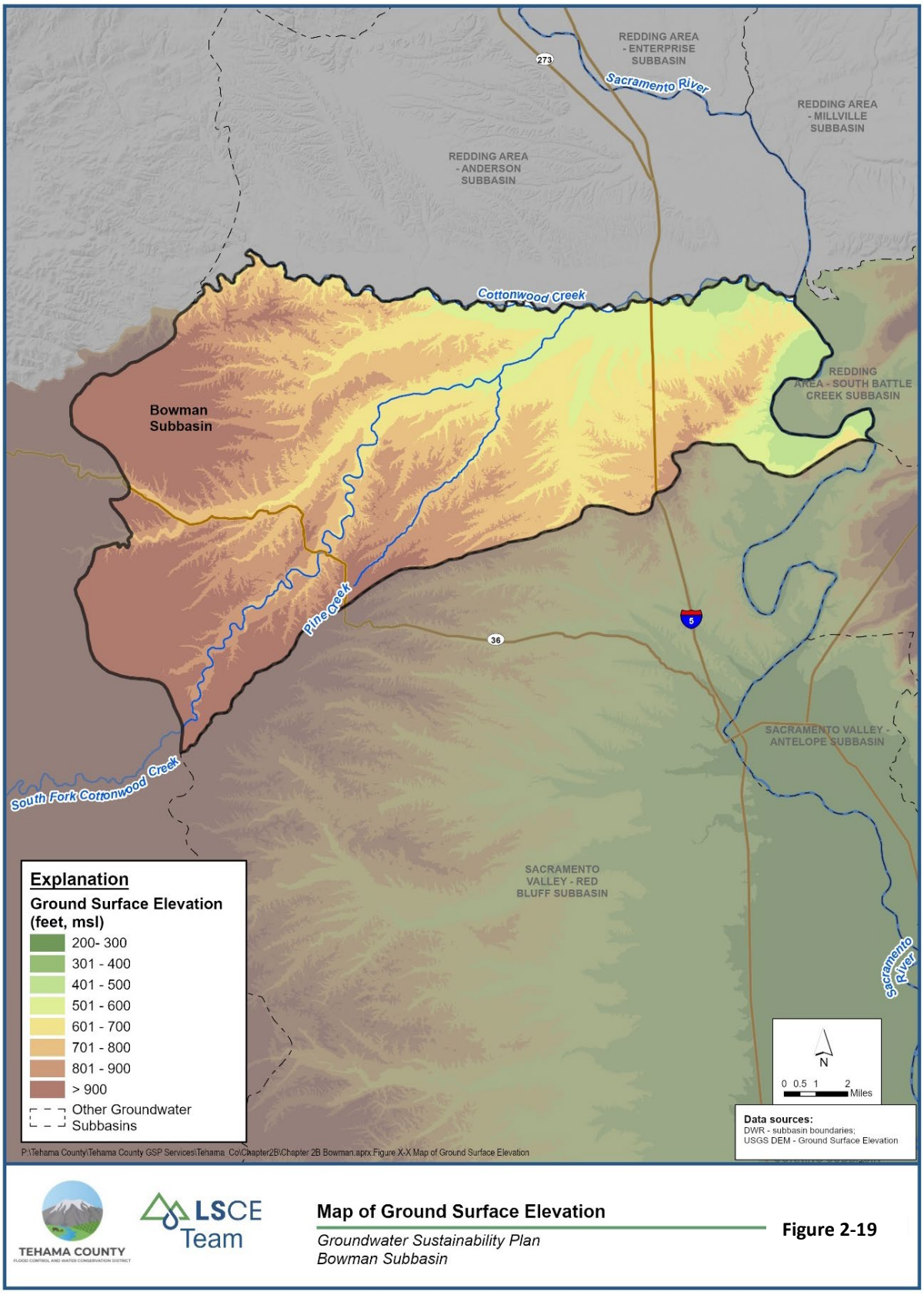
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Map of Topographic Slope

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Bowman Subbasin

Figure 2-18



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Map of Ground Surface Elevation

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-19

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 2-20**).

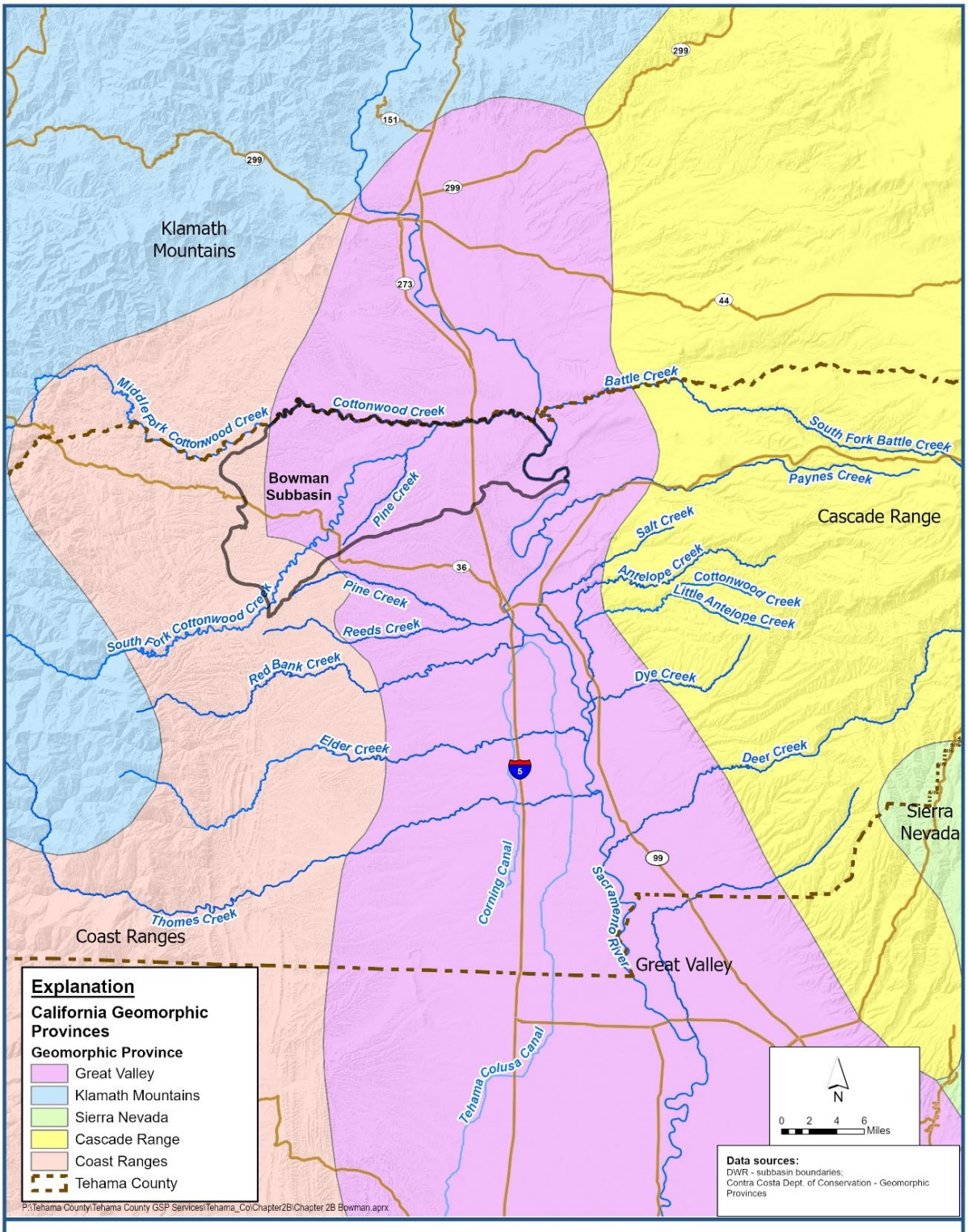
Klamath Geologic Province

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). Some streams and tributaries drain the Klamath Geologic Province in the vicinity of the Subbasin.

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 flow through the Subbasin that feed the Sacramento River drain this area of the Coast Ranges.



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Map of Geologic Provinces

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Bowman Subbasin

Figure 2-20

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 borders the northern Sacramento Valley 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. No streams and rivers currently drain the Cascade Range in the vicinity of the Subbasin. Eastern fluvial systems feed the Sacramento River and transport 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 2-20**) 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 Ranges 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 often 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 in the east 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*

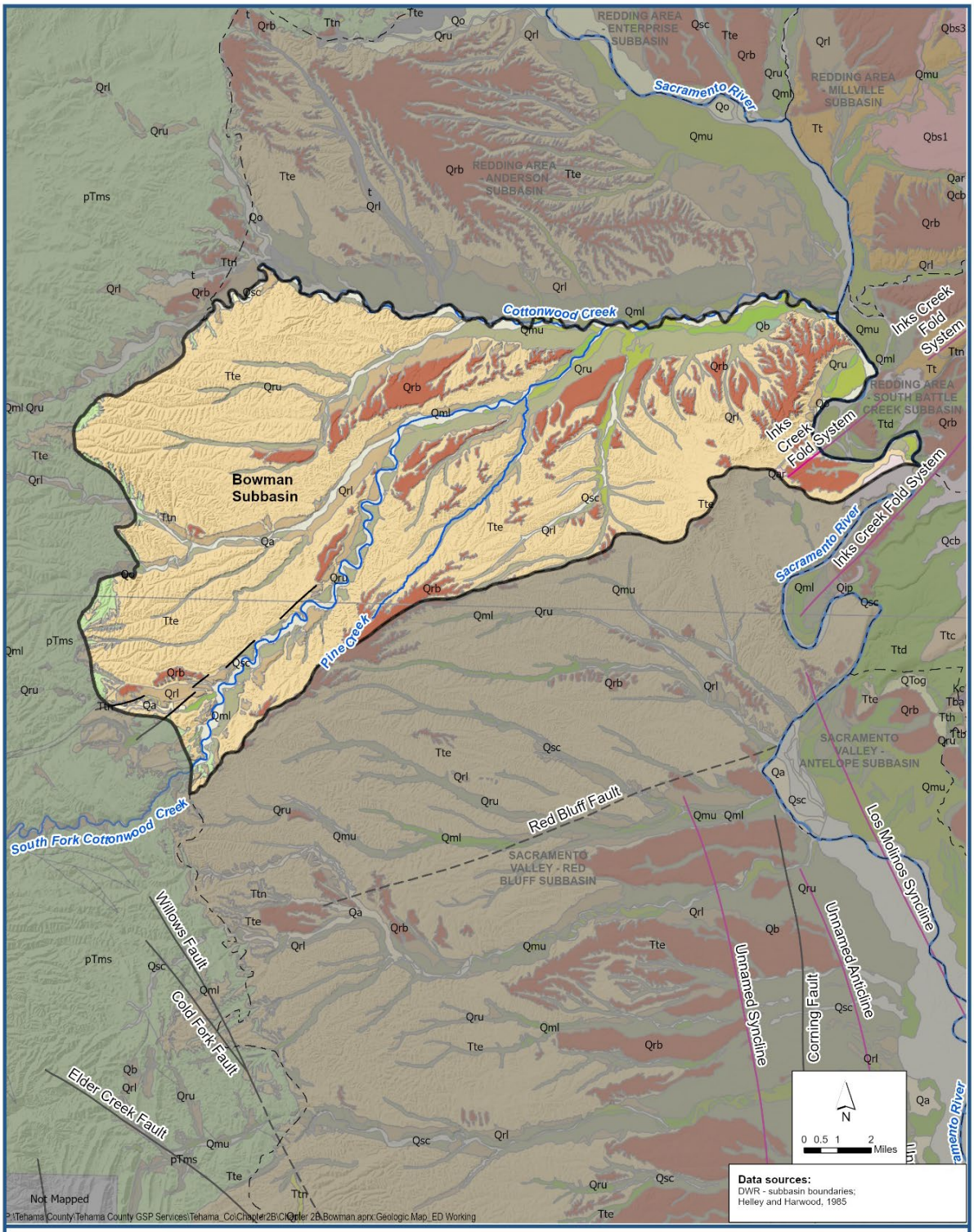
Geologic formations were mapped by Helley and Harwood (1985) and digitized by DWR (2014). The digitized maps were modified and are presented as **Figure 2-21** and **Figure 2-21B**. Geologic Cross sections were constructed using available data, locations of cross sections are presented as **Figure 2-22** and **Figure 2-22B,** and cross sections are presented as **Figure 2-23** and **Figure 2-24**. In addition, a DWR cross section (DWR, 2003) that includes the Subbasin and extends into the Red Bluff Subbasin, is presented as **Figure 2-25** and **Figure 2-25B**. A summary of stratigraphic relationships and water bearing character is presented as **Table 2-8**.

Great Valley Sequence

The Great Valley sequence (pTms on **Figure 2-21**) 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 east and west 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 up to 2,700 ft bgs in the Subbasin (**Figure 2-25**). 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 subsurface in the southeast and pinches out in the north (**Figure 2-25**). 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).



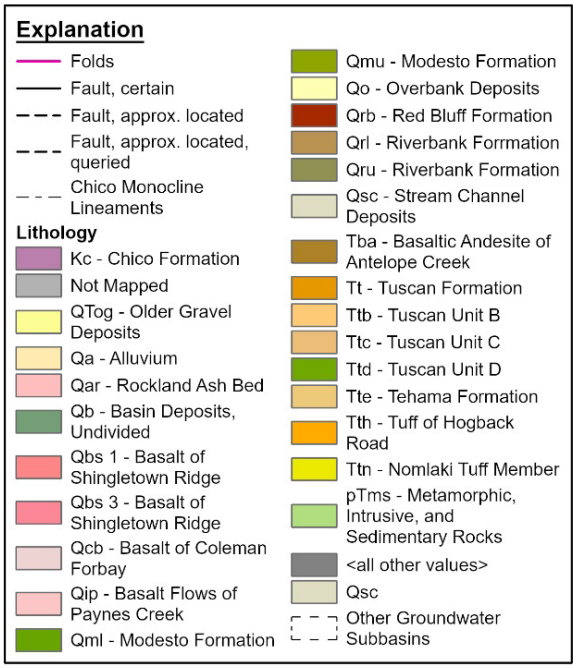
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Geologic Map with Faults

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-21



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

P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B Bowman.aprx:Geologic Map_ED Working

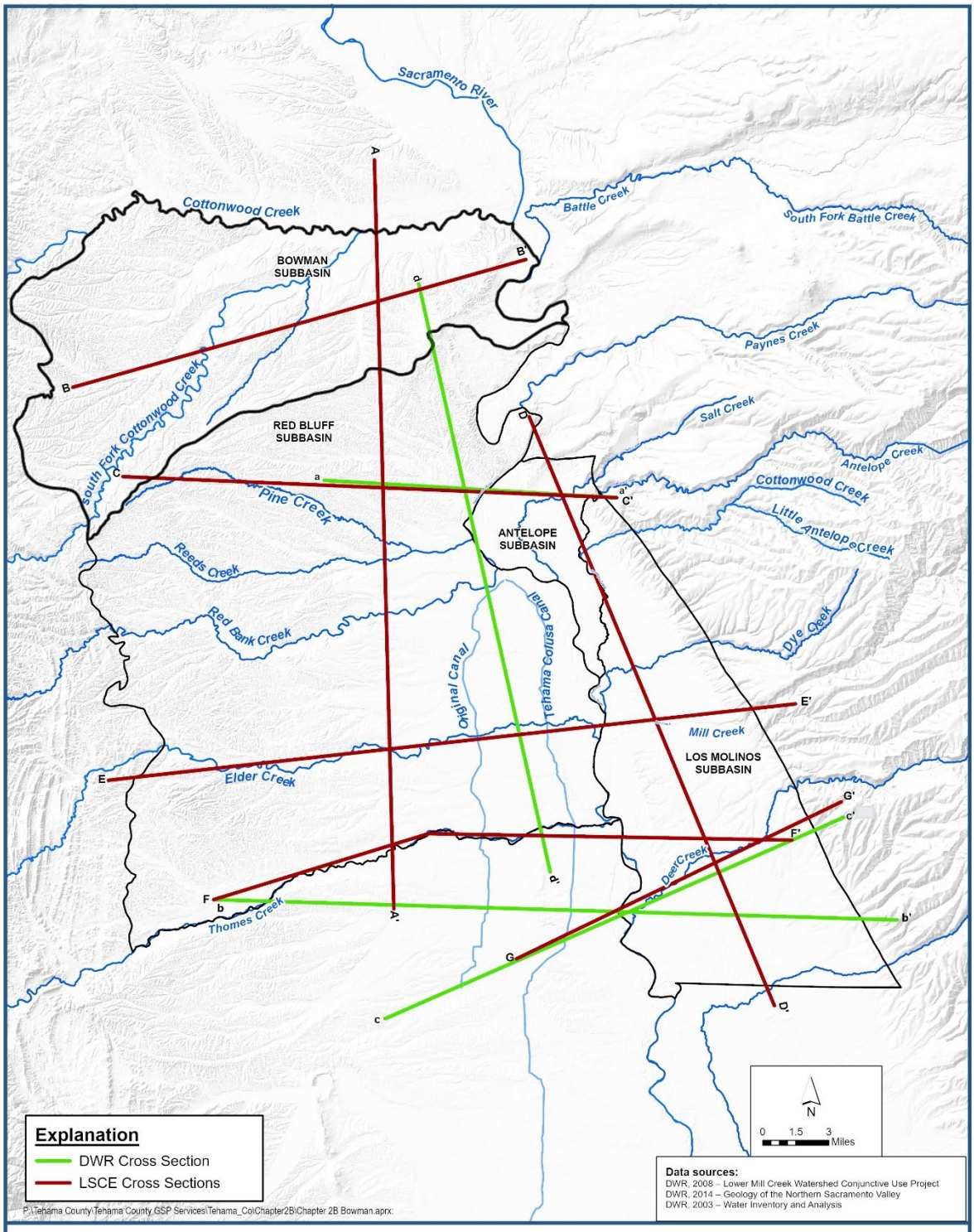
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Geologic Map with Faults

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-21B



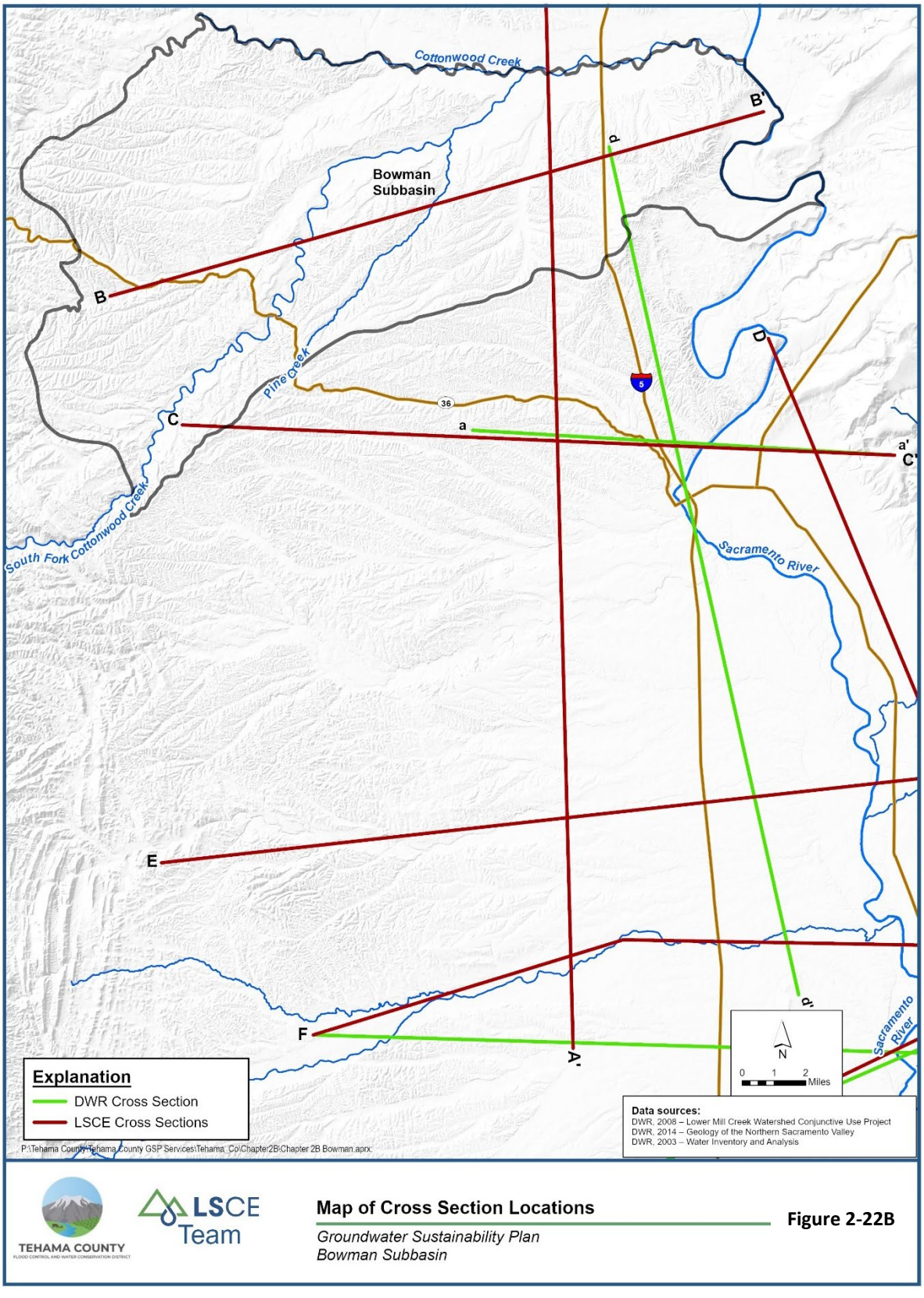
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Map of Cross Section Locations

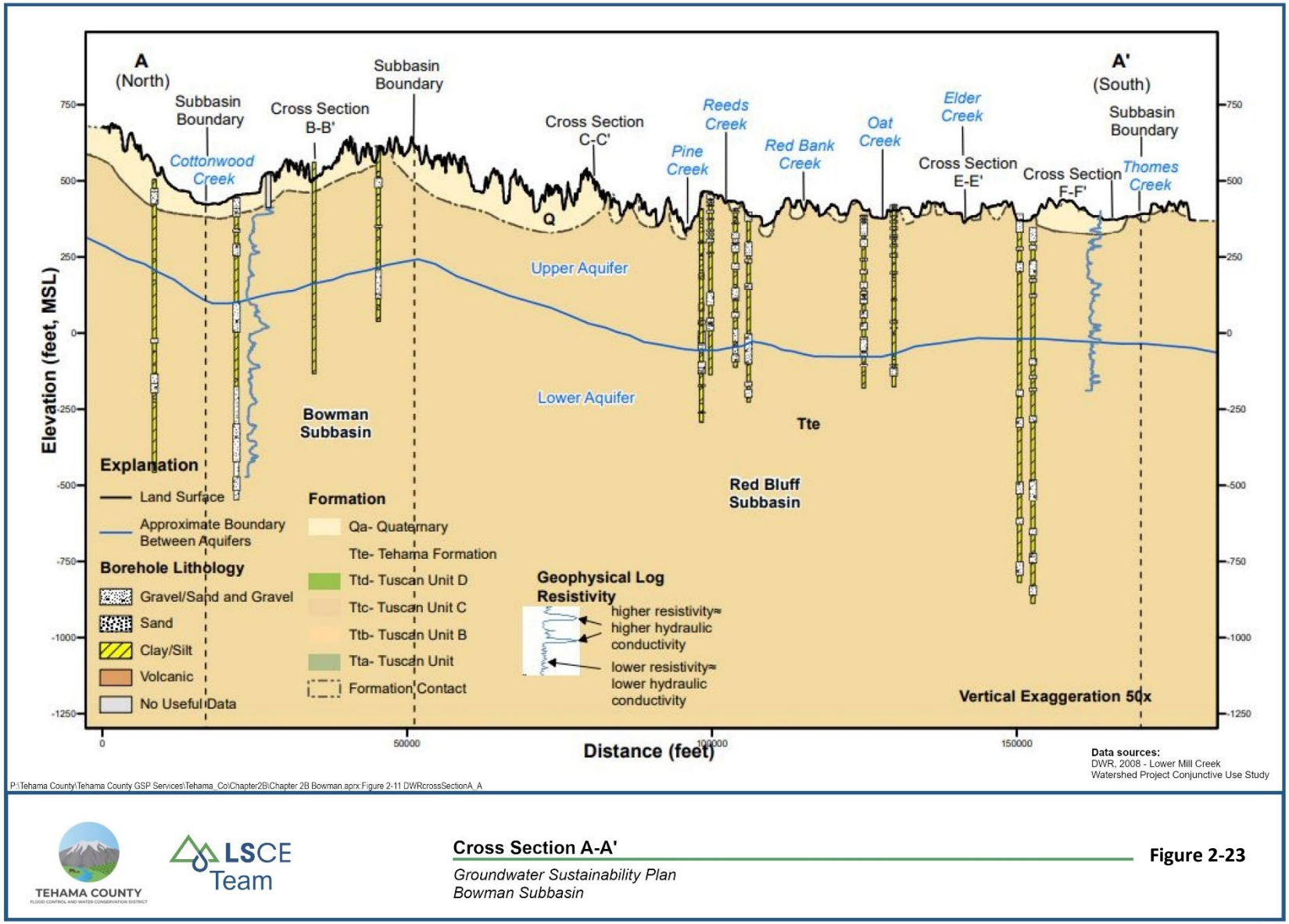
Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-22



Map of Cross Section Locations — **Figure 2-22B**

Groundwater Sustainability Plan
Bowman Subbasin

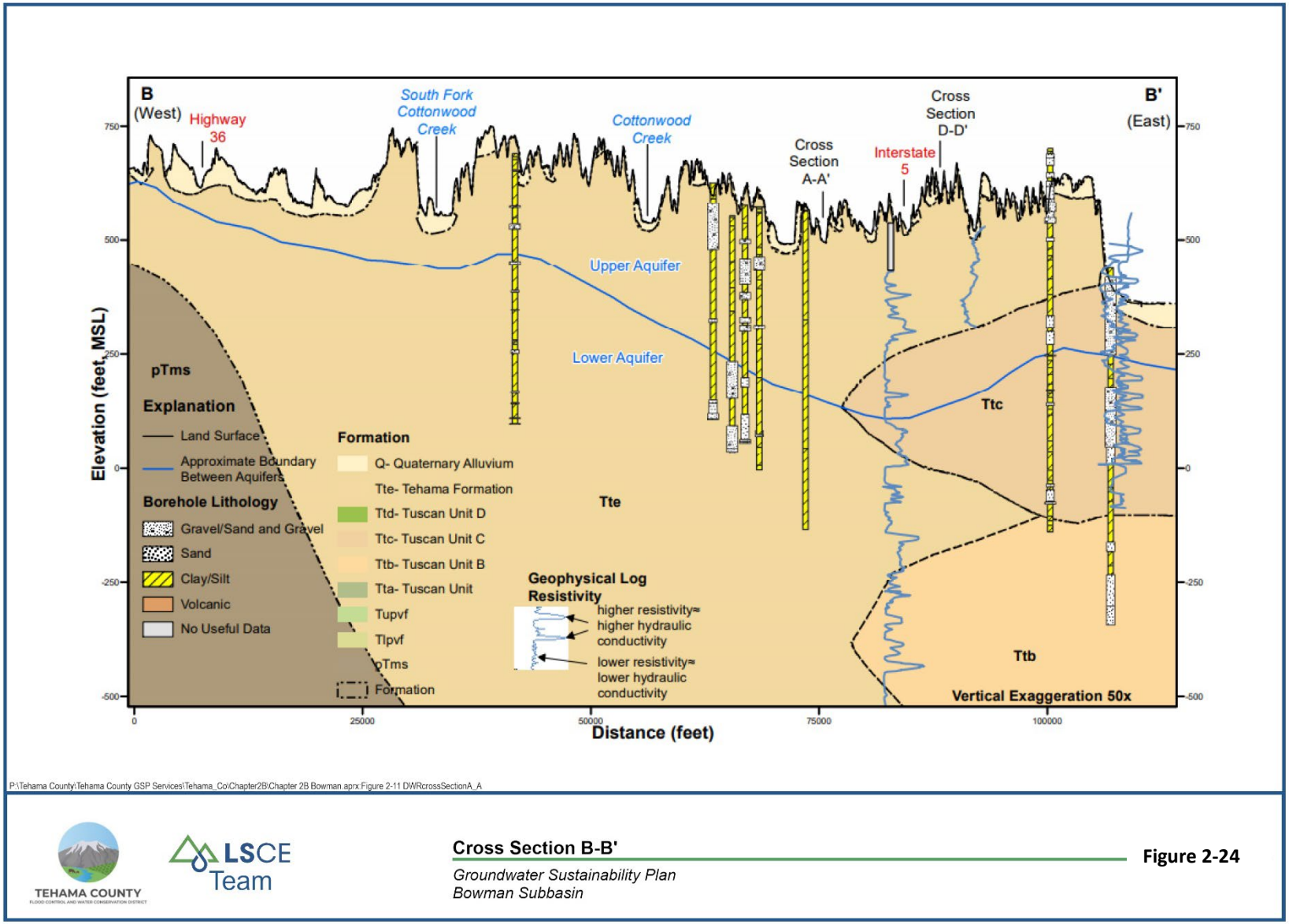


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Cross Section A-A' **Figure 2-23**

Groundwater Sustainability Plan
Bowman Subbasin



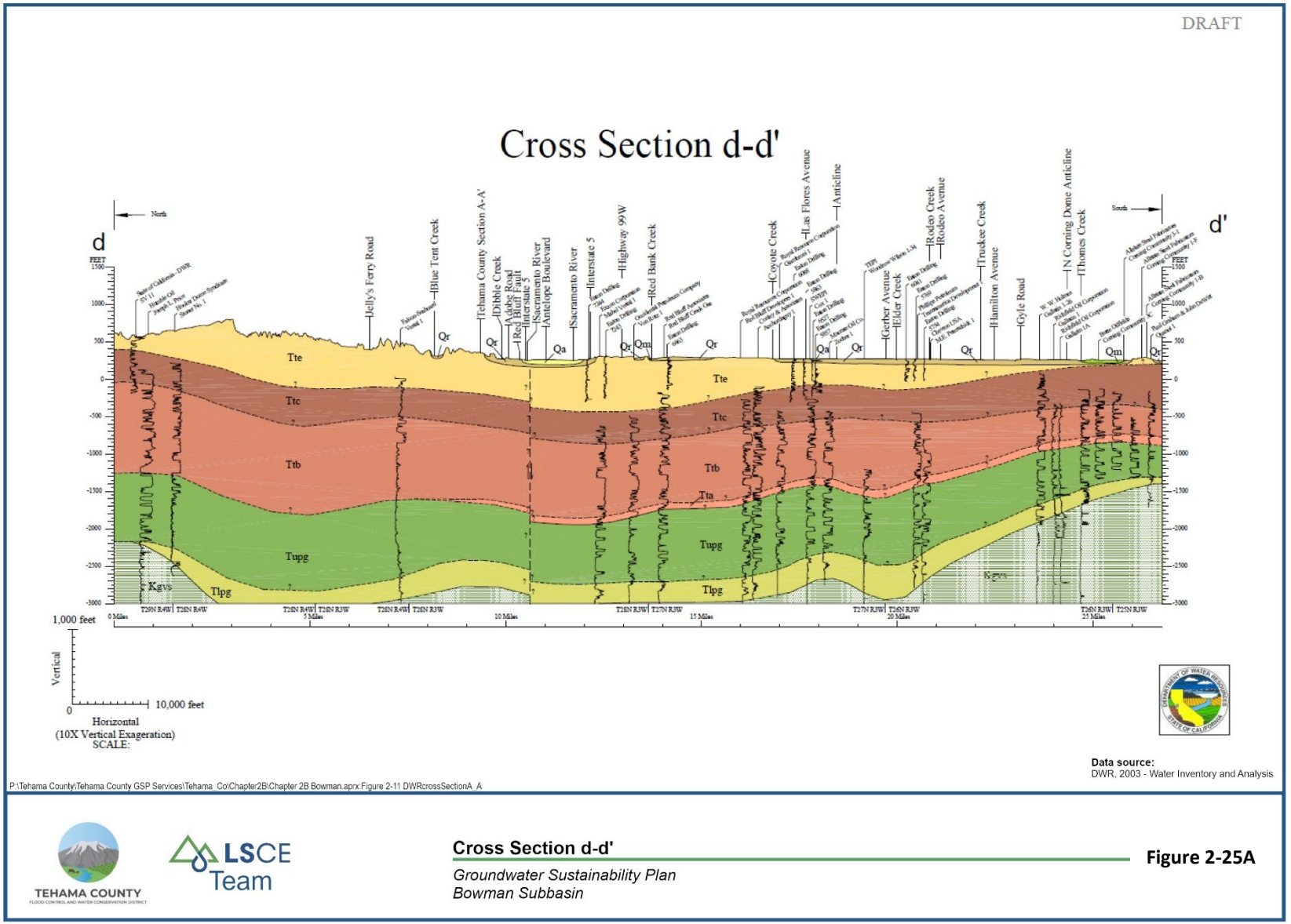
TEHAMA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT

LSCE Team

Cross Section B-B'

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-24



TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT

LSCE Team

Cross Section d-d'

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-25A

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).*

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TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT

LSCE Team

DWR Cross Section Legend

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-25B

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)	30 ft (DWR, 2004)	Upper	Moderately permeable but not a significant source of groundwater in the Subbasin due to limited extent (DWR, 2004)
Neogene	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, 2004)	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, 2004)	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).
		Tehama Formation	Pale green, gray, and tan sandstone, and siltstone with lenses of pebble and cobble conglomerate (DWR, 2014)	2,500 ft (DWR, 2004)	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)	1,600 ft (DWR, 2003)	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)	1,000 ft (DWR, 2003)	Brackish	
	Eocene	Lower Princeton Submarine Fill	Marine Sandstone, conglomerate, and interbedded silty shale (DWR, 2014)	350 ft (DWR 2003)	Saline	
Cretaceous		Great Valley Sequence	Marine clastic sedimentary rock consisting of siltstone, shale, sandstone, and conglomerate (DWR, 2014)	1,500 ft (DWR, 2003)	Saline	

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). 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).

Tuscan Formation

The late Pliocene Tuscan Formation (Tt on **Figure 2-21**) 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 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 1,600 ft (**Figure 2-25**).

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 (Ttb on **Figure 2-21**) similarly yields water readily. Unit B 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 (Tehama County FCWCD, 2003). Unit C (Ttc on **Figure 2-21**) 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 2-21**) is characterized by masses of andesite, pumice, and fragments of black obsidian in a mudstone matrix (Gonzalez, 2014). In the Subbasin, the Tuscan formation's extent is limited to the subsurface in the vicinity of the Sacramento River.

Tehama Formation

The Tehama Formation (Tte on **Figure 2-21**) 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 outcrops in the majority of the Subbasin (**Figure 2-21**). Thickness of the Tehama Formation can be 500 ft in the Subbasin (**Figure 2-25**).

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 2-21**) is composed of sandy gravels on 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). In the Subbasin, the Red Bluff Formation's extent is mainly limited to the north and east (**Figure 2-21**).

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 Formation is predominately in the east and on the banks of the creeks and streams that feed the Sacramento River (**Figure 2-21**).

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 2-21**) occupies the lower terrace positions while the lower member (Qrl on **Figure 2-21**) 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 (DWR, 2004). 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 along streams and creeks within the Subbasin and at thicknesses up to 50 ft (**Figure 2-21;** DWR, 2004). Groundwater occurs in the formation under unconfined conditions (DWR, 2014).

The Modesto Formation consists of a lower member (Qml on **Figure 2-21**) occupying higher topographic areas and an upper member (Qmu on **Figure 2-21**) 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).

Surficial Alluvium

The surficial alluvium (QTog, Qa, Qo, and Qsc on **Figure 2-21**) 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). The maximum thickness of the surficial alluvium has been observed up to 30 feet (Helley and Harwood, 1985). The maximum thickness in the Subbasin is interpreted to be up to 30 ft (DWR, 2004). 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 Red Bluff Arch is present in the Subbasin, and the other structures are discussed for regional context (**Figure 2-21**).

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.

Elder Creek Fault

The Elder Creek Fault is a northwest-trending reverse fault that lies south of the Willows fault (Helley and Harwood, 1985). The fault converges with the Stony Creek Fault at the Coast Range Ophiolite (DWR, 2014). Estimated movement along the fault is as recent as 3.4 Ma (DWR, 2014).

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).

Willows Fault

The Willows Fault is a north-trending high-angle reverse fault with no surface expression (DWR, 2014). The main evidence for the fault is subsurface surveys in previous studies (Redwine, 1972; Harwood and Helley, 1987). The fault has been observed at a dip of over 74 degrees east with greater degrees of offset on older rocks (DWR, 2014).

Corning Fault

The Corning Fault is a north-trending reverse fault with no surface expression. It branches off the Willows Fault south of Tehama County. 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 and Chico Monocline 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 control the major bends in the Sacramento River (Harwood and Helley, 1987). The system is a hydrologic drainage divide that separates the Red Bluff Arch

in the west from the Chico monocline in the east (DWR, 2014). 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 in 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 a collection of smaller geologic structures. Major structures that encompass the Red Bluff Arch are 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 that are present in the Bowman Subbasin belong to 94 unique map units. These soil types are grouped into 31 soil series and shown in **Figure 2-26** and **Figure 2-26B**. The most dominant soil series in the Subbasin is the Newville series. The Newville Series is abundant in uplands across the Subbasin covering about 55% of the Subbasin. These soils are moderately deep, well drained and formed from weathering of calcareous shale and sandstone. The Arbuckle series soils occur throughout the Subbasin in narrow terraces along drainages. These soils are very deep, well drained and formed in alluvium from sedimentary and metamorphic rocks. The Dibble series soils occur on foothills and fan remnants. These soils are moderately deep, well drained and formed in from shale, sandstone, and semi consolidated dense materials. Other dominant soil series in the Subbasin are the Red Bluff, Redding,

Perkins, and Riverwash series soils. These soils collectively account for about 15% of the Subbasin area. All other soil series that exist in the Subbasin collectively cover about 30% of the land surface, and the contribution of each series varies from less than 1% to 2%.

Soil Texture

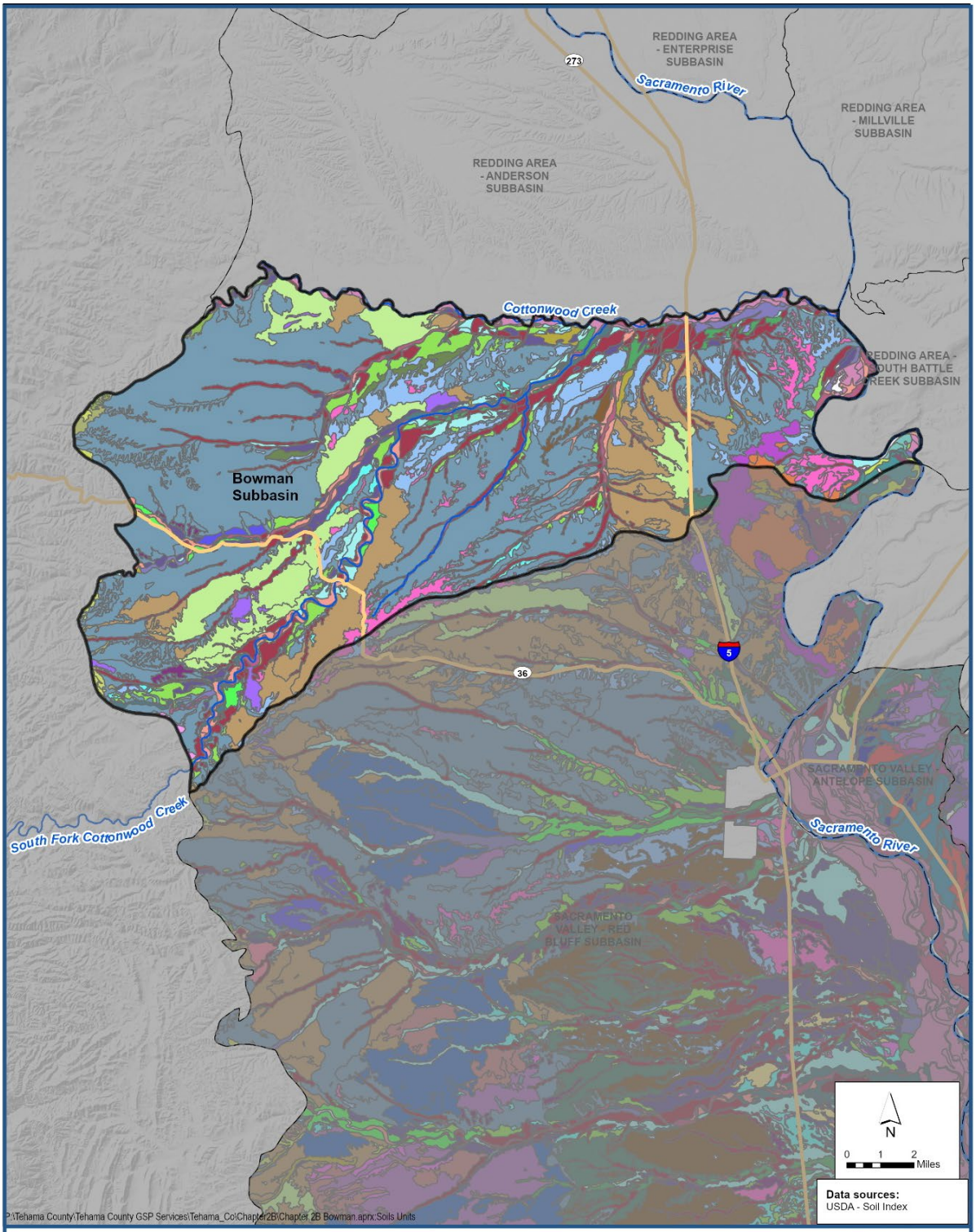
Soil textural classes are defined based on relative percentages of sand, silt, and clay (Soil Science Division Staff, 2017). Spatial distribution of soil textural classes in the Bowman Subbasin are shown in **Figure 2-27**. Loam (a soil composed mostly of sand and silt with a small amount of clay), and different variations of loam are the dominant surficial soil textures in the Subbasin. Gravelly loam soil (loam soil with abundant gravel) covers about 77% of the surface area and exists throughout the Subbasin. Silty clay loam (loam soil with abundant silt and clay) covers about 8% of the Subbasin. Clay loam (loam soil with abundant clay) covers about 5% of the surface.

Hydraulic Conductivity

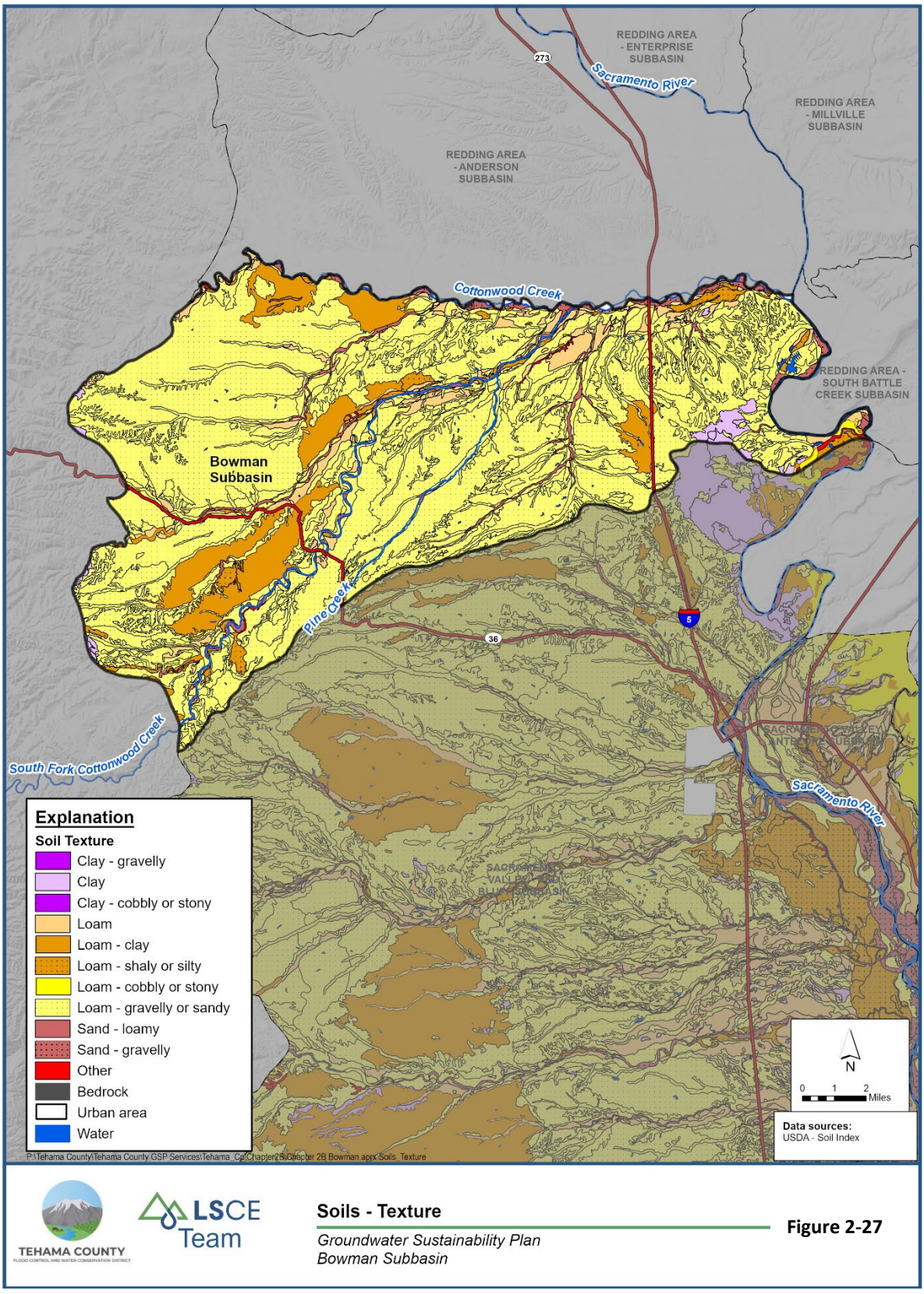
The saturated hydraulic conductivity of surficial soils, which is a measure of a soil's ability to transmit water under a hydraulic gradient, ranges from approximately 0.3 ft/d to 35 ft/d in the Bowman Subbasin (**Figure 2-28**). The spatial distribution of hydraulic conductivity throughout the Subbasin is related to the distribution of soil texture. Relatively fine texture soils such as clays, clay loam and loam have low hydraulic conductivities. Coarse texture soils such as sandy, gravelly, or cobbly loams, and gravelly sand have high hydraulic conductivities. Hydraulic conductivities over 2.0 ft/d are limited to areas along active streams, where soils with gravelly sand texture are common (about 12% of the Subbasin area). About 88% of the Subbasin area has surficial soils with hydraulic conductivities of less than 1.0 ft/d, most likely due to the presence of low-permeability, fine-textured soil horizons.

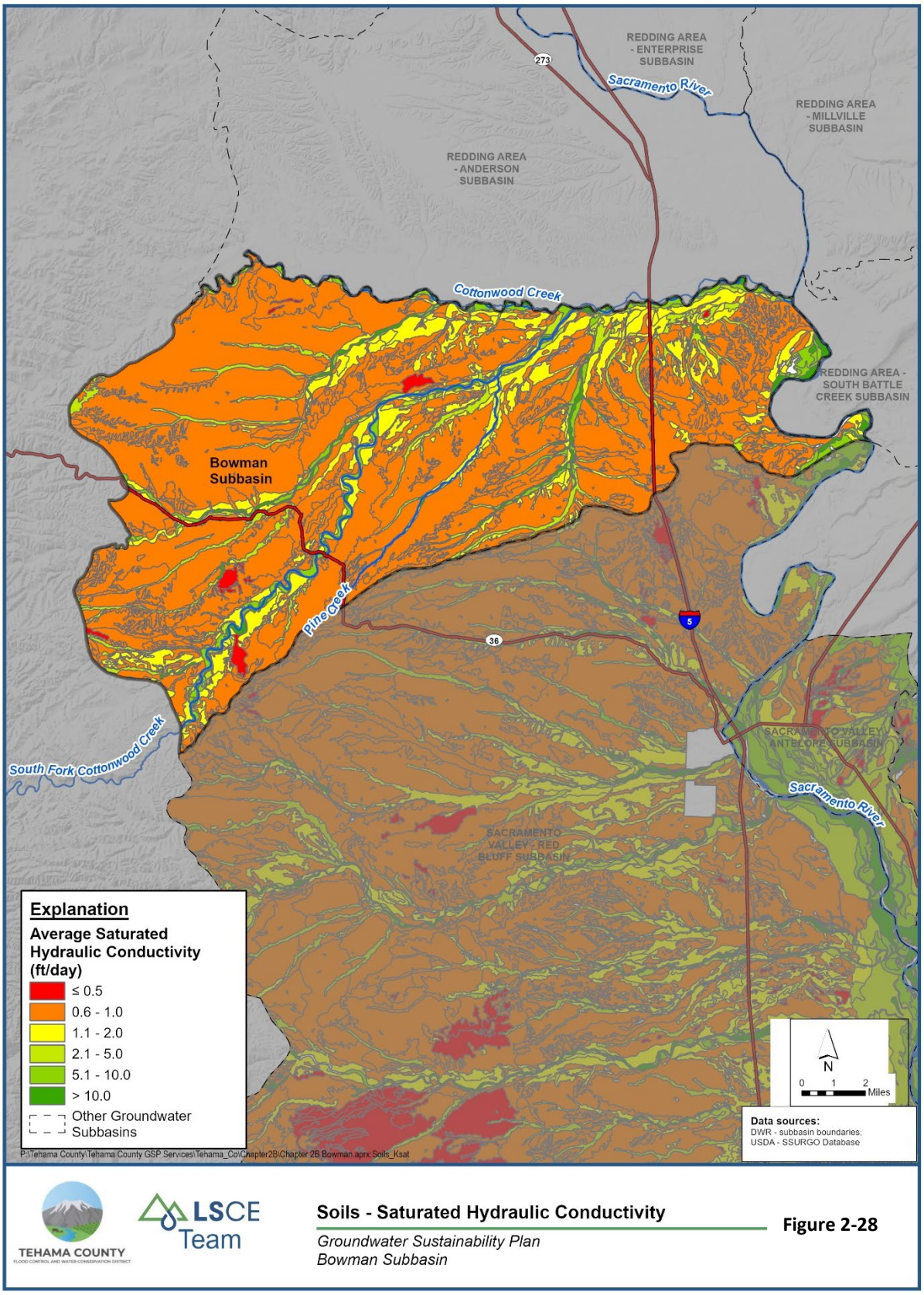
Drainage

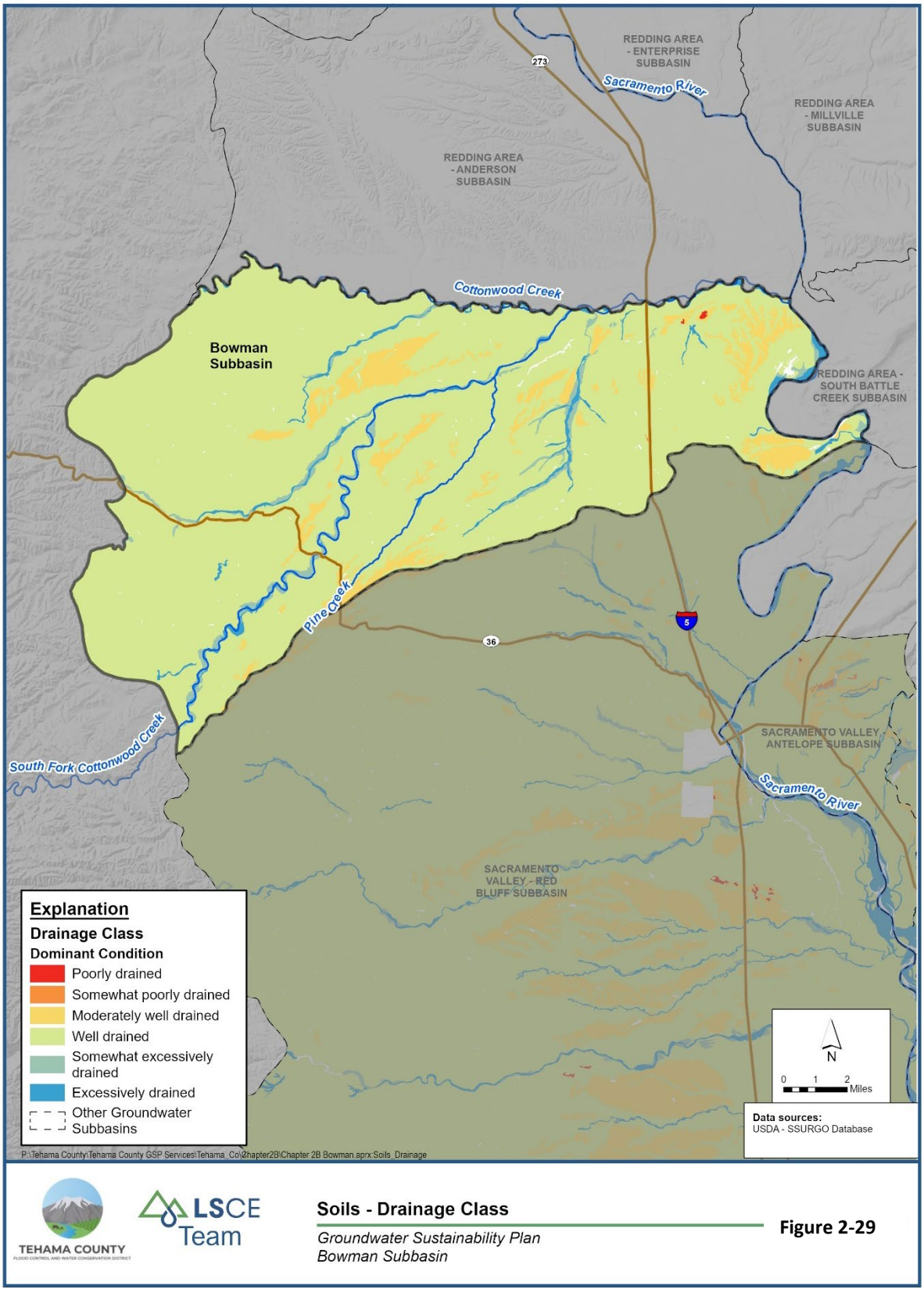
Soil drainage classes indicate the ability of a soil to drain water. Spatial distribution of soil drainage properties in the Bowman Subbasin closely resembles the distribution of saturated hydraulic conductivity and soil texture (**Figure 2-29**). About 88% of the Subbasin area is categorized as well drained soils, while about 7% of the area is categorized as moderately well drained soils. Somewhat excessively drained and excessively drained soils occur adjacent to drainage ways, where coarse soils are abundant, covering a total of about 5% of the area. Small patches of poorly drained soils cover less than 1% of the Subbasin.


REDDING AREA - ENTERPRISE SUBBASIN
Sacramento River
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
Cottonwood Creek
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
Bowman Subbasin
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
South Fork Cottonwood Creek
Sacramento River
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
N
0 1 2 Miles
Data sources:
USDA - Soil Index
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TEHAMA COUNTY
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Soils - Type by Soil Series
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-26


Explanation
Soils Type
Soil Series
Alltamont
Anita
Anita-Galt
Anita-Keefers
Arbuckle
Arbuckle-Tehama
Berrendos
Bosquejo
Charger
Clear Lake
Colluvial Land
Columbia
Corning
Corning-Newville
Corning-Redding
Cortina
Dibble
Dibble-Gullied
Doemill-Jokerst
Farwell
Gianella
Hillgate
Inks
Jokerst-Doemill-Typic
Keefers
Kimball
Langlier
Lodo-Millsholm
Los Robles
Maywood
Millrace
Millsap
Millsholm
Millsholm-Millsap
Moda
Molinos
Munjar-Tuscan
Myers
Nacimiento
Nacimiento-Altamont
Nacimiento-Newville
Newville
Newville-Dibble
Newville-Laniger
Orland
Perkins
Perkins-Kimball
Peters
Peters-Newville
Pleasanton
Red Bluff
Redding
Redding-Newville
Redsluff
Redtough-Fallager-Anita
Redtough-Redswale
Reiff
Riverwash
Sehorn
Sehorn-Millsholm
Supan
Tailings and Placer Diggings
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 Bowman.aprx:Soils Units
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Soils - Type by Soil Series
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Figure 2-26B


REDDING AREA - ENTERPRISE SUBBASIN
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
Sacramento River
Cottonwood Creek
Bowman Subbasin
Pine Creek
South Fork Cottonwood Creek
273
5
36
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
N
0 1 2 Miles
Data sources:
USDA - Soil Index
P:\Tehama County\Tehama County GSP Services\Tehama_Ca\Chapter2B\Chapter 2B Bowman.aprx Soils_Texture
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Soils - Texture
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Bowman Subbasin
Figure 2-27


REDDING AREA - ENTERPRISE SUBBASIN
Sacramento River
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
Cottonwood Creek
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
Bowman Subbasin
Pine Creek
South Fork Cottonwood Creek
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
SACRAMENTO VALLEY - RED BLUFF 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 1 2 Miles
Data sources:
DWR - subbasin boundaries;
USDA - SSURGO Database
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B Bowman.aprx:Soils_Ksat
TEHAMA COUNTY
LSCE Team
Soils - Saturated Hydraulic Conductivity
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-28

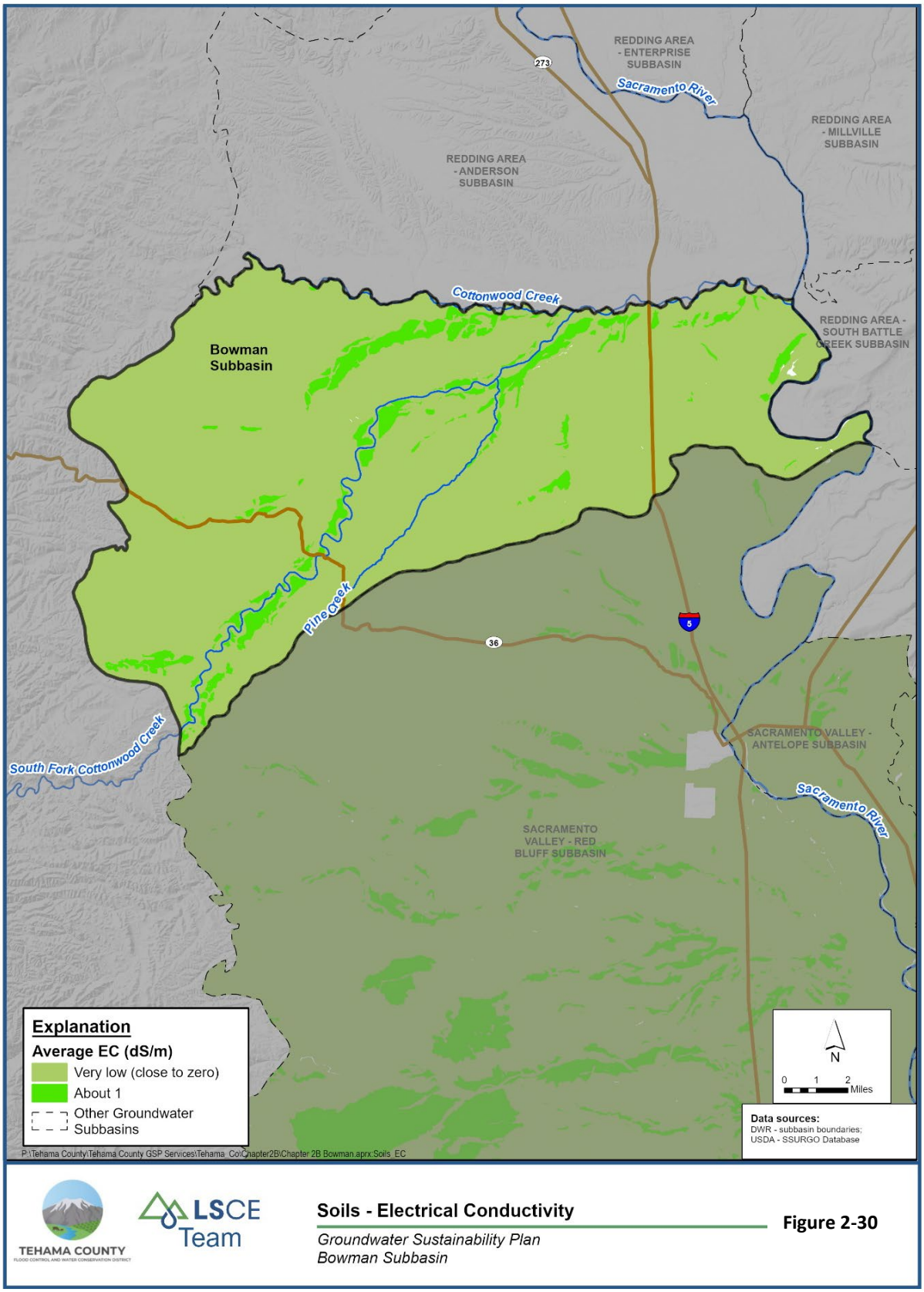

REDDING AREA - ENTERPRISE SUBBASIN
Sacramento River
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
Cottonwood Creek
Bowman Subbasin
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
Pine Creek
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
South Fork Cottonwood Creek
Sacramento River
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Explanation
Drainage Class
Dominant Condition
Poorly drained
Somewhat poorly drained
Moderately well drained
Well drained
Somewhat excessively drained
Excessively drained
Other Groundwater Subbasins
N
0 1 2 Miles
Data sources:
USDA - SSURGO Database
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Soils - Drainage Class
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-29

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 the increase of the salinity of groundwater. All surficial soils in the Bowman Subbasin fall into non-saline class, where EC values are less than two 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 2-30**).

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 Bowman Subbasin ranges between 5.0 and 7.9, but the range is between 5.6 and 7.0 in about 99% of the area (**Figure 2-31**). Soils with pH values less than 5.6 occur throughout the Subbasin in small patches (about 1% of the area). In general, solubility of minerals increases with acidity of the soil and water. Acidity or alkalinity of surficial soils in the Subbasin are not expected to adversely alter water quality.



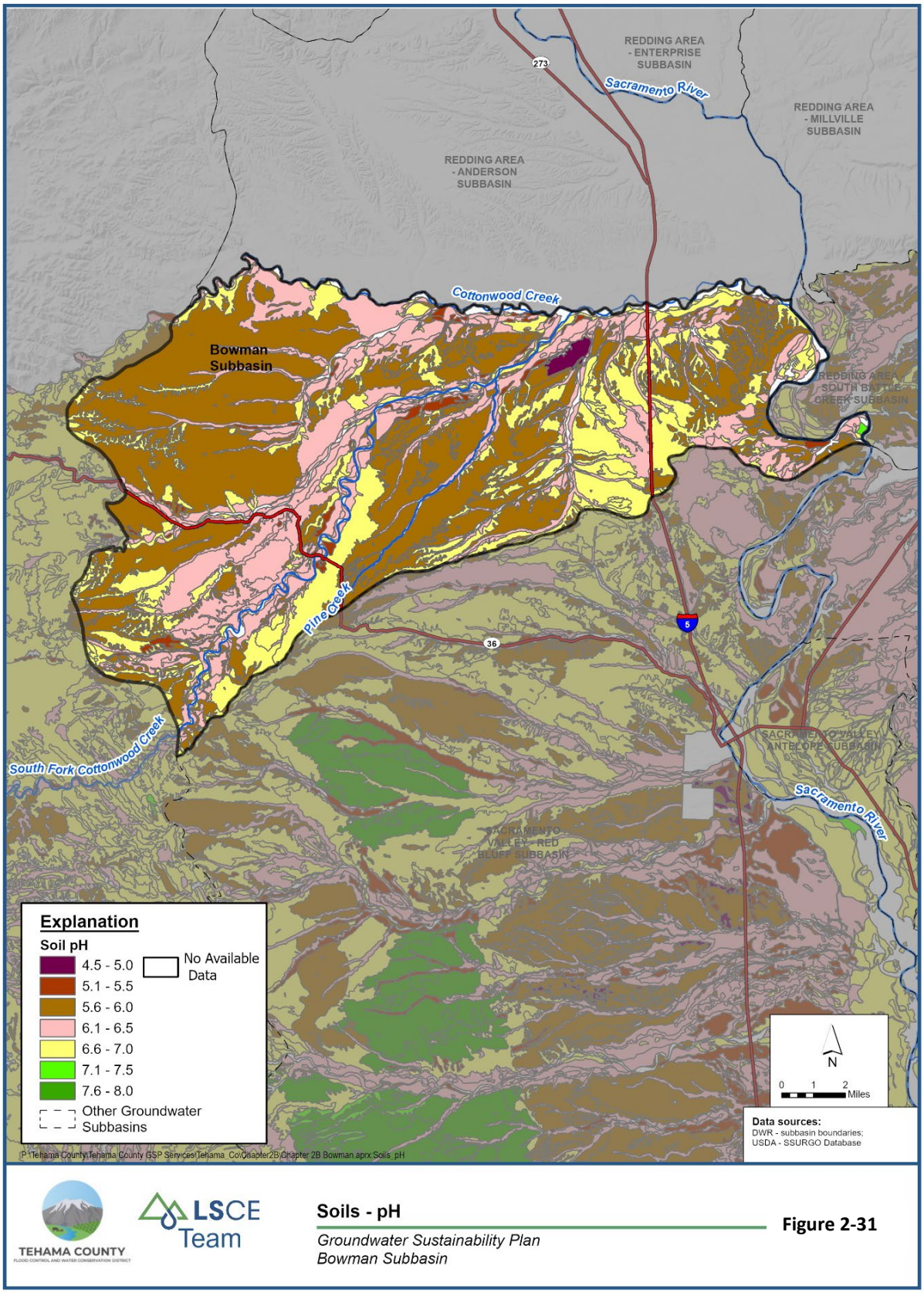
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Soils - Electrical Conductivity

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-30


REDDING AREA - ENTERPRISE SUBBASIN
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Sacramento River
Cottonwood Creek
Bowman Subbasin
Pine Creek
South Fork Cottonwood Creek
273
5
36
Explanation
Soil pH
4.5 - 5.0
5.1 - 5.5
5.6 - 6.0
6.1 - 6.5
6.6 - 7.0
7.1 - 7.5
7.6 - 8.0
No Available Data
Other Groundwater Subbasins
N
0 1 2 Miles
Data sources:
DWR - subbasin boundaries;
USDA - SSURGO Database
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TEHAMA COUNTY
LSCE Team
Soils - pH
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-31

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 similarly 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 (**Figure 2-23 and Figure 2-24**). 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 majority of 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 largely for domestic purposes. The depth to the bottom of the Upper Aquifer is approximately 350-450 ft bgs (**Figure 2-23 and Figure 2-24**).

Site-specific aquifer properties obtained from aquifer tests are available for localized areas of the Subbasin. In addition, aquifer tests were conducted in surrounding subbasins. Hydraulic conductivity (rate at which water moves through an aquifer), transmissivity (hydraulic conductivity multiplied by aquifer thickness), 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 at the Holiday Ranch Site south of Cottonwood and in neighboring subbasins. Aquifer tests were conducted in a well screened from 140 ft bgs to 520 ft bgs at the Holiday Ranch Site near Cottonwood (Lawrence and Associates, 2007). Transmissivity at the Holiday Ranch Site is 90,000 ft^2/d and hydraulic conductivity is 450 to 500 ft/d with a storage coefficient of 0.00025 (Lawrence and Associates, 2007). As the test well

spans both the Upper Aquifer and Lower Aquifer horizons the aquifer parameter values represent a combination of both aquifers.

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). In the Vina Subbasin to the southeast, the transmissivity of the upper portion of the Tuscan Formation (70-530 ft bgs) is estimated to be approximately 14,000 square feet per day (ft^2/d) to approximately 55,000 ft^2/d (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. Lack of a continuous confining layer in the Subbasin creates challenges for defining the top of the Lower Aquifer.

The lack of wells screened in the Lower Aquifer in the Subbasin creates a data gap for hydraulic properties. Hydraulic properties of the Tehama Formation have been characterized in the Subbasin but are not specific to the Lower Aquifer. In a well screened from 200-500 ft bgs, average transmissivity is 90,000 ft^2/d, hydraulic conductivity is 450-500 ft/d, and the storage coefficient is 0.00025 at the Holiday Ranch Site near Cottonwood in the Subbasin (Lawrence and Associates, 2007). As the test well spans both the Upper Aquifer and Lower Aquifer horizons the aquifer parameter values represent a combination of both aquifers.

The Tehama Formation has an average transmissivity of 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). The Tuscan Formation has not been directly characterized in the Subbasin; however, 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 in the Los Molinos Subbasin (DWR, 2003). Storativity in the Los Molinos Subbasin is estimated to be 0.0025 and hydraulic conductivity is estimated to be 40 ft/d to 60 ft/d (Harrison, 1989; Ely, 1994; DWR, 2003).

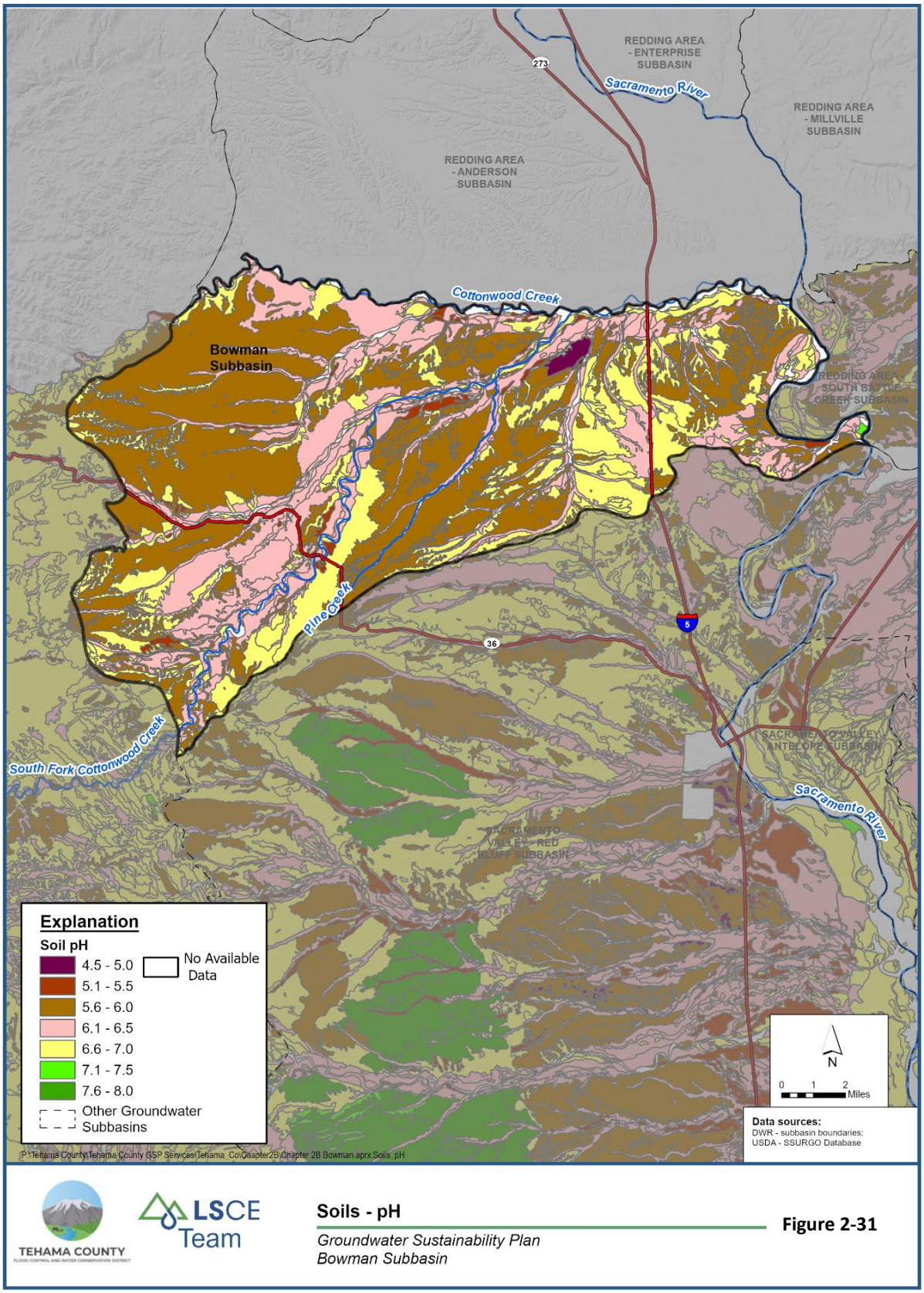
2.2.1.6 Definable Bottom of Basin

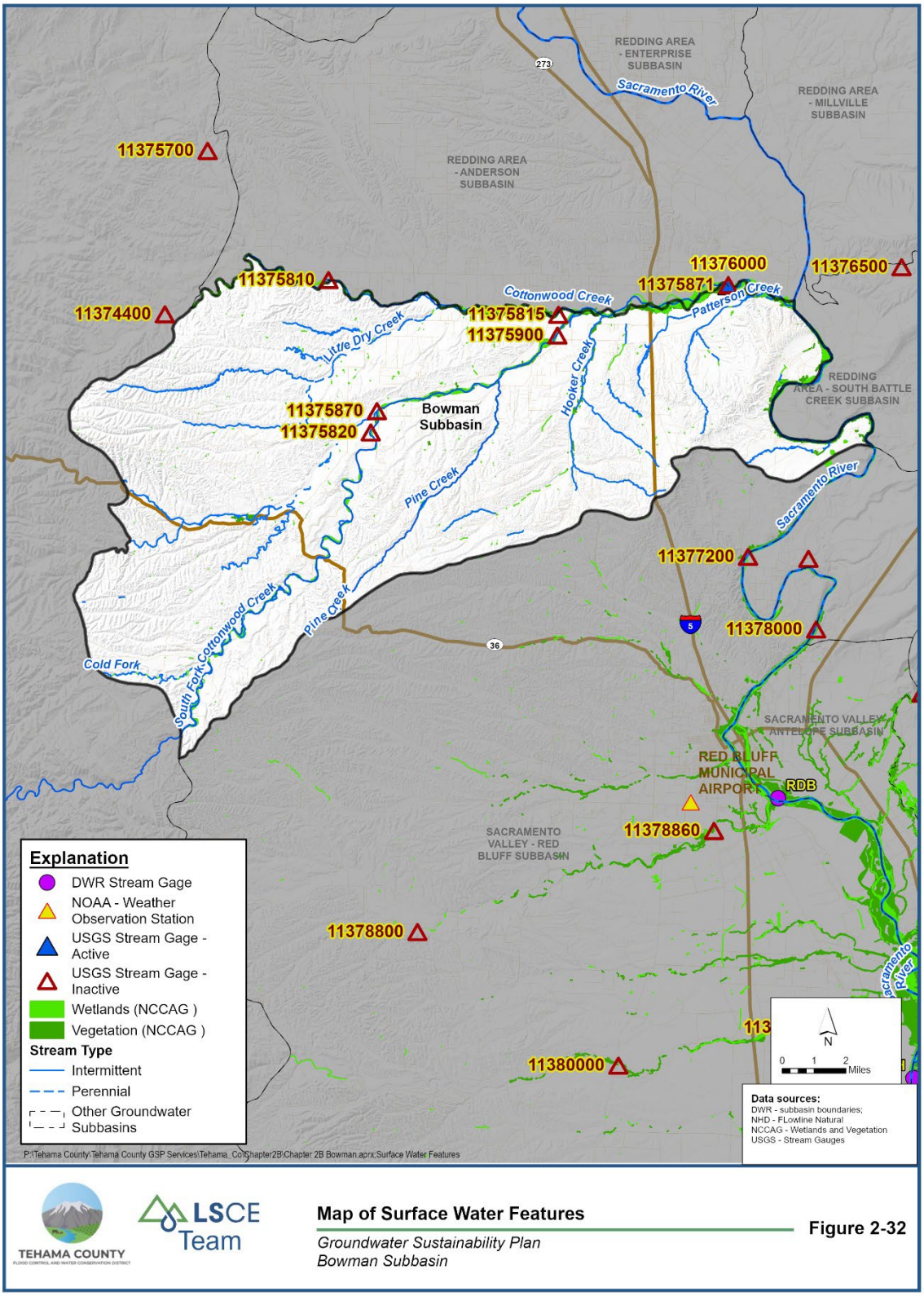
The base of the post-Eocene continental deposits is defined as the bottom of the basin. The post-Eocene deposits are the deepest locations where fresh water may exist. Contours of the base of post-Eocene deposits (**Figure 2-17)** are on the base of the upper Princeton Valley Fill in the majority of 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 (EC) of 3,000 micromhos per centimeter (µmhos/cm) (Berkstresser, 1973). The base of fresh water is the shallowest in the west at elevations above -400 ft mean sea level (msl) and deepest in the east at elevations deeper than -1,200 ft, msl (**Figure 2-16;** Berkstresser, 1973). 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, Cottonwood Creek (including the South Fork), Little Dry Creek, Hooker Creek, Patterson Creek, and Pine Creek (**Figure 2-32**). The Sacramento River and Cottonwood Creek flow throughout the year (perennial), but the remaining streams flow seasonally. The Sacramento River flows southward along the eastern boundary of the Subbasin. The other streams flow northward draining the Subbasin and feeding Cottonwood Creek. Cottonwood Creek flows eastward where it enters the Sacramento River at the eastern boundary. Several small seasonal ponds (surface area less than 10 acres) occur along streams, but there are no natural lakes or reservoirs within the Subbasin.


REDDING AREA - ENTERPRISE SUBBASIN
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
Sacramento River
Cottonwood Creek
Bowman Subbasin
Pine Creek
South Fork Cottonwood Creek
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
273
5
36
Explanation
Soil pH
4.5 - 5.0
5.1 - 5.5
5.6 - 6.0
6.1 - 6.5
6.6 - 7.0
7.1 - 7.5
7.6 - 8.0
No Available Data
Other Groundwater Subbasins
N
0 1 2 Miles
Data sources:
DWR - subbasin boundaries;
USDA - SSURGO Database
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B Bowman.aprx\Soils_pH
TEHAMA COUNTY
LSCE Team
Soils - pH
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-31


REDDING AREA - ENTERPRISE SUBBASIN
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Bowman Subbasin
Sacramento River
Cottonwood Creek
Patterson Creek
Little Dry Creek
Hooker Creek
Pine Creek
South Fork Cottonwood Creek
Cold Fork
RED BLUFF MUNICIPAL AIRPORT
RDB
11375700
11375810
11374400
11375815
11375900
11376000
11375871
11376500
11375870
11375820
11377200
11378000
11378860
11378800
11380000
Explanation
DWR Stream Gage
NOAA - Weather Observation Station
USGS Stream Gage - Active
USGS Stream Gage - Inactive
Wetlands (NCCAG)
Vegetation (NCCAG)
Stream Type
Intermittent
Perennial
Other Groundwater Subbasins
N
0 1 2 Miles
Data sources:
DWR - subbasin boundaries;
NHD - FLowline Natural
NCCAG - Wetlands and Vegetation
USGS - Stream Gauges
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B Bowman.aprx:Surface Water Features
TEHAMA COUNTY
LSCE Team
Map of Surface Water Features
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-32

Groundwater recharge of the Subbasin primarily occurs from the flow of the Sacramento River and the other streams and tributaries in the Subbasin (DWR, 2004). Some of the groundwater recharge contributions from smaller streams and tributaries likely supports 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 2-28**). 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 2-33**). 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, Cottonwood Creek, and the South Fork of Cottonwood Creek (**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).

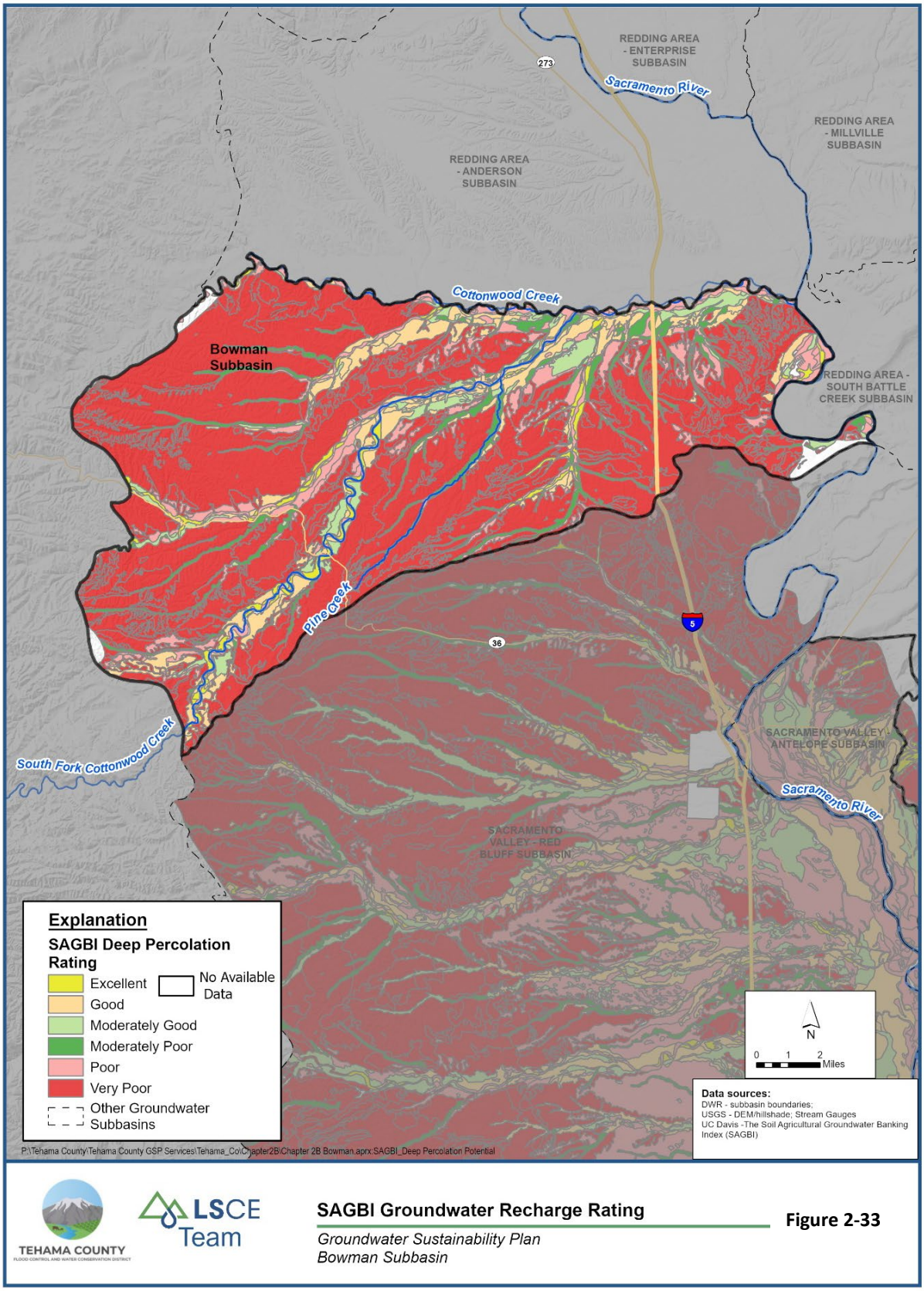
2.2.1.8 Data Gaps and Uncertainty

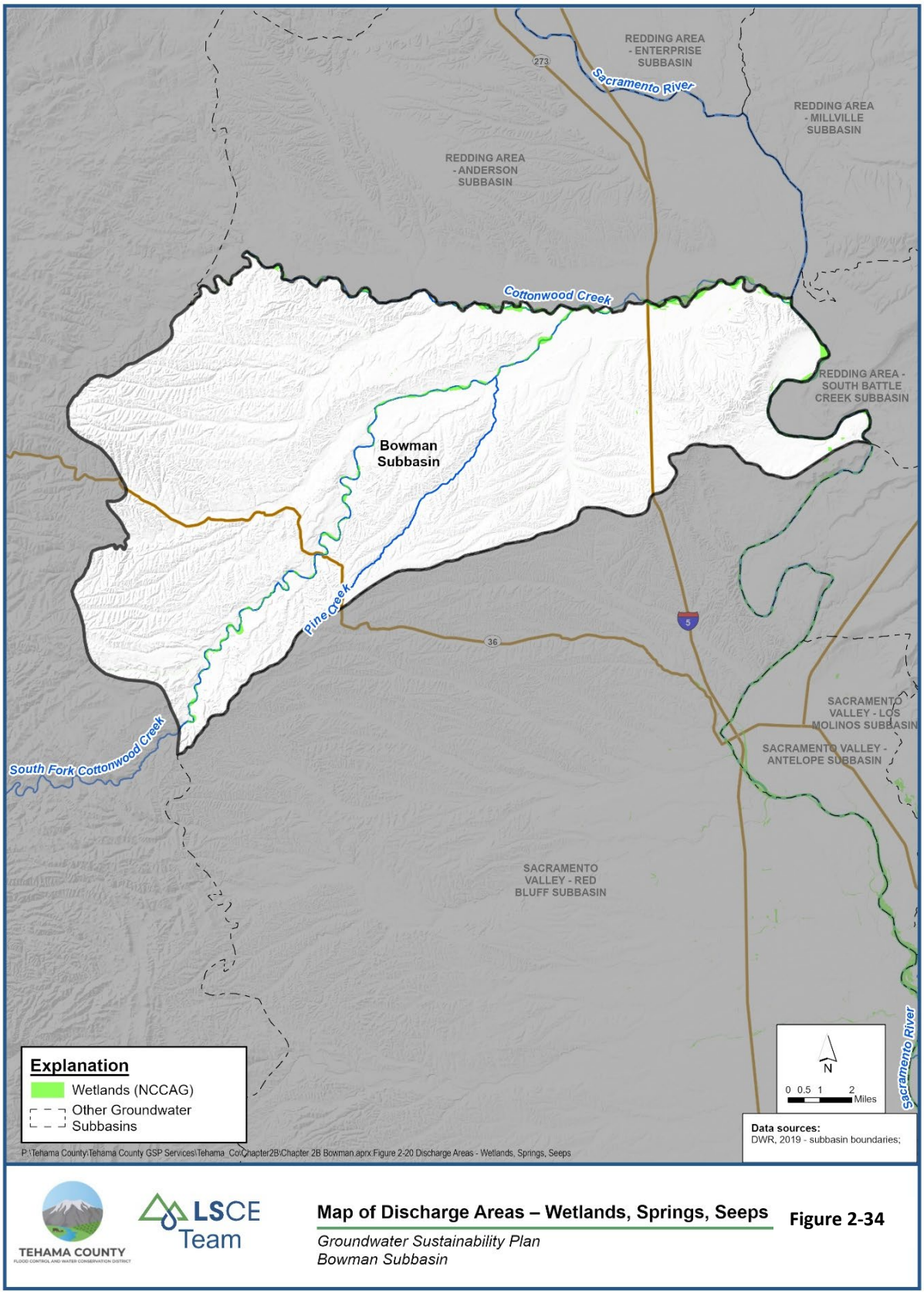
Stratigraphy

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. Parameters have been estimated for geologic formations within the Subbasin at localized sites; however, the formations vary with extent and may be different in different 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.


REDDING AREA - ENTERPRISE SUBBASIN
Sacramento River
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
Cottonwood Creek
Bowman Subbasin
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
Pine Creek
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
South Fork Cottonwood Creek
Sacramento River
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Explanation
SAGBI Deep Percolation Rating
Excellent
Good
Moderately Good
Moderately Poor
Poor
Very Poor
No Available Data
Other Groundwater Subbasins
N
0 1 2 Miles
Data sources:
DWR - subbasin boundaries;
USGS - DEM/hillshade; Stream Gauges
UC Davis -The Soil Agricultural Groundwater Banking Index (SAGBI)
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TEHAMA COUNTY
LSCE Team
SAGBI Groundwater Recharge Rating
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-33



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Map of Discharge Areas – Wetlands, Springs, Seeps **Figure 2-34**

Groundwater Sustainability Plan
Bowman 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 from new proximal shallow monitor 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 2-35**, 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 (about 10 miles south from the southern boundary of the Subbasin) shows a strong positive correlation with the Sacramento Valley Water Year Index (Pearson's correlation coefficients of 0.72). **Figure 2-36** shows the annual precipitation and cumulative departure curve of precipitation at Red Bluff Municipal Airport. 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**).

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

Upper Aquifer

Seasonal high-water levels in the Upper Aquifer (in winter/spring seasons) during wet periods range between about 20 and 190 ft bgs. Depth to water is shallower (about 20 - 30 ft bgs) close to the northeastern boundary of the Subbasin (close to the Cottonwood Creek in areas east of the Little Dry Creek) compared to that in the other areas of the Subbasin. Local topography is also a major factor that determines the depth to water at a location. 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 of the Subbasin. 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.

Lower Aquifer

Depth to water in the Lower Aquifer ranges from about 40 ft bgs to 140 ft bgs in the northeastern portion of the Subbasin (measured at three locations). Seasonal fluctuations, as well as fluctuations that correspond to wet and dry climatic conditions, are less than 10 ft in this area. Historical water level data in other parts of the Subbasin are not available.

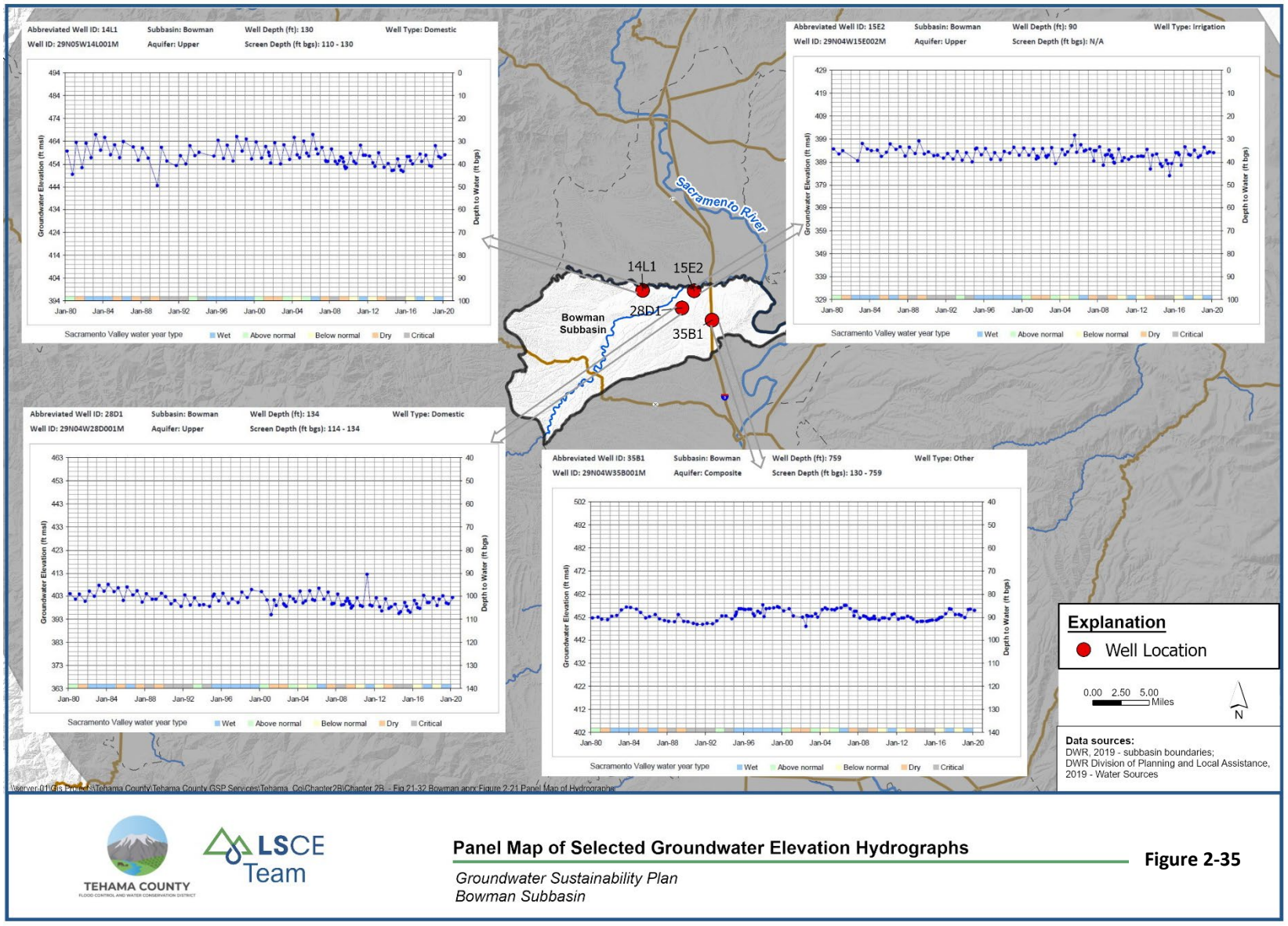
Trends in Groundwater Levels

Statistical analysis of data from four wells, which have records spanning the entirety of the 1990 through 2018 hydrologic base period, show stable groundwater levels. Three of these four wells are screened in the Upper Aquifer, and the other well is screened in both aquifers (a composite well). Seasonal high water levels of two Upper Aquifer wells and the composite well do not show a significant trend of change during this period. Water levels of the other Upper Aquifer well show a very small declining rate of about 0.2 feet per year. Lower Aquifer wells with water level data that span the entirety of the 1990-2018 period do not exist in the Subbasin. However, data collected from few wells since 2000 show stable water levels in the Lower Aquifer during the last two decades. 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**.

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 the Upper Aquifer. Seasonal high and seasonal low water elevations of Upper Aquifer wells were used to develop contours of equal groundwater elevation ("Contours"). Water levels of wells that are entirely screened within the top 50 ft bgs and wells without construction details were excluded from contouring, since these wells are likely not representative of the areas of the aquifer where groundwater pumping occurs. Contours were initially developed using spatial analyst tools in ArcGIS software, and then modified based on professional judgement. Contours were not developed for areas where data was lacking (mainly the western half of the Subbasin). Also, contours were not created for the Lower Aquifer because of the lack of data.

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 seasonal high and seasonal low groundwater elevation of water year 2019 (**Figures 2-37 and 2-38**). 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 (**Figures 2-39 through 2-44**).

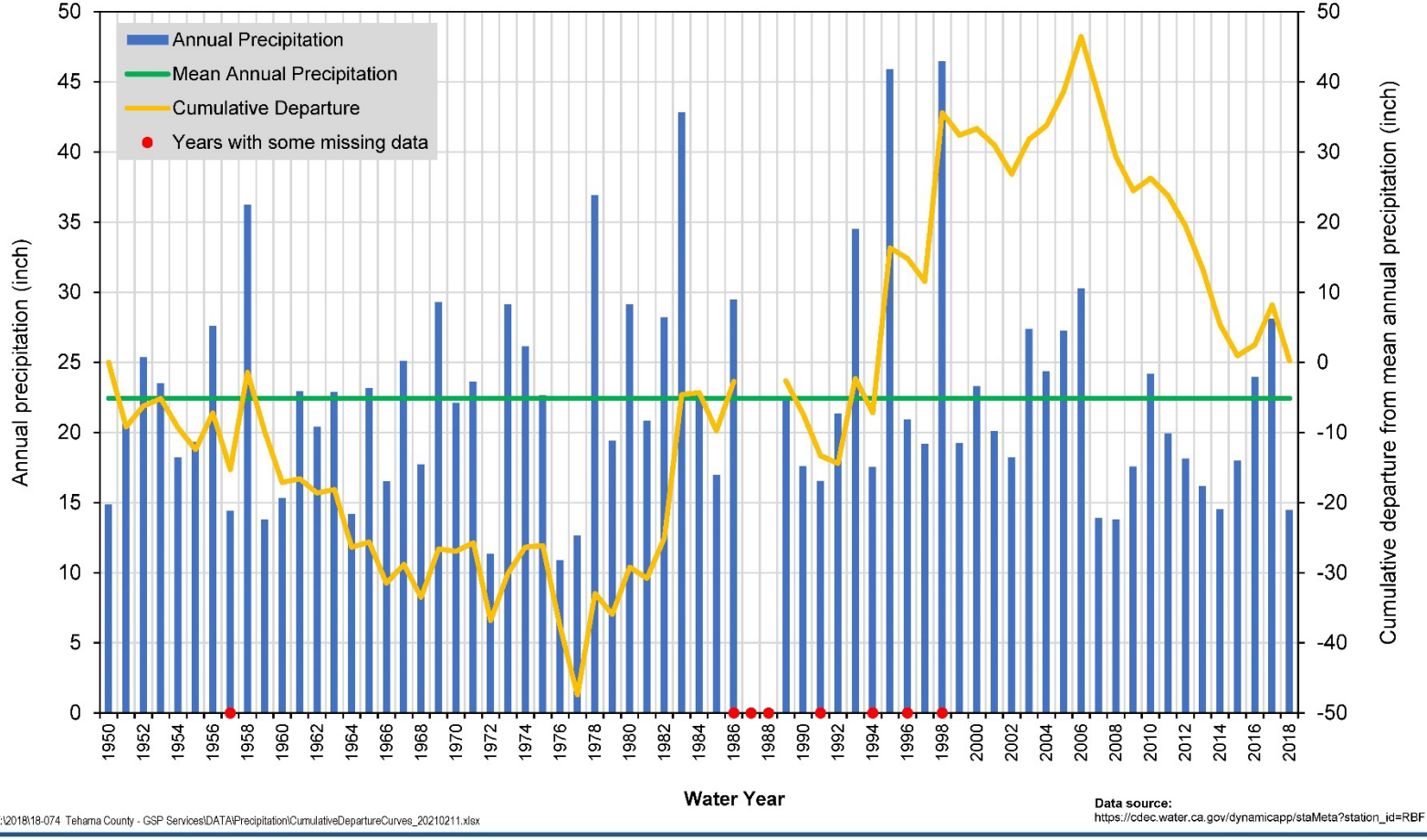


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Panel Map of Selected Groundwater Elevation Hydrographs **Figure 2-35**

Groundwater Sustainability Plan
Bowman Subbasin



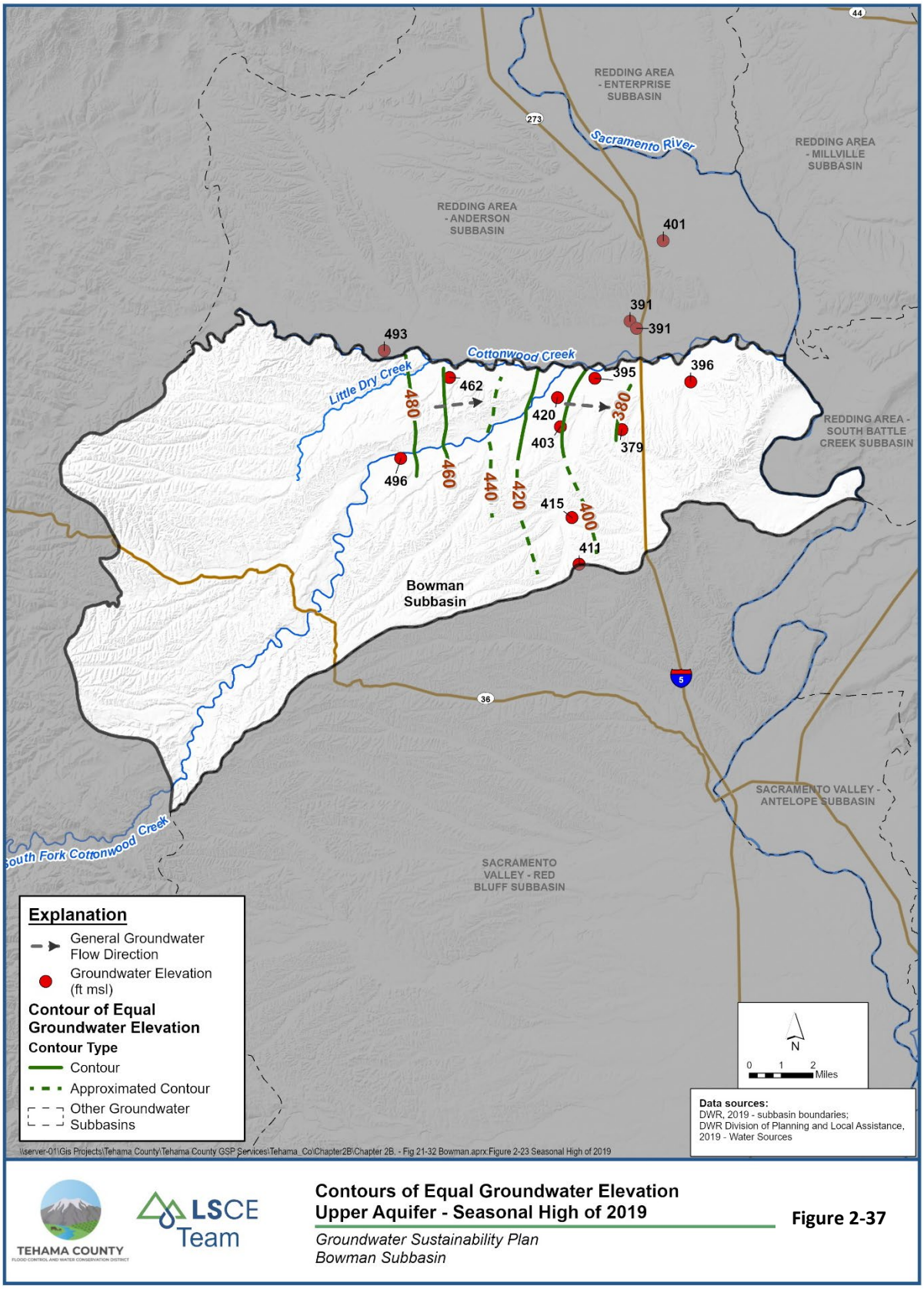
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LSCE Team

Annual Precipitation and Cumulative Departure at Red Bluff Municipal Airport

Figure 2-36

Groundwater Sustainability Plan
Bowman Subbasin



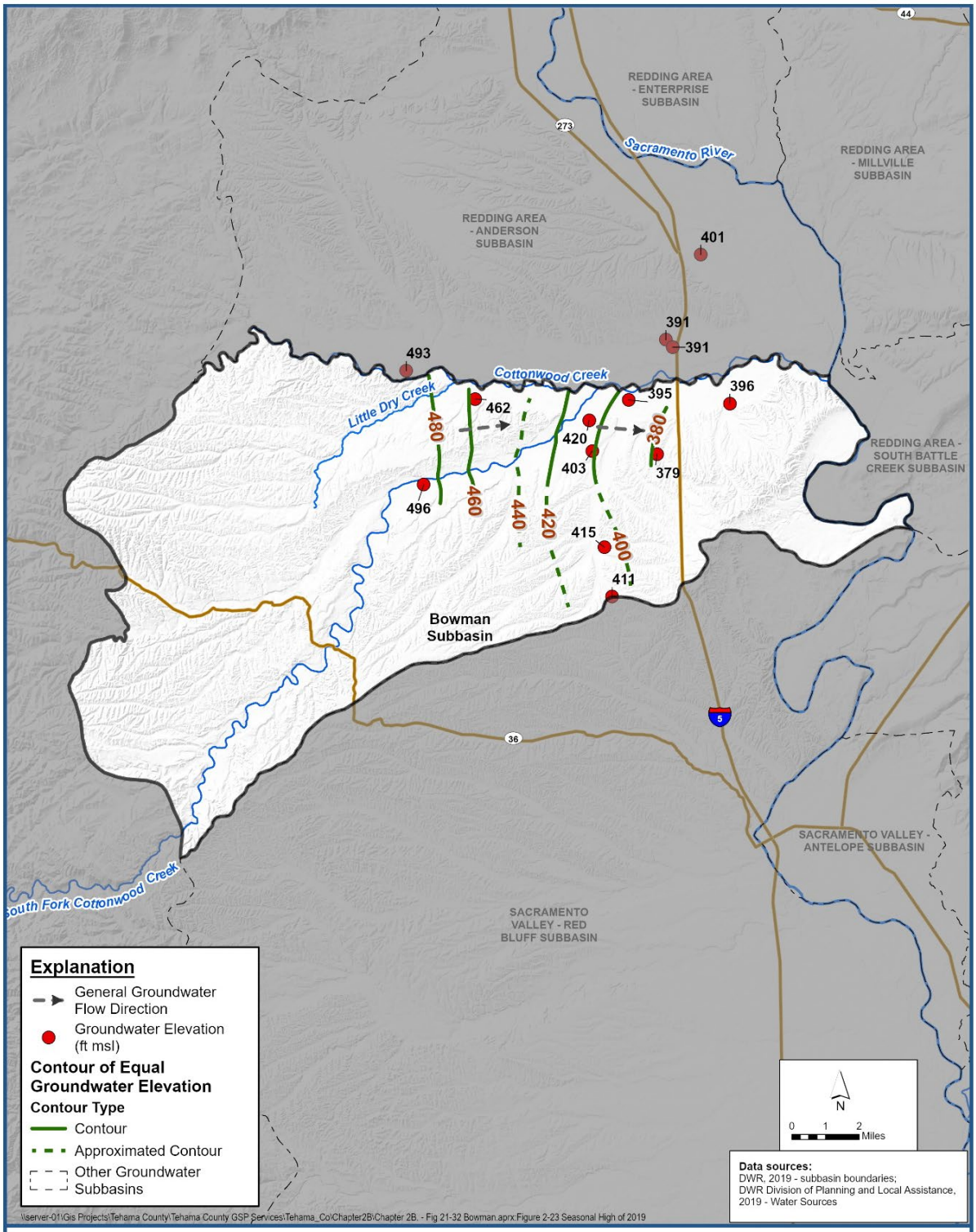
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Contours of Equal Groundwater Elevation
Upper Aquifer - Seasonal High of 2019

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-37



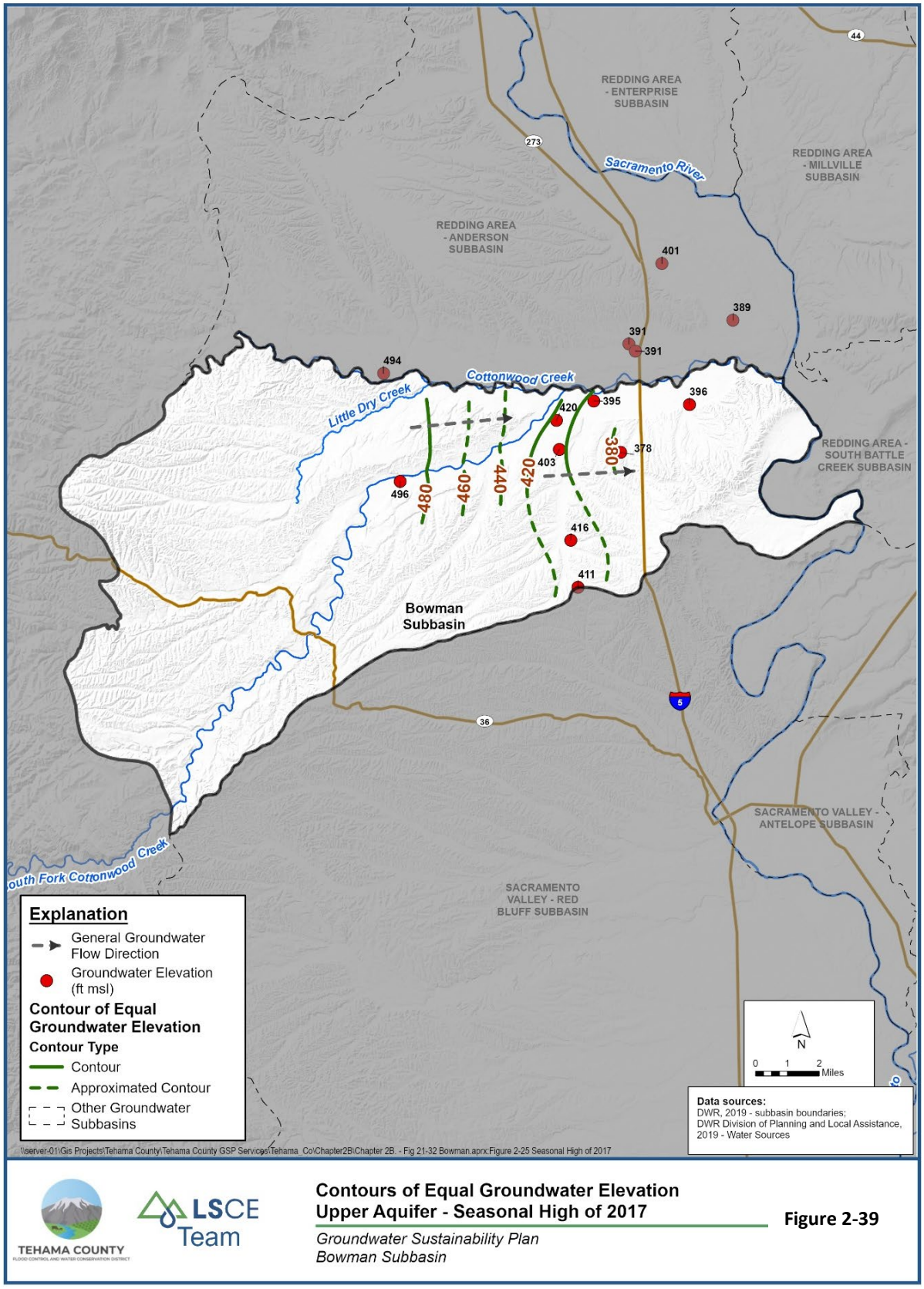
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Contours of Equal Groundwater Elevation
Upper Aquifer - Seasonal High of 2019

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-38



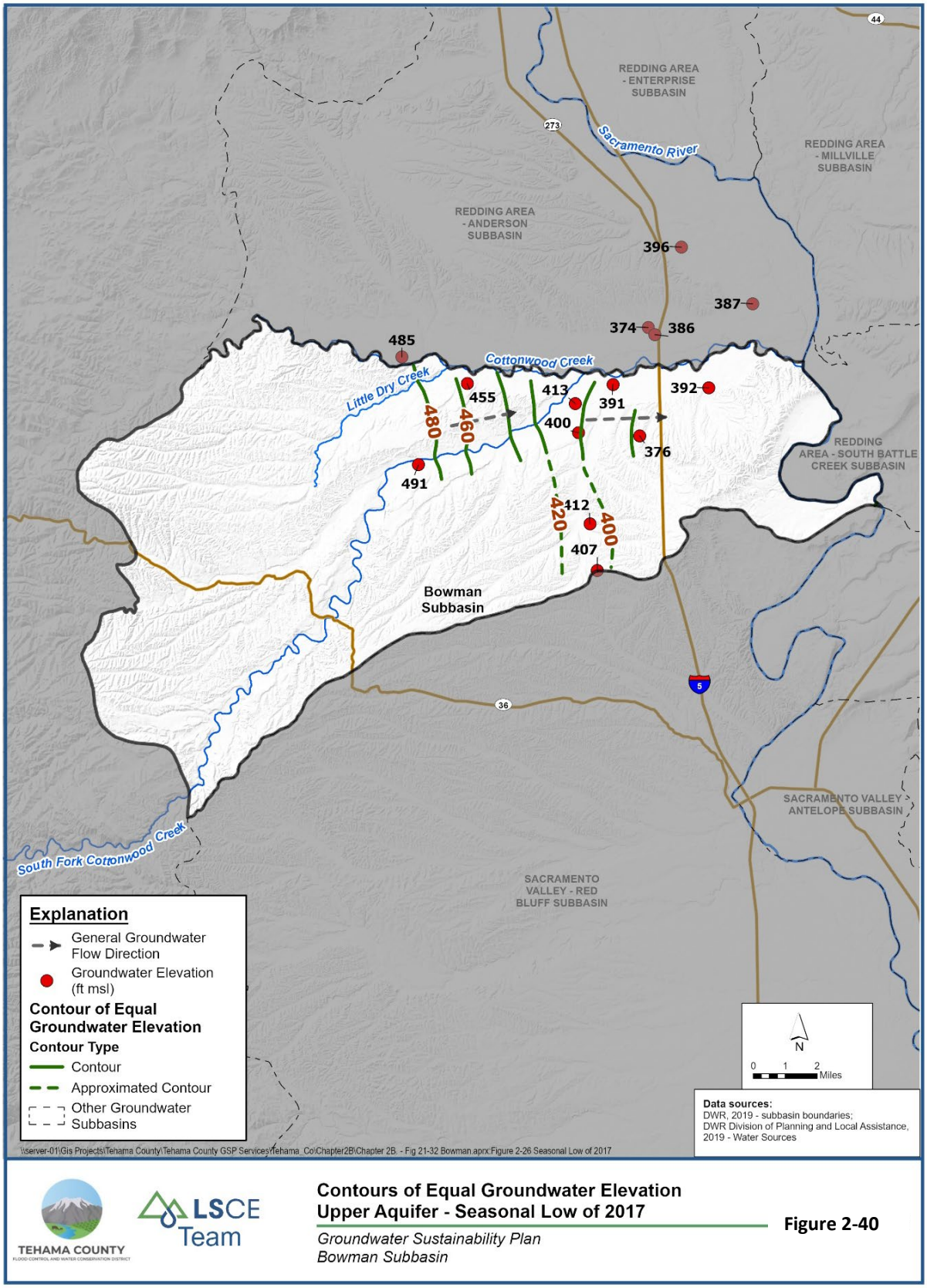
TEHAMA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT

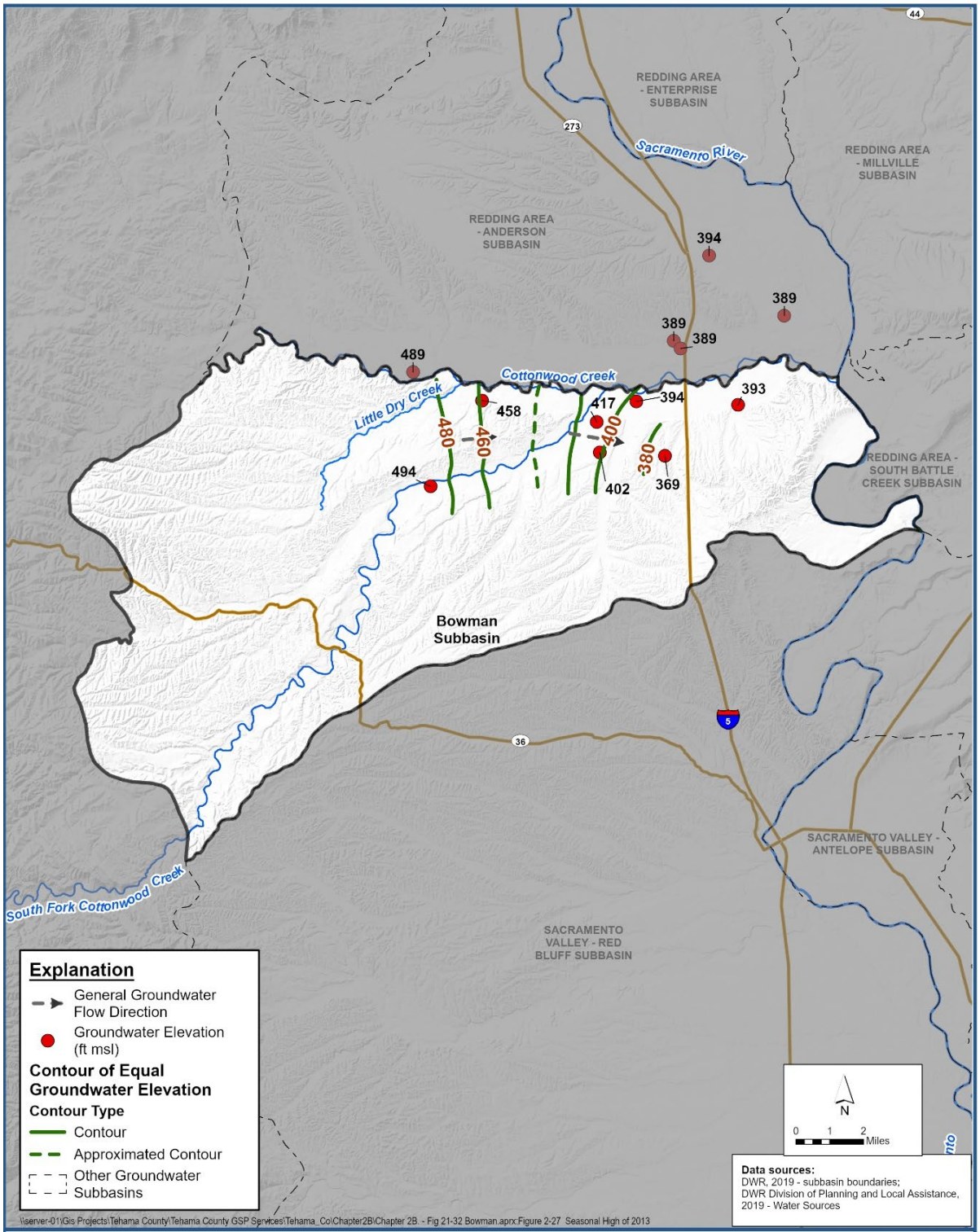
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Contours of Equal Groundwater Elevation
Upper Aquifer - Seasonal High of 2017

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-39


REDDING AREA - ENTERPRISE SUBBASIN
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Sacramento River
Cottonwood Creek
Little Dry Creek
South Fork Cottonwood Creek
Bowman Subbasin
396
387
374
386
485
455
413
391
392
400
376
491
412
407
480
460
420
400
44
273
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 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 21-32 Bowman.aprx:Figure 2-26 Seasonal Low of 2017
TEHAMA COUNTY
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Contours of Equal Groundwater Elevation
Upper Aquifer - Seasonal Low of 2017
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-40



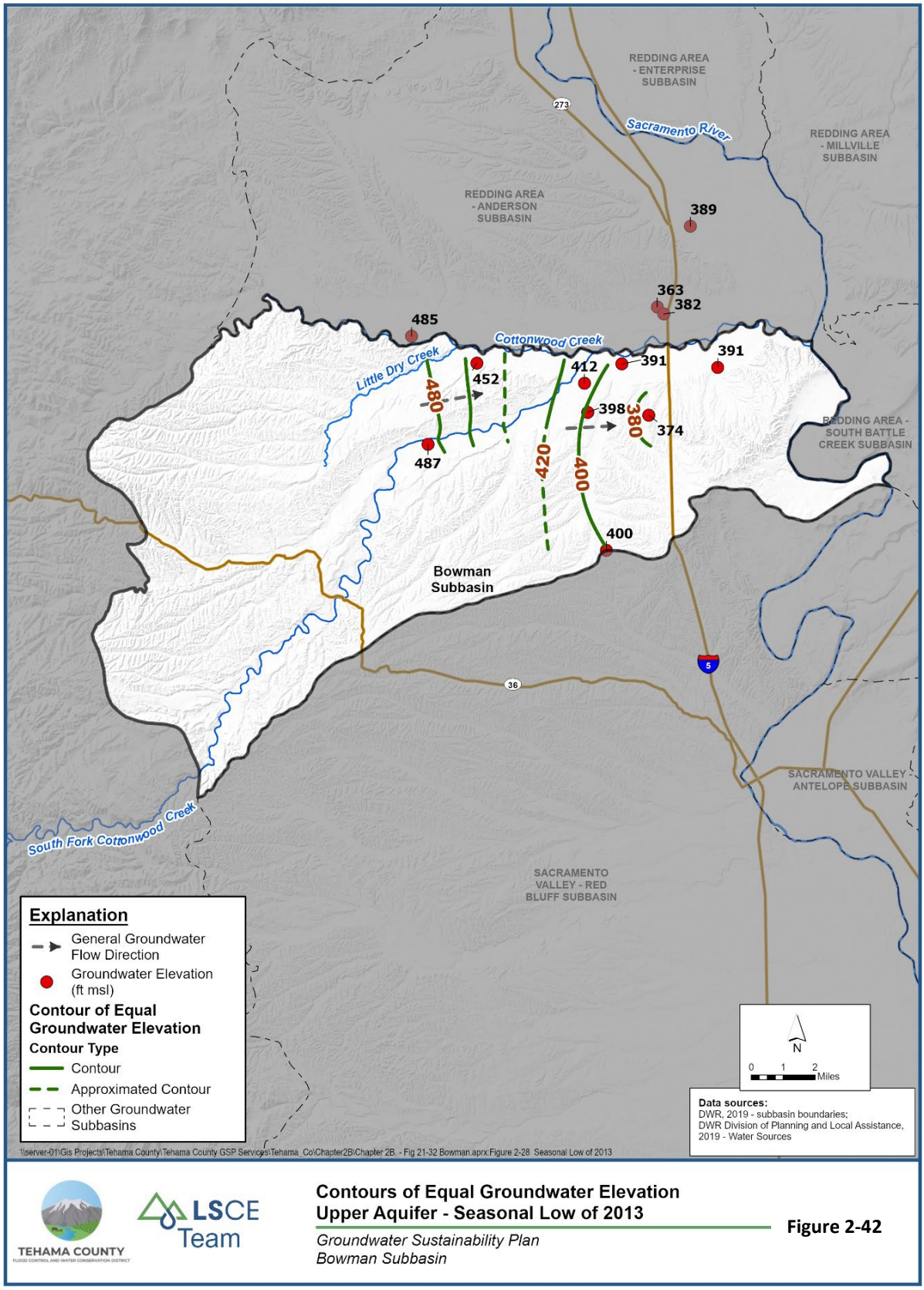
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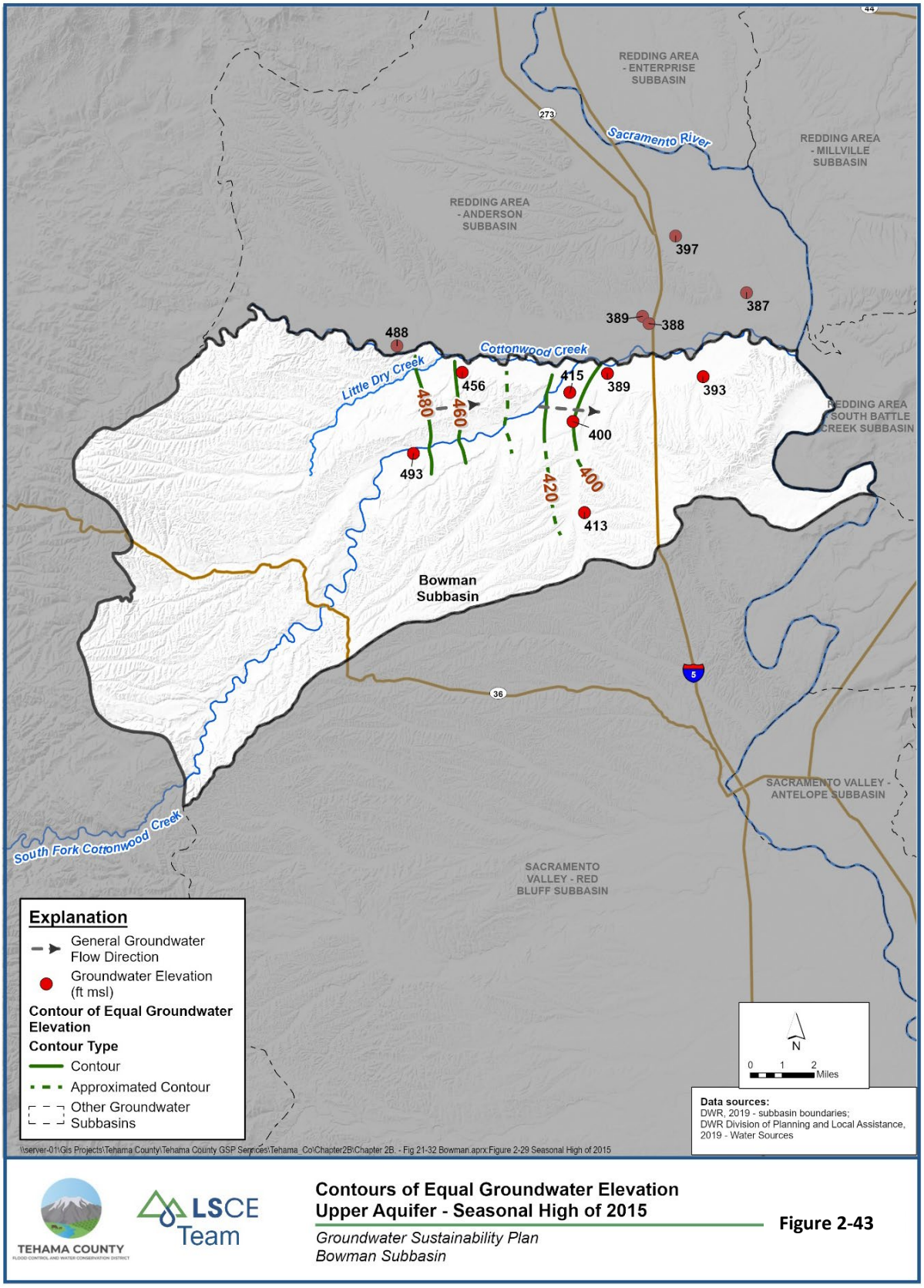
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Contours of Equal Groundwater Elevation
Upper Aquifer - Seasonal High of 2013

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-41


REDDING AREA - ENTERPRISE SUBBASIN
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Sacramento River
Cottonwood Creek
Little Dry Creek
South Fork Cottonwood Creek
Bowman Subbasin
273
36
5
389
363
382
485
452
391
412
391
398
374
487
400
480
420
400
380
Explanation
General Groundwater Flow Direction
Groundwater Elevation (ft msl)
Contour of Equal Groundwater Elevation
Contour Type
Contour
Approximated Contour
Other Groundwater Subbasins
N
0 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 21-32 Bowman.aprx:Figure 2-28 Seasonal Low of 2013
TEHAMA COUNTY
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Contours of Equal Groundwater Elevation
Upper Aquifer - Seasonal Low of 2013
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-42



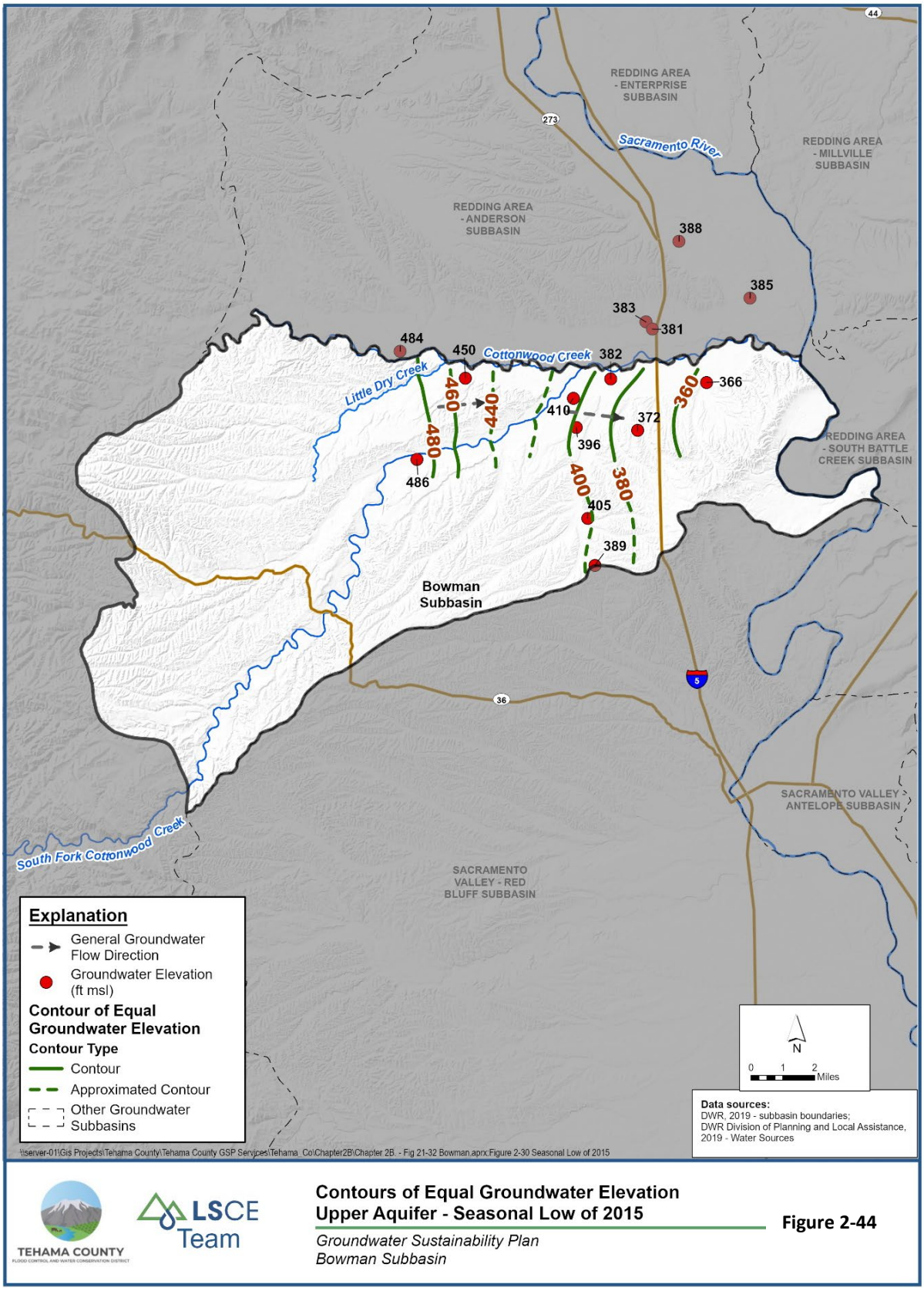
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Contours of Equal Groundwater Elevation
Upper Aquifer - Seasonal High of 2015

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-43



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

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-44

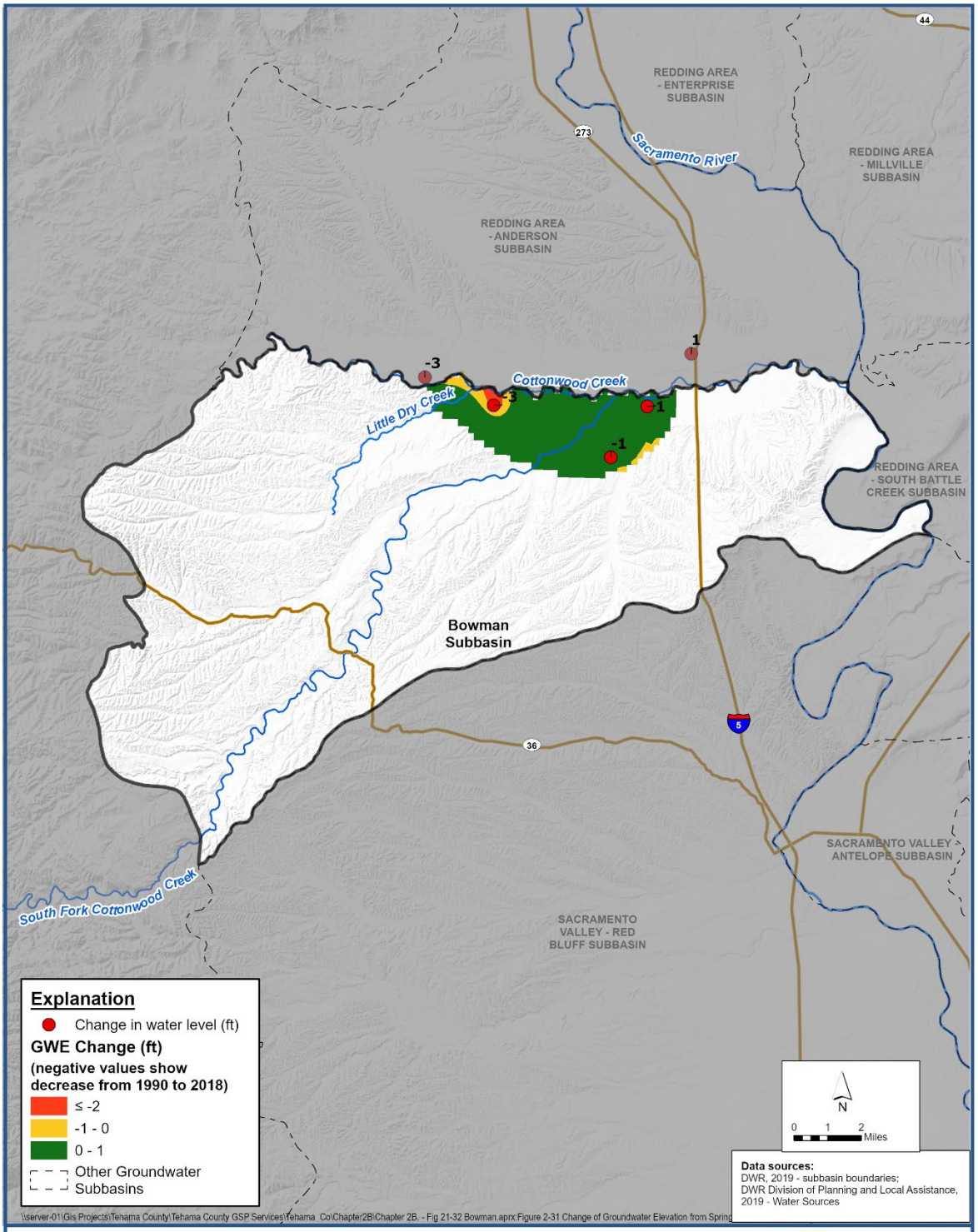
Upper Aquifer contour maps show that the water levels in the Subbasin are relatively unchanged between winter/spring and fall seasons, as well as between current conditions and different water year types. Groundwater elevations are lowest in the eastern side of the Subbasin, and gradually increase towards west. Historically, elevations remained between about 370 ft in the east (around Interstate-5) and 500 ft in the central area of the Subbasin with few feet of seasonal and annual fluctuations. Groundwater flow is generally towards the Sacramento River at the eastern Subbasin boundary, with a lateral hydraulic gradient that historically remained between 16 and 18 feet per mile. A northeasterly groundwater flow is expected in the southwestern portion of the Subbasin, because of the groundwater divide at the southern boundary of the Subbasin. Water level data from two separate sets of nested/clustered wells indicate consistently downward hydraulic gradients (0.01 to 0.06) within the Upper Aquifer and between the Upper Aquifer and Lower Aquifer. Direction of the vertical gradient in the Lower Aquifer changed from downward (up to 0.01) to upward (up to 0.02) at different times. Water level hydrographs of nested/clustered wells (shown in **Appendix 2-F**) indicate weak hydraulic separation between the Upper Aquifer and Lower Aquifer. Temporal fluctuations of water levels in both aquifers have similar patterns and comparable magnitudes.

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 during the hydrologic base period. Groundwater elevation surfaces of the Upper Aquifer for 1990 and 2018 were separately created by interpolating available water levels in each year. Then the difference between these two surfaces (**Figure 2-45**), 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 northern portion of the Subbasin shown in **Figure 2-45**. Between 1990 and 2018, groundwater elevations, thus the groundwater storage, in this area did not change considerably. The area where groundwater elevation change was estimated is approximately 8,900 acres, which is about 7% of the Subbasin area. However, this area includes about 40% of all irrigated lands in the Subbasin (2018 land use data). The specific year-to-year historical groundwater storage changes are also estimated using a surface water-groundwater flow model discussed in the Chapter 2B.

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, 2020; SWRCB, 2009 and Tehama County FCWCD, 2012) and evaluation of groundwater quality data collected from SWRCB GeoTracker and GeoTracker GAMA databases. SWRCB GeoTracker database identifies one currently open groundwater clean-up site (a leaking underground storage tank site with active monitoring) within the Subbasin (shown in **Figure 2-12** in Chapter 2.1). Occurrence of synthetic organic compounds and volatile organic compounds associated with industrial products and pesticides at concentrations higher than their Maximum Contaminant Levels have been reported in the Subbasin. These contaminants are listed in Chapter 2.1. Widespread presence of contaminants at undesirable levels has not been reported in groundwater samples in the Subbasin. The following discussion focuses on total dissolved solid (TDS), nitrate, and arsenic concentrations in the Subbasin.



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Change of Groundwater Elevation - Upper Aquifer from Spring 1990 to Spring 2018

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-45

Total Dissolved Solid (TDS)

The occurrence of Total Dissolved Solids (TDS) at undesirable concentrations is not a concern at present. A total of 442 groundwater samples were tested for TDS since 1957, and results of only one sample exceeded the Secondary Maximum Contaminant Level of 500 mg/L (a concentration of 3,300 mg/L in a 10 ft deep well in 1995). Only three other samples from three different wells had results over 400 mg/L (**Figure 2-46, Appendix 2-G**). TDS concentrations of all other samples (from 147 wells) indicate stable TDS levels between 100 and 400 mg/L in the Subbasin. Test results of all 19 samples collected from seven Lower Aquifer wells between 1991 and 2017 ranged from 100 to 200 mg/L.

Nitrate

Occurrence of nitrate (nitrate, expressed as nitrogen) concentrations that exceed the Maximum Contaminant Level (MCL) of 10 mg/L is not a concern at present (**Figure 2-47**). DWR (2020) identified one shallow well with a nitrate concentration of 27.3 mg/L. However, all other sample results (382 samples from 129 wells) tested since 1955 were below the MCL. One sample with a concentration of 10 mg/L was reported in 1979 (the maximum concentration in the Subbasin). Test results of seven samples from different wells had concentrations between 5.0 mg/L and 7.0 mg/L, while all other 374 samples had concentrations less than 4.0 mg/L. Test results of all 75 of the Lower Aquifer samples were less than 3.1 mg/L.

Arsenic

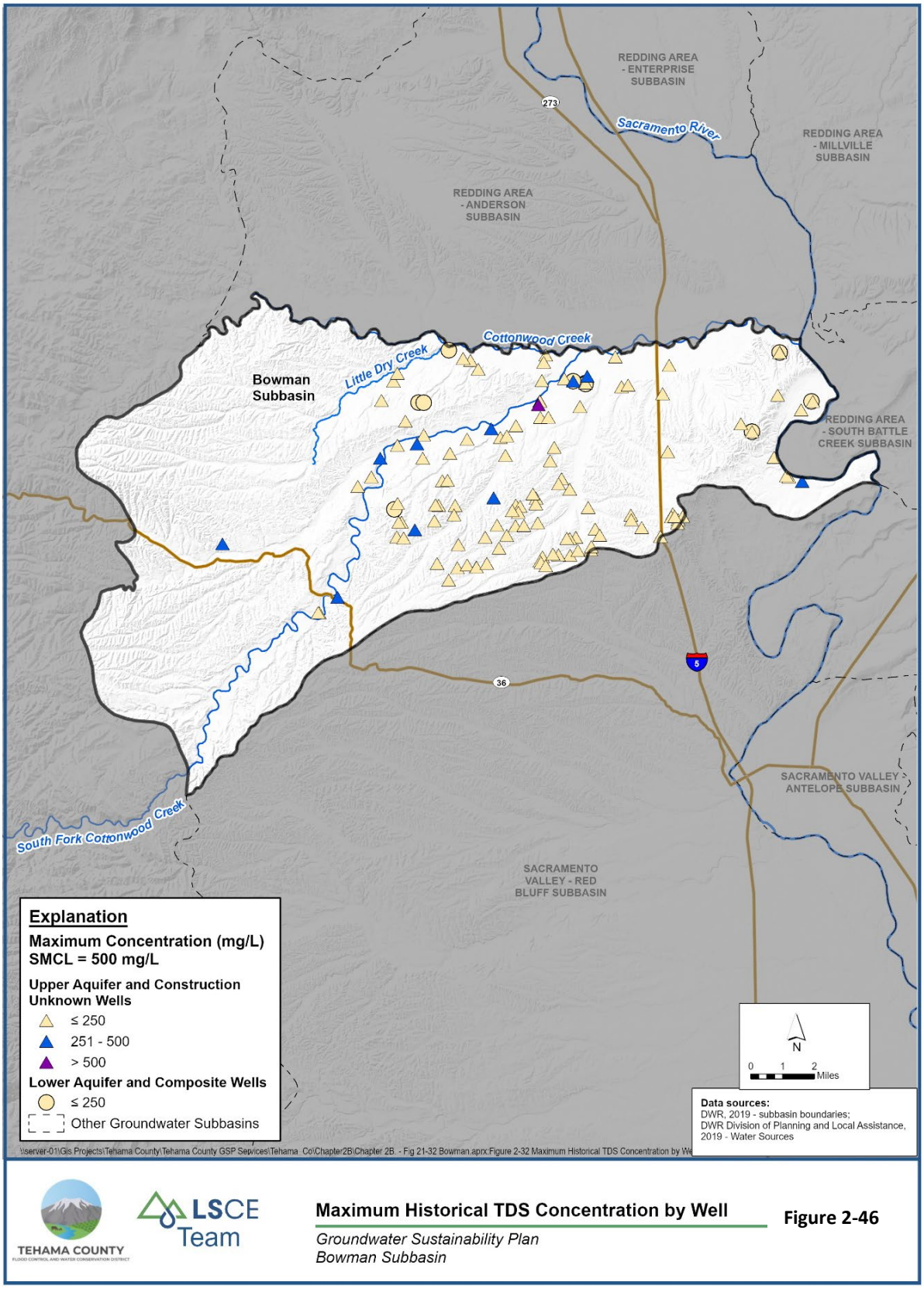
The occurrence of arsenic at concentrations exceeding the MCL of 10 micrograms per liter (µg/L) is not a widespread groundwater quality concern in the Subbasin. Since 1956, 240 samples collected from 86 wells were tested and only four samples from four wells exceeded the MCL (**Figure 2-48)**. The highest historical arsenic concentration in the Subbasin, 20 µg/L, was reported in 1976. All other samples had test results below 6.0 µg/L, and results of all 31 samples collected from seven Lower Aquifer wells had results below 2.5 µg/L. Arsenic is a naturally occurring chemical that originates from volcanic rocks of the Tuscan formation (Tehama County FCWCD, 2012).

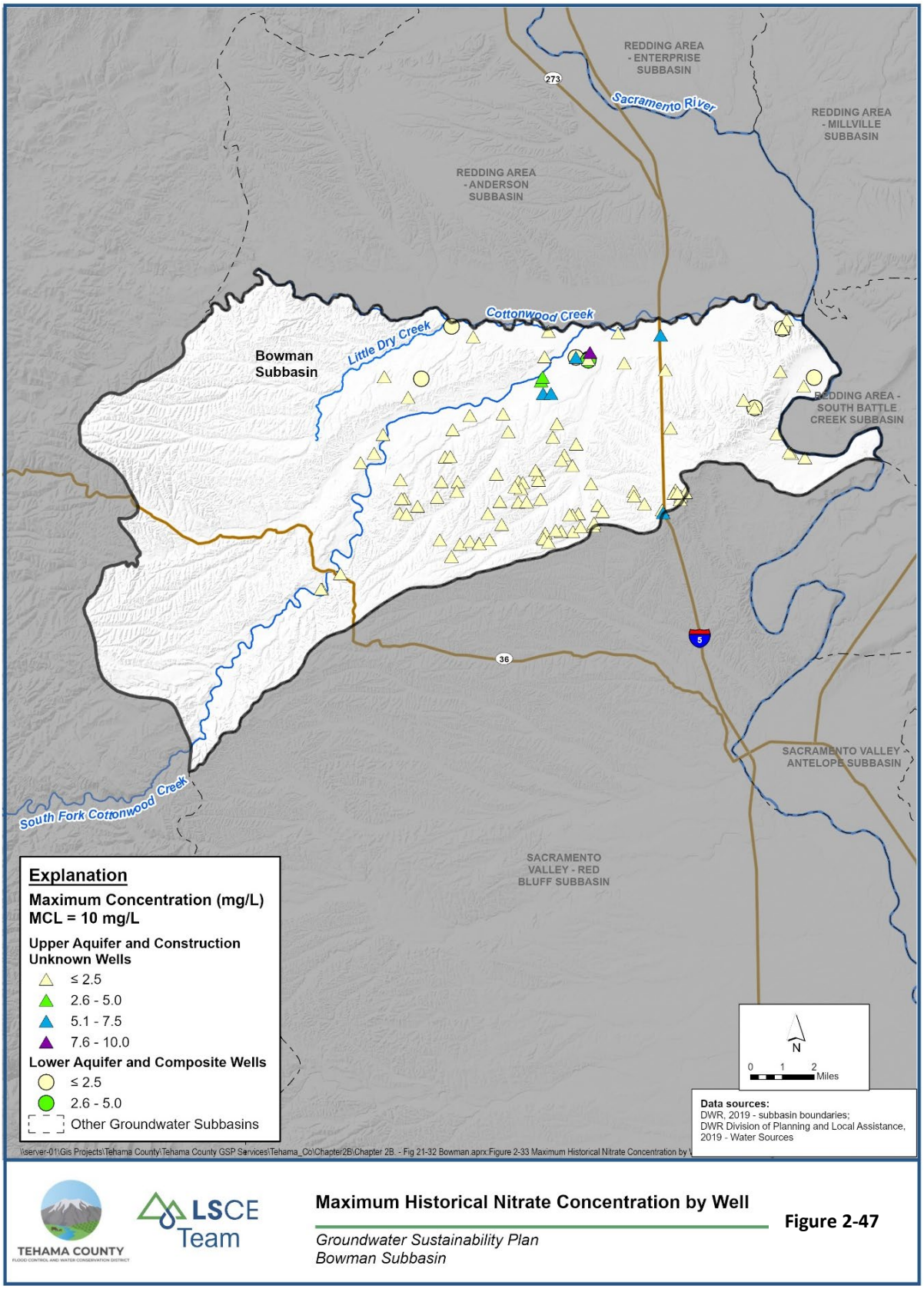
2.2.2.4 Seawater Intrusion

Seawater intrusion is not an applicable sustainability indicator for the Bowman 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

Bowman 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 2-49**). Subsidence monitoring in the Subbasin is available from two surveys conducted by DWR. 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.


REDDING AREA - ENTERPRISE SUBBASIN
273
Sacramento River
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
Cottonwood Creek
Little Dry Creek
Bowman Subbasin
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
5
36
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
South Fork Cottonwood Creek
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Explanation
Maximum Concentration (mg/L)
SMCL = 500 mg/L
Upper Aquifer and Construction Unknown Wells
≤ 250
251 - 500
> 500
Lower Aquifer and Composite Wells
≤ 250
Other Groundwater Subbasins
N
0 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 21-32 Bowman.aprx:Figure 2-32 Maximum Historical TDS Concentration by We
TEHAMA COUNTY
LSCE Team
Maximum Historical TDS Concentration by Well
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-46



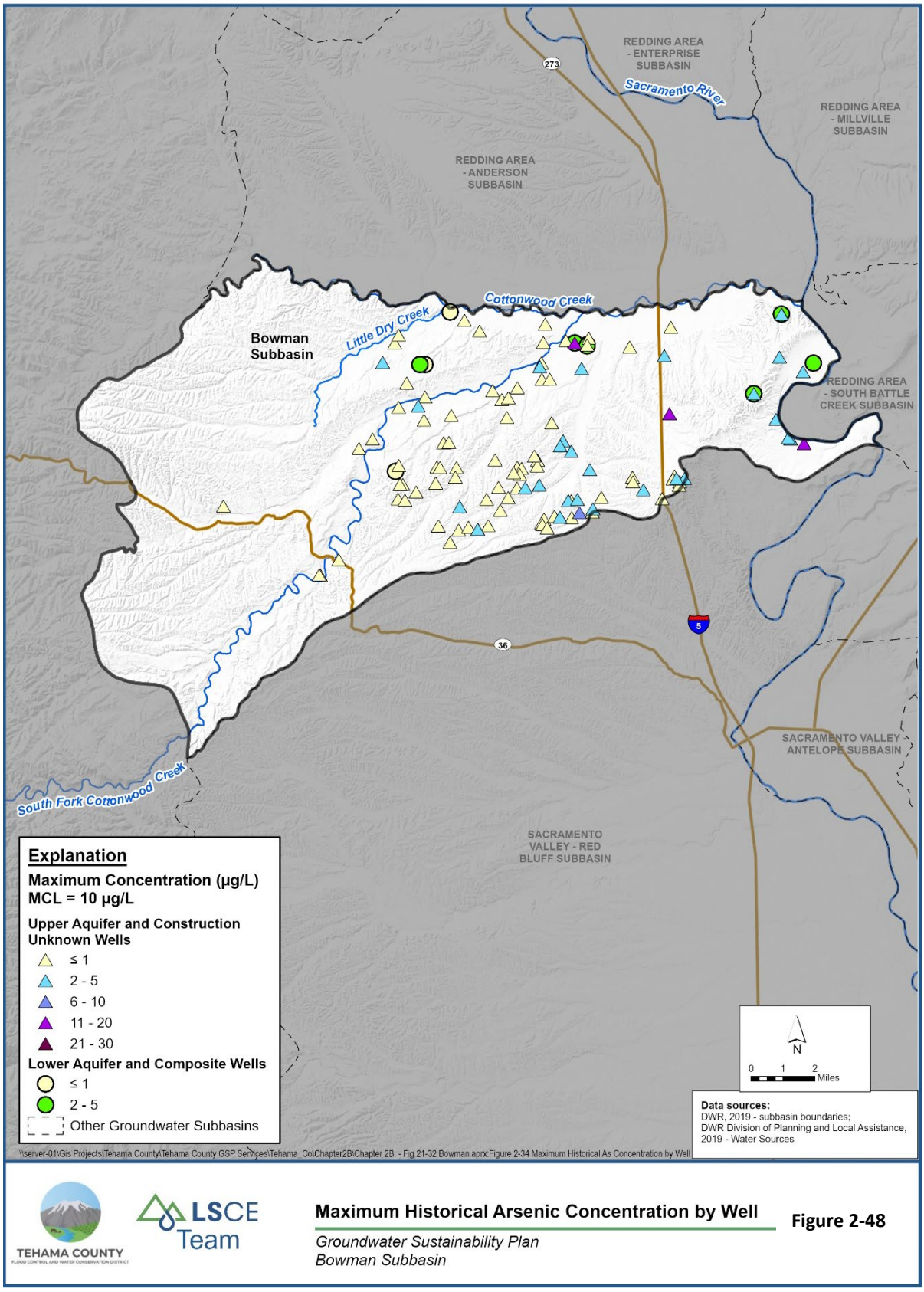
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Maximum Historical Nitrate Concentration by Well

Figure 2-47

Groundwater Sustainability Plan
Bowman Subbasin

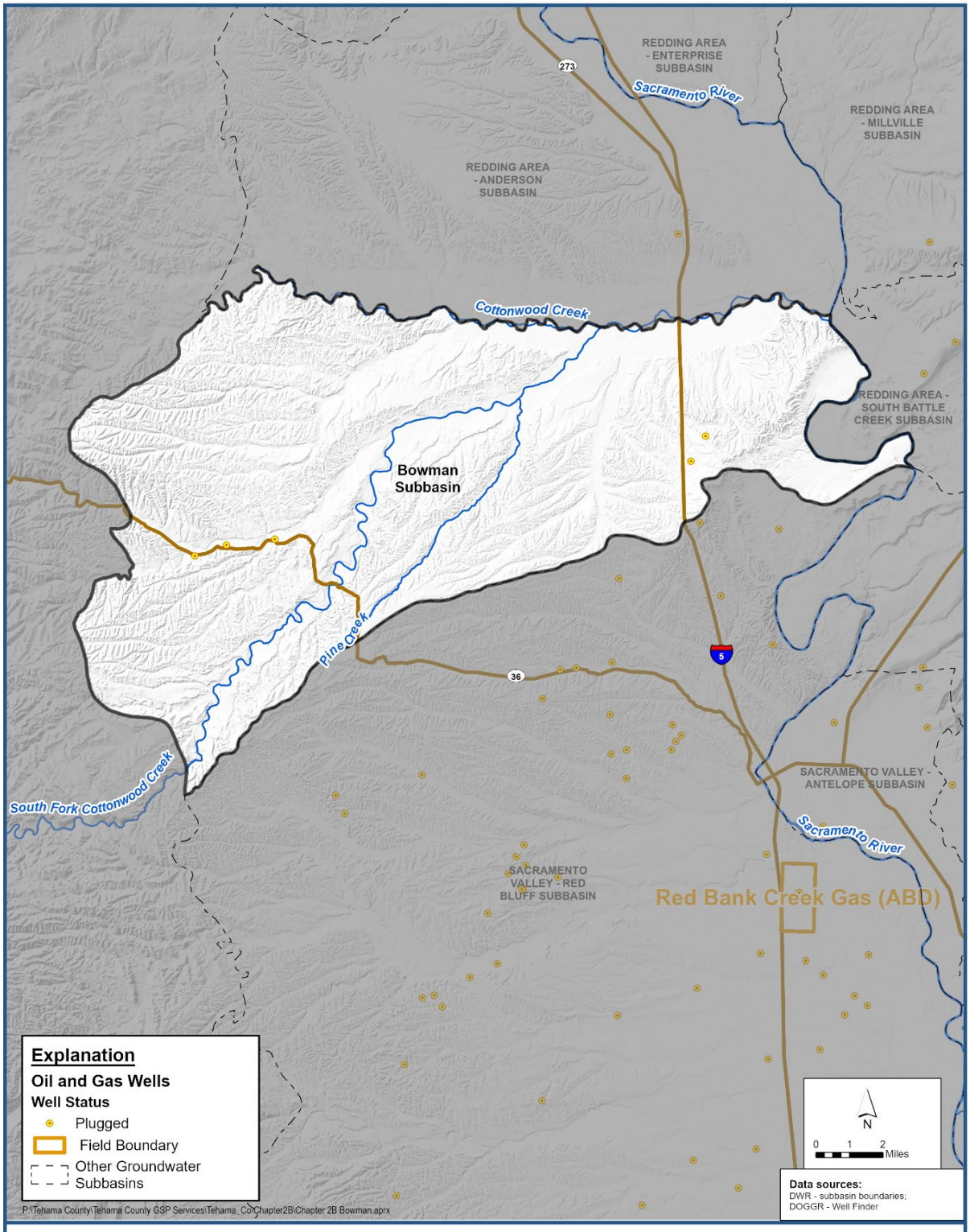


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Maximum Historical Arsenic Concentration by Well **Figure 2-48**

Groundwater Sustainability Plan
Bowman Subbasin


REDDING AREA - ENTERPRISE SUBBASIN
Sacramento River
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
Cottonwood Creek
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
Bowman Subbasin
Pine Creek
South Fork Cottonwood Creek
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
Sacramento River
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Red Bank Creek Gas (ABD)
Explanation
Oil and Gas Wells
Well Status
Plugged
Field Boundary
Other Groundwater Subbasins
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B Bowman.aprx
N
0 1 2 Miles
Data sources:
DWR - subbasin boundaries;
DOGGR - Well Finder
TEHAMA COUNTY
LSCE Team
Map of Oil and Gas Fields and Wells
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-49

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; 3 survey monuments are within the Subbasin boundaries (**Figure 2-50**). 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. In the Subbasin, measured ground surface elevation ranged from -0.129 ft at the station near I-5 and Cottonwood Creek to -0.073 ft at the southernmost station (**Figure 2-50**). On average, subsidence in the Subbasin was approximately -0.011 feet per year over the duration of the study.

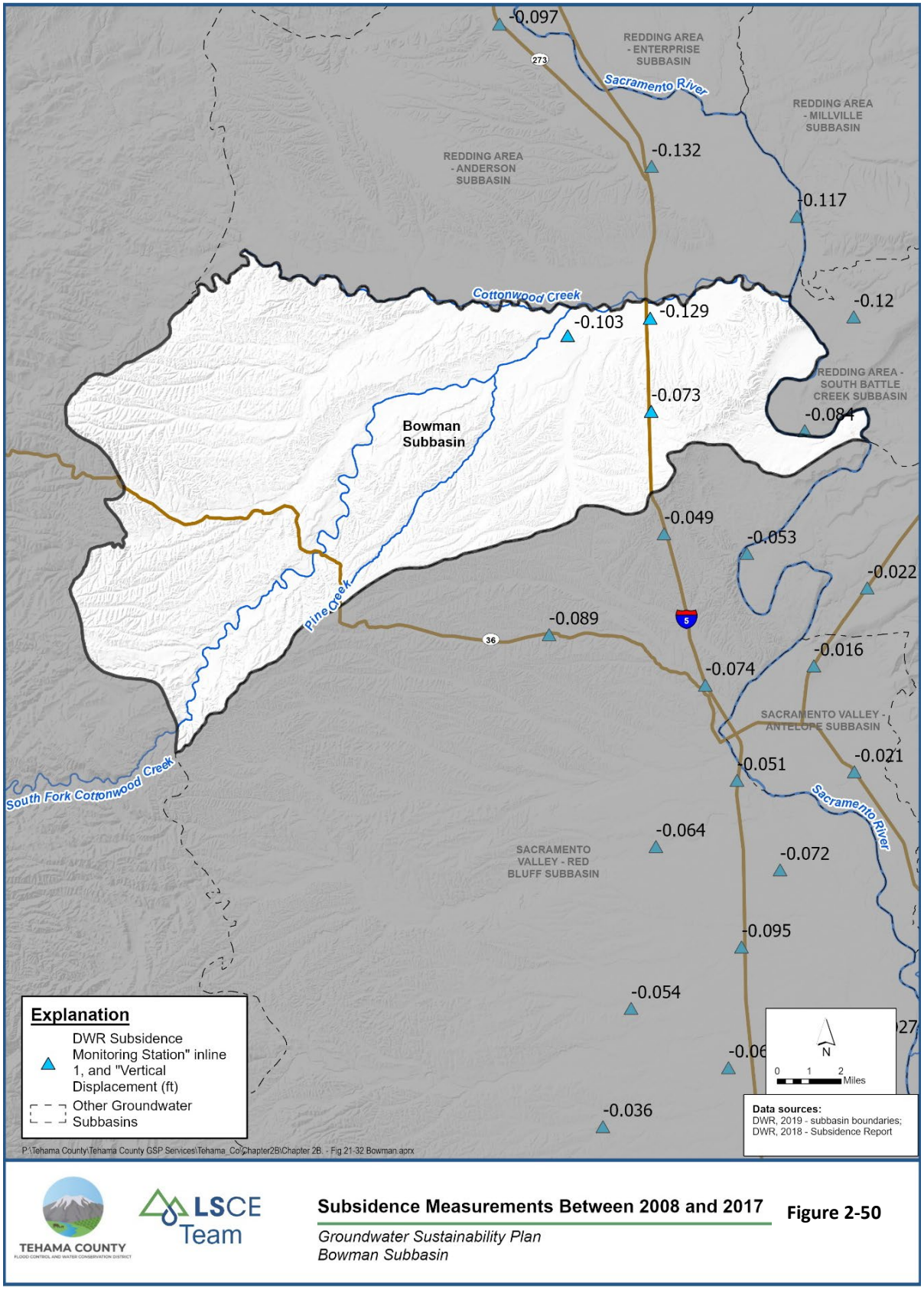
In 2015 DWR began reporting Interferometric Synthetic Aperture Radar (InSAR) surveys to assist with subsidence studies related to SGMA. Vertical measurements are collected by the European Space Agency Sentinal-1A satellite and compared to previous measurements to establish a change in surface elevation. 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 2-51**). Vertical displacement measured using the InSAR approach from July 2015 to June 2019 was between -0.09 ft to 0.05 ft in the Subbasin over the entire period of study (**Figure 2-51**). Average annual subsidence rate within the Subbasin based on InSAR data is -0.02 ft/year to 0.01 ft/year.

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, Cottonwood Creek, the South Fork of Cottonwood Creek, Pine Creek, Hooker Creek, and Little Dry Creek are the main surface water features. The Sacramento River and Cottonwood Creek flow throughout the year (perennial), but the remaining creeks flow seasonally. Only Cottonwood Creek has active stream gages within the Subbasin (**Figure 2-32**). The Sacramento River has a currently active gaging station approximately 2.5 miles to the south of the Subbasin boundary (**Figure 2-32**).

The Sacramento River has one currently active gaging station close to the Subbasin; USGS/USBR station #11377100 at Bend Bridge (BND). USGS/USBR station BND is located about 2.5 miles downstream of the southern boundary of the Subbasin (**Figure 2-32**) with a daily record since 1963. Based on historical data from BND, the mean annual flow rate is about 12,500 cubic feet per second (CFS) with highest flows from January through March (historical mean over 16,800 CFS), and lowest flows in October (historical mean about 7,000 CFS) (USGS NWIS stream flow data).

Flow of Cottonwood Creek has been measured since 1941 at USGS station #11376000 at Cottonwood Creek near Cottonwood about two miles upstream of the Sacramento. The mean annual flow rate is about 858 CFS with highest flows in January and February (mean of over 2,000 CFS), and lowest in August and September (mean of less than 75 CFS). In addition, there are five inactive USGS stream gages on Cottonwood Creek and the South Fork of Cottonwood Creek. The most recent records available from these stations are from 1986.

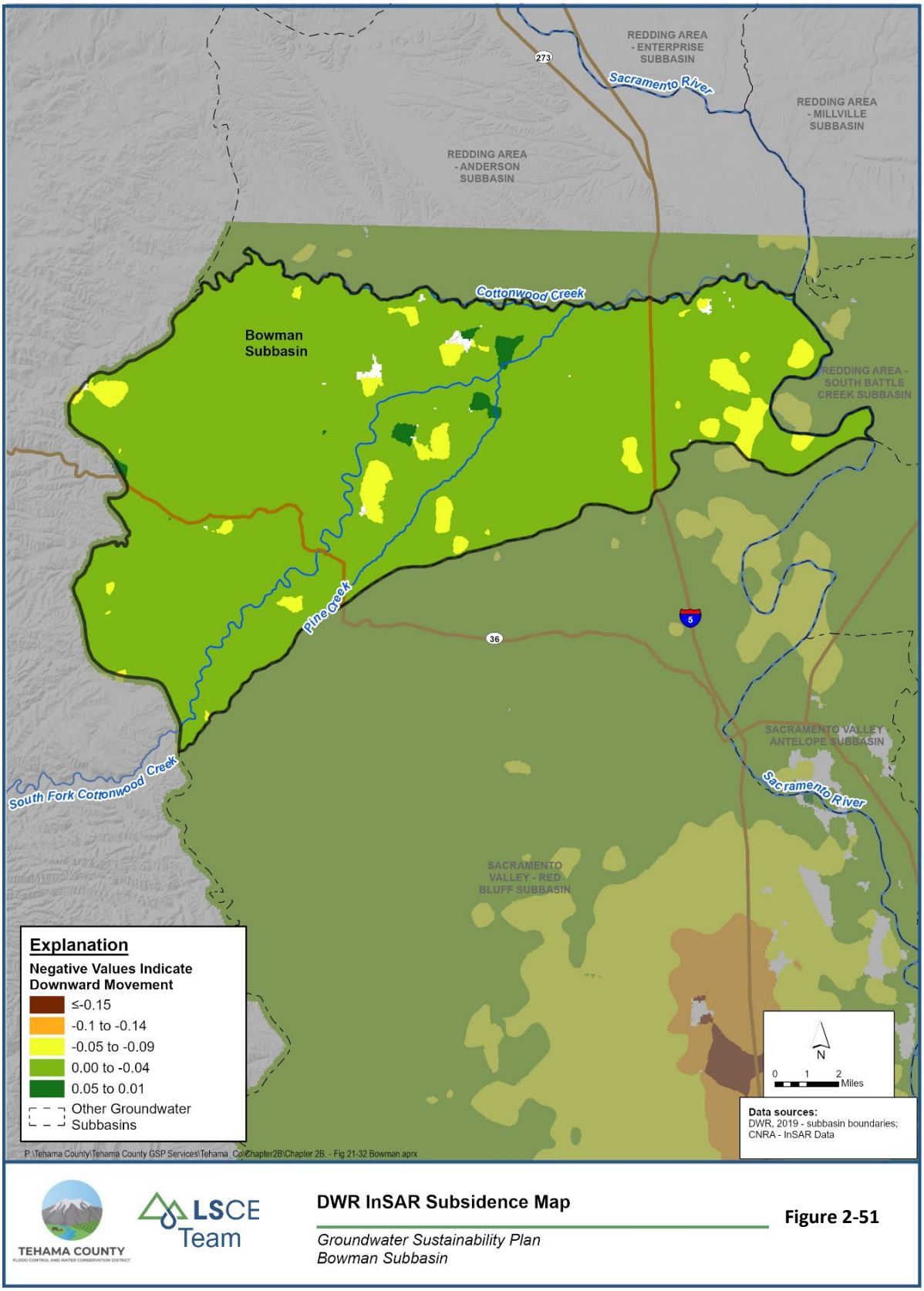


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Subsidence Measurements Between 2008 and 2017 **Figure 2-50**

Groundwater Sustainability Plan
Bowman Subbasin


REDDING AREA - ENTERPRISE SUBBASIN
Sacramento River
REDDING AREA - MILLVILLE SUBBASIN
REDDING AREA - ANDERSON SUBBASIN
Cottonwood Creek
Bowman Subbasin
REDDING AREA - SOUTH BATTLE CREEK SUBBASIN
Pine Creek
SACRAMENTO VALLEY - ANTELOPE SUBBASIN
South Fork Cottonwood Creek
Sacramento River
SACRAMENTO VALLEY - RED BLUFF SUBBASIN
Explanation
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 1 2 Miles
Data sources:
DWR, 2019 - subbasin boundaries;
CNRA - InSAR Data
P:\Tehama County\Tehama County GSP Services\Tehama_Co\Chapter2B\Chapter 2B. - Fig 21-32 Bowman.aprx
TEHAMA COUNTY
LSCE Team
DWR InSAR Subsidence Map
Groundwater Sustainability Plan
Bowman Subbasin
Figure 2-51

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 Chapter 2B. 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. To establish if streams are connected, stream data like flow magnitude or stage height coupled with shallow groundwater elevation or flow direction is needed.

The Subbasin does not contain active stream gages near shallow monitoring wells needed to accurately define interconnectivity of surface water and groundwater (**Figure 2-52)**. As discussed in section 2.2.2.6, USGS station #11376000 is the only currently active source of stream stage data within the Subbasin. There are three currently monitored shallow CASGEM wells in the Subbasin. The closest CASGEM well to an active station is four miles away from USGS station #11376000. Installation of shallow monitor wells near the currently active gage station would help to characterize the interconnectivity of the Sacramento River and the groundwater in the Subbasin. There are several inactive stream gages near shallow monitoring wells, however records are not overlapping **Table 2-10**.

Figure 2-52 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.**

Table 2-10 List of Currently Inactive Stream Gages Close to Shallow Monitoring Wells

Stream Gage			Groundwater Monitoring Well		
Station Number	Start Year	End Year	State Well Number	Start Year	End Year
11375870	1976	1986	29N05W33A005M	2000	2020
11375815	1981	1985	29N04W20A004M	2007	2020
11375900	1981	1985	29N04W20A004M	2007	2020

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 Bowman 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 2-52**). The process used to identify potential GDEs in the Subbasin was accomplished by:

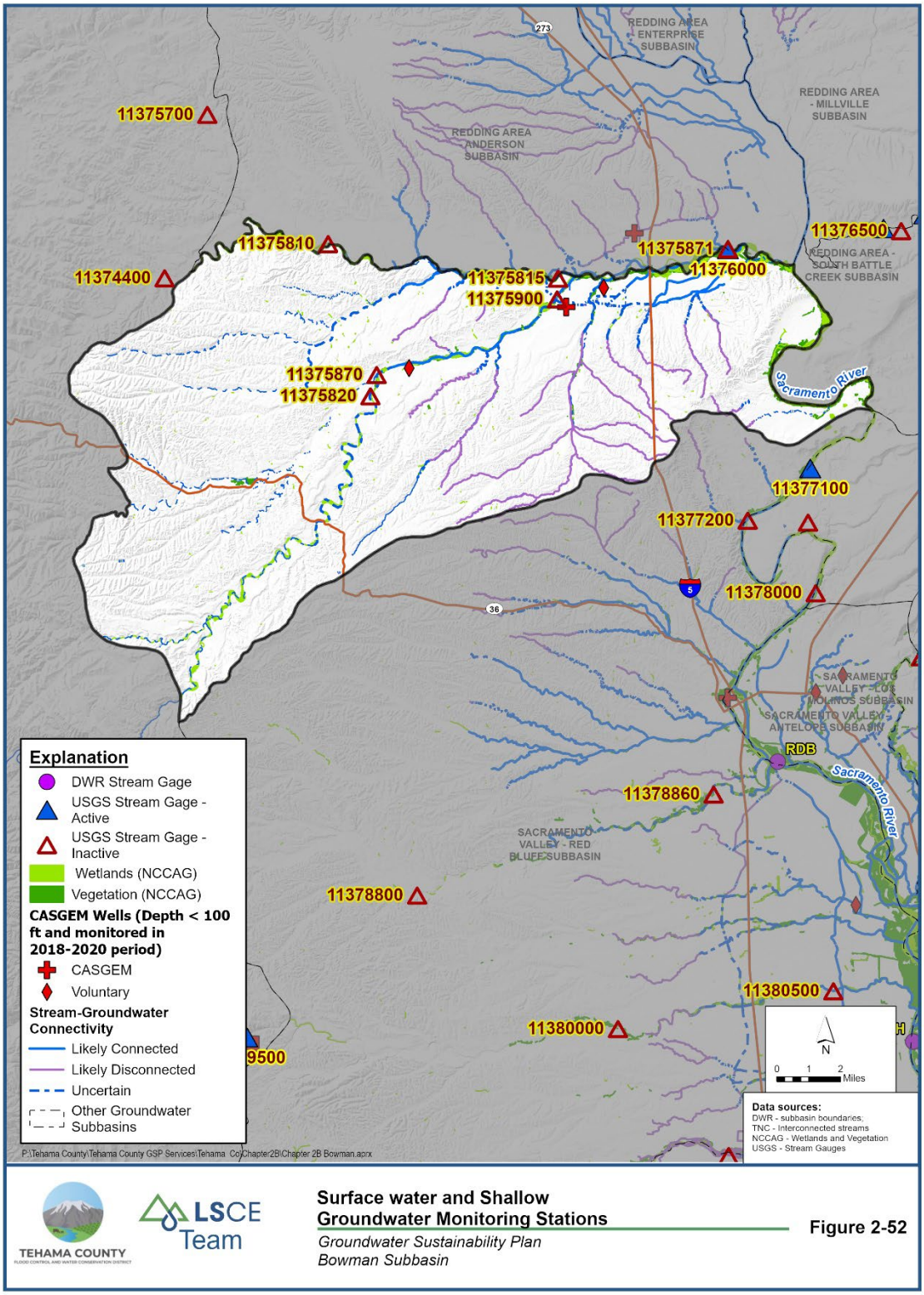
- a comparison of iGDEs with recent land cover data to update the map of iGDEs. This step is required because some iGDEs given in the NCCAG dataset are sourced from datasets mapped many years before 2015, which is the baseline year of SGMA. IGDEs found to exist within developed or irrigated lands were 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-I**Surface Water Depletion and GDE Methodology and Analysis. The steps above reduce the original NCCAG dataset of iGDEs from an area of 894 acres to 882 acres of GDEs, a reduction of 1.5%.

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 30 acres within the Subbasin

(**Figure 2-53**). 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.

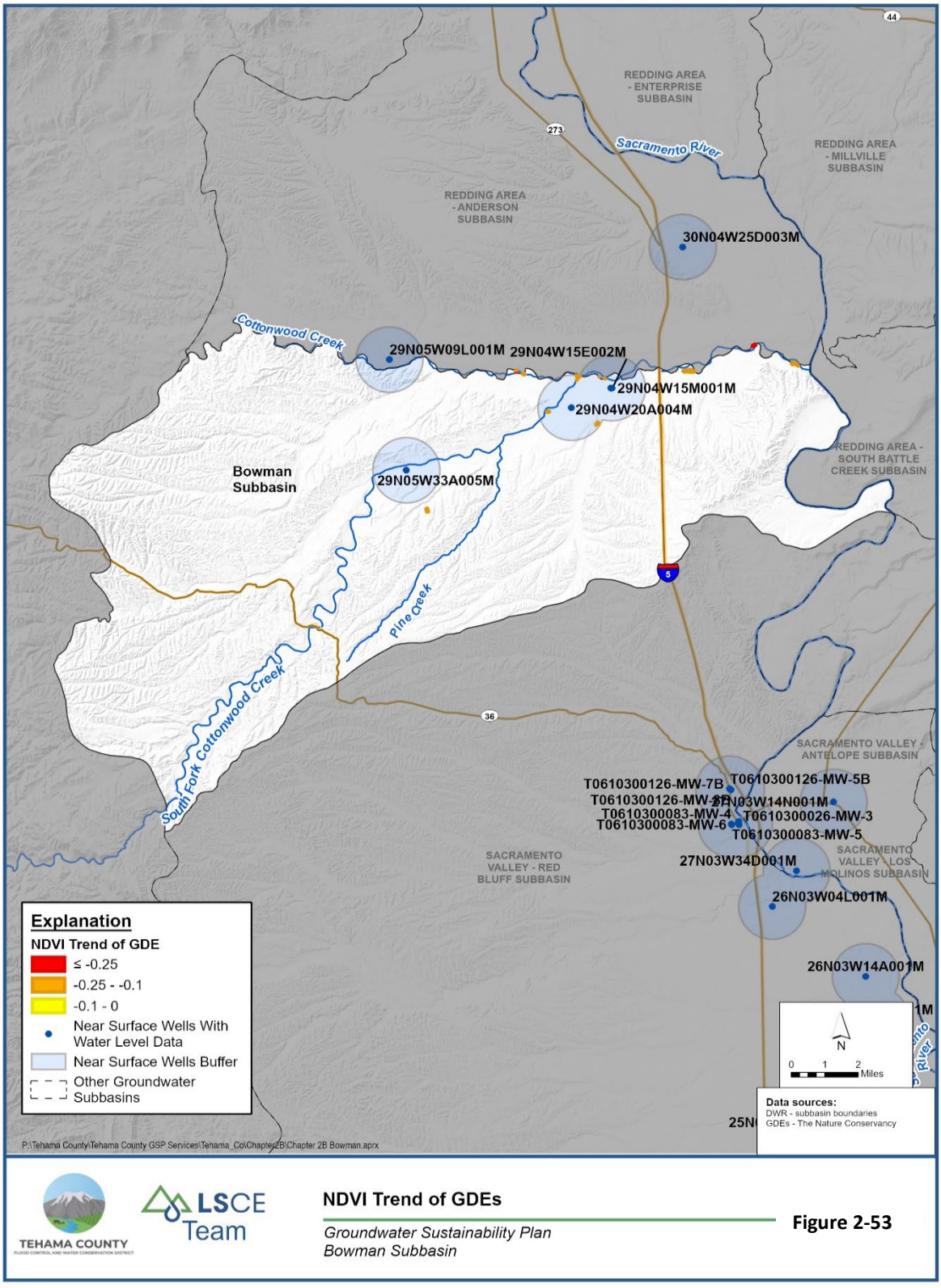
High priority GDEs were further evaluated to determine if temporal changes of vegetation metrics and local groundwater levels were correlated. Identifying such correlations would be useful to establish groundwater levels that can sustain GDEs. Only wells that were perforated within the top 100 feet below 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 four wells that met above criteria (**Figure 2-53**) were analyzed, but three of these wells did not have sufficient water level data to identify correlations. Water levels of the other well (29N04W15E002M in **Figure 2-53**) and vegetation metrics of an adjacent GDE had a very poor (insignificant) correlation (**Figure 2-54**). 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.



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Surface water and Shallow Groundwater Monitoring Stations — **Figure 2-52**

Groundwater Sustainability Plan
Bowman Subbasin



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NDVI Trend of GDEs

Groundwater Sustainability Plan
Bowman Subbasin

Figure 2-53

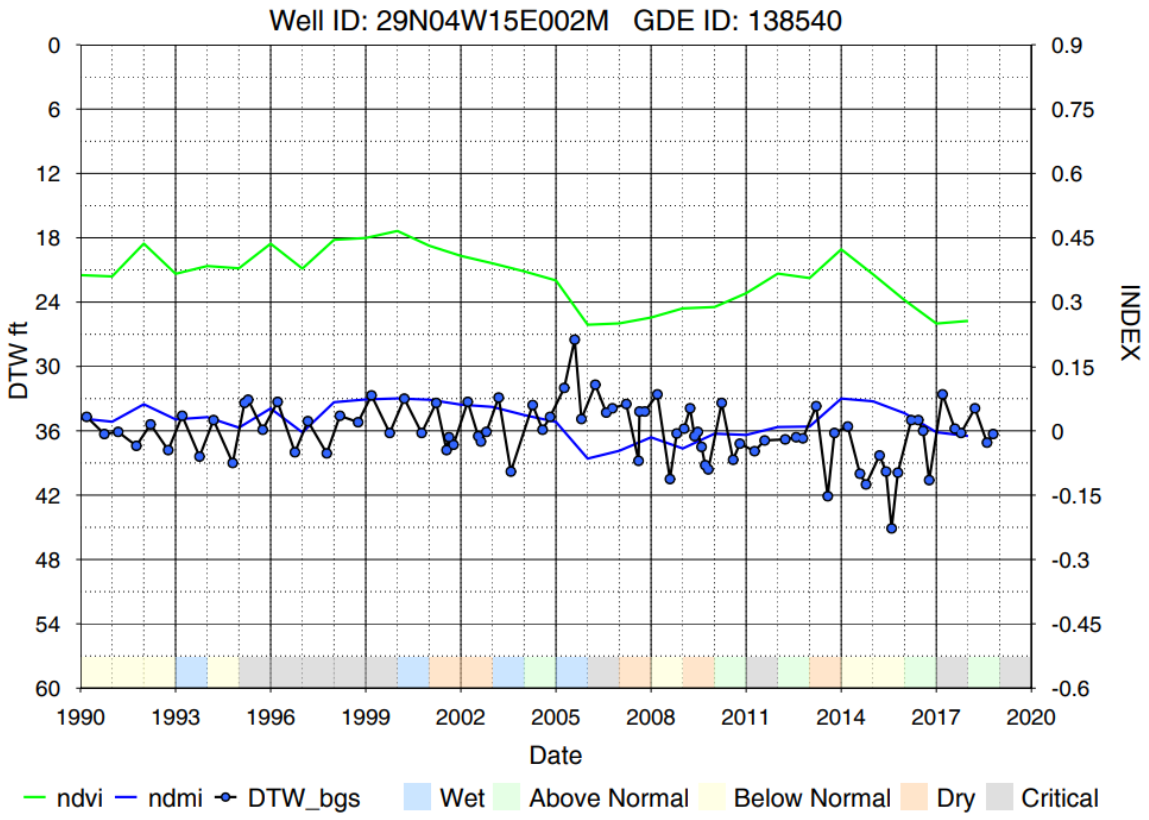


Figure 2-54. Timeseries graph of NDVI and NDMI of a GDE and depth to water at an adjacent well

2.2.3 Basin Setting Summary

In the Bowman Subbasin, groundwater generally flows eastward towards the Sacramento River with downward vertical movement in the Upper Aquifer driven by natural recharge. Water typically follows topography flowing from high elevation areas in the south and west toward low elevations near Cottonwood Creek and the Sacramento River in the north and east. Recharge contributions to the deeper geologic formations occurs where the formations outcrop at the surface. Aquifer recharge also generally occurs along Cottonwood Creek, the South Fork of Cottonwood Creek, and the Sacramento River, as well as 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.

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 Bowman Subbasin is bounded to the north by Cottonwood Creek, to the east by the Sacramento River, to the south by the Red Bluff Arch, and to the west by the Coast Ranges Geologic Province.
- Fresh water occurs as groundwater to a maximum depth of over -1,200 ft msl in the west 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 west to east with steeper slopes in the east of the Subbasin.
- Widespread presence of contaminants at undesirable levels have not been reported in groundwater samples in the Subbasin.
- The Bowman Subbasin has little to no reported evidence of subsidence, with recent rates of -0.02 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 Chapter 2B.
- Recharge of the Subbasin primarily occurs from the flow of Cottonwood Creek, the South Fork of Cottonwood Creek, the Sacramento River and the other streams and tributaries in the Subbasin.
- Subsurface geologic formations can be recharged directly where they outcrop in the Subbasin.
- Groundwater contour maps of the Upper Aquifer indicate an easterly general flow from the elevated areas of the valley towards Cottonwood Creek and the Sacramento River in the valley floor.
- Horizontal groundwater gradient magnitude ranges from about 16 ft/mile to 18 ft/mile in the eastern half of the Subbasin, and data are not available to estimate the gradient in the western half.
- Seasonal high-water levels in the Upper Aquifer during wet periods range between about 20 and 190 ft bgs, with shallower depths (about 20 – 30 bgs) close to the northeastern boundary of the Subbasin.
- Depth to water in the Lower Aquifer ranges from about 40 ft bgs to 140 ft in the northeastern portion of the Subbasin, and historical data are not available from other areas.
- Seasonal water fluctuations, as well as fluctuations between dry and wet climatic periods, are generally less than five feet and 10 feet in the Upper Aquifer and Lower Aquifer, respectively.
- Vertical hydraulic gradient within the Upper Aquifer, as well as between the Upper Aquifer and Lower Aquifer consistently remains downward (0.01 to 0.06).
- Direction of the vertical gradient in the Lower Aquifer can change from downward (up to 0.01) to upward (up to 0.02) at different times.
- Wells with long-term water level data show stable groundwater levels in the Subbasin.
- At present, groundwater quality in the Subbasin is good with no widespread presence of contaminants at undesirable levels.

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