# FINAL REPORT

*Red Bluff Subbasin*

Sustainable Groundwater Management Act

# Groundwater Sustainability Plan

## (Chapter 2B – Basin Setting)

**January 2022 Revised April 2024**

**Prepared For:**

Tehama County Flood Control and Water Conservation District

**Prepared By:**

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## LIST OF ACRONYMS & ABBREVIATIONS

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

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

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

# 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 Red Bluff 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 Red Bluff 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. No changes to the Red Bluff Subbasin boundary descriptions were included in the 2016 or 2018 Bulletin 118 updates. 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 the Bowman Subbasin separated by the Red Bluff Arch. The western boundary is defined as the Coast Ranges and the eastern boundary is defined as the Sacramento River (DWR, 2004). Thomes Creek separates the Subbasin from the Corning Subbasin to the south although the Red Bluff Subbasin geologic material is likely contiguous and connected to the Corning Subbasin (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**.


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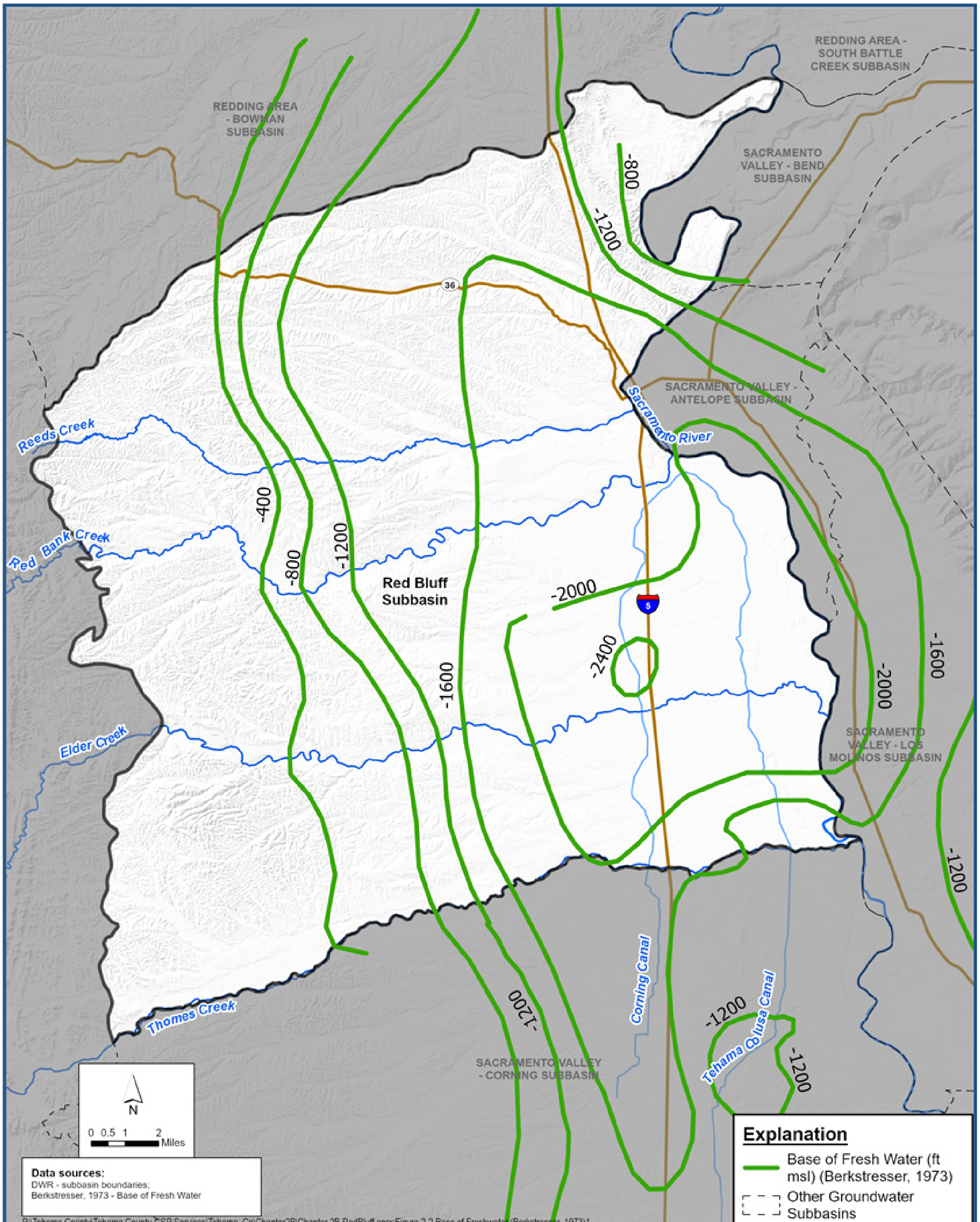
**Lateral Subbasin Boundary**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-15**

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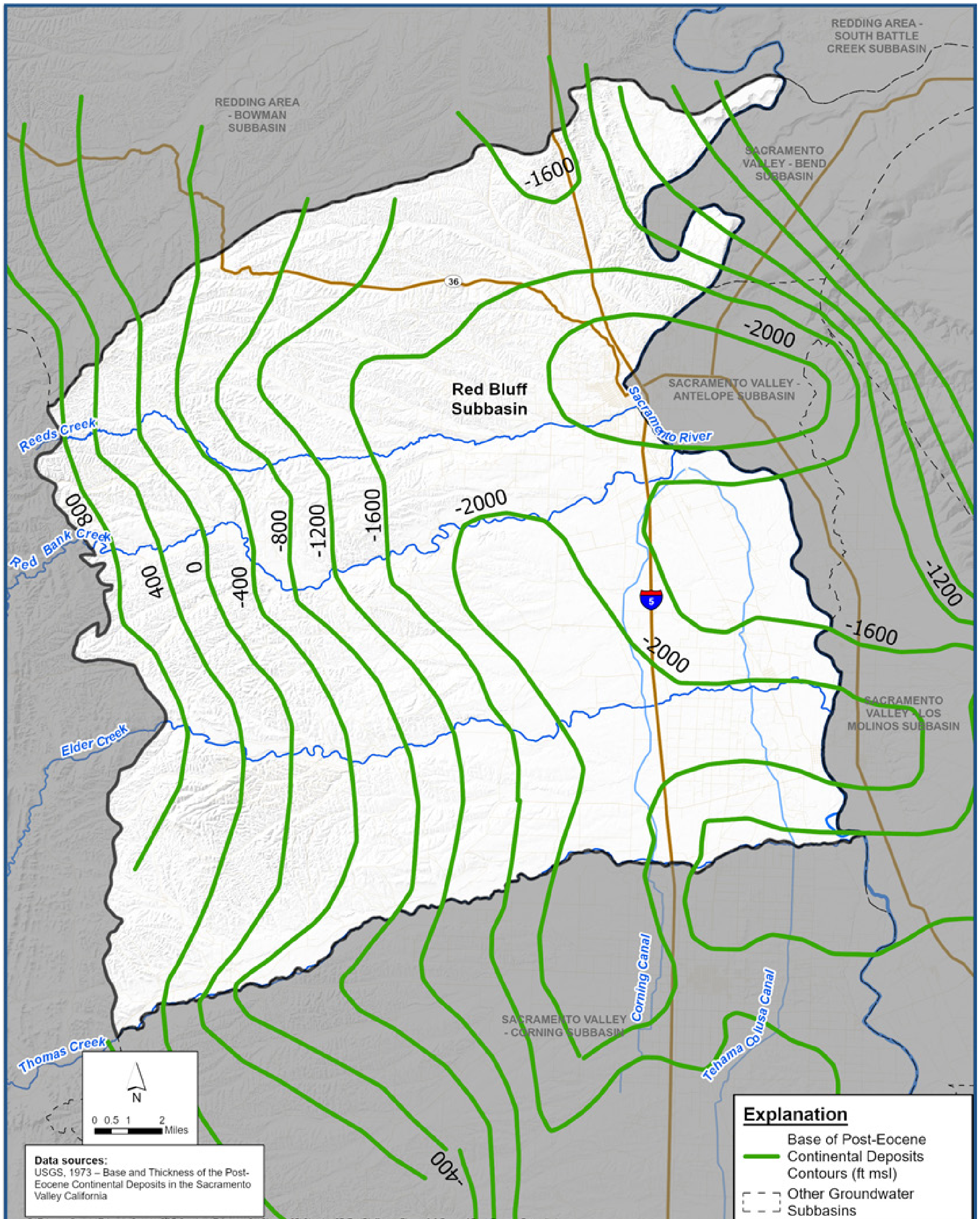
**Contours of Equal Groundwater Elevation, Base of Freshwater**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-16**




**Contours of Equal Elevation, Base of Post-Eocene Deposits**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-17**

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### 2.2.1.2. Topographic Information

The Red Bluff Subbasin is characterized by a relatively flat topographic setting along the western side of the Sacramento Valley 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 eastern half 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 southwest corner of the Subbasin to less than 750 ft msl in the majority of the Subbasin (**Figure 2-19**).

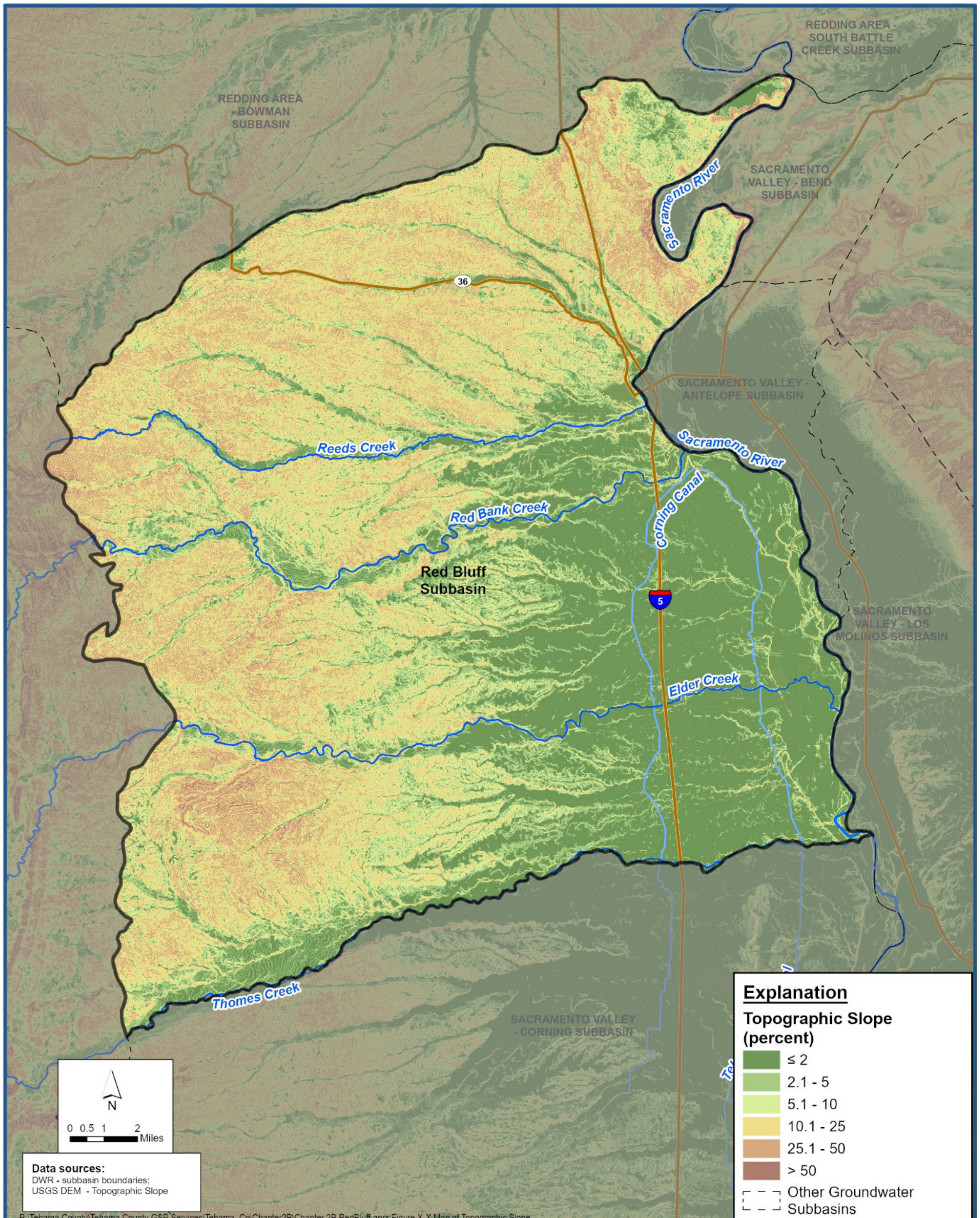
### 2.2.1.3. Geologic Setting

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). The Department of Water Resources (DWR) conducted an extensive literature review and study to compile the most current geology and groundwater information in a 2014 report (DWR, 2014).

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

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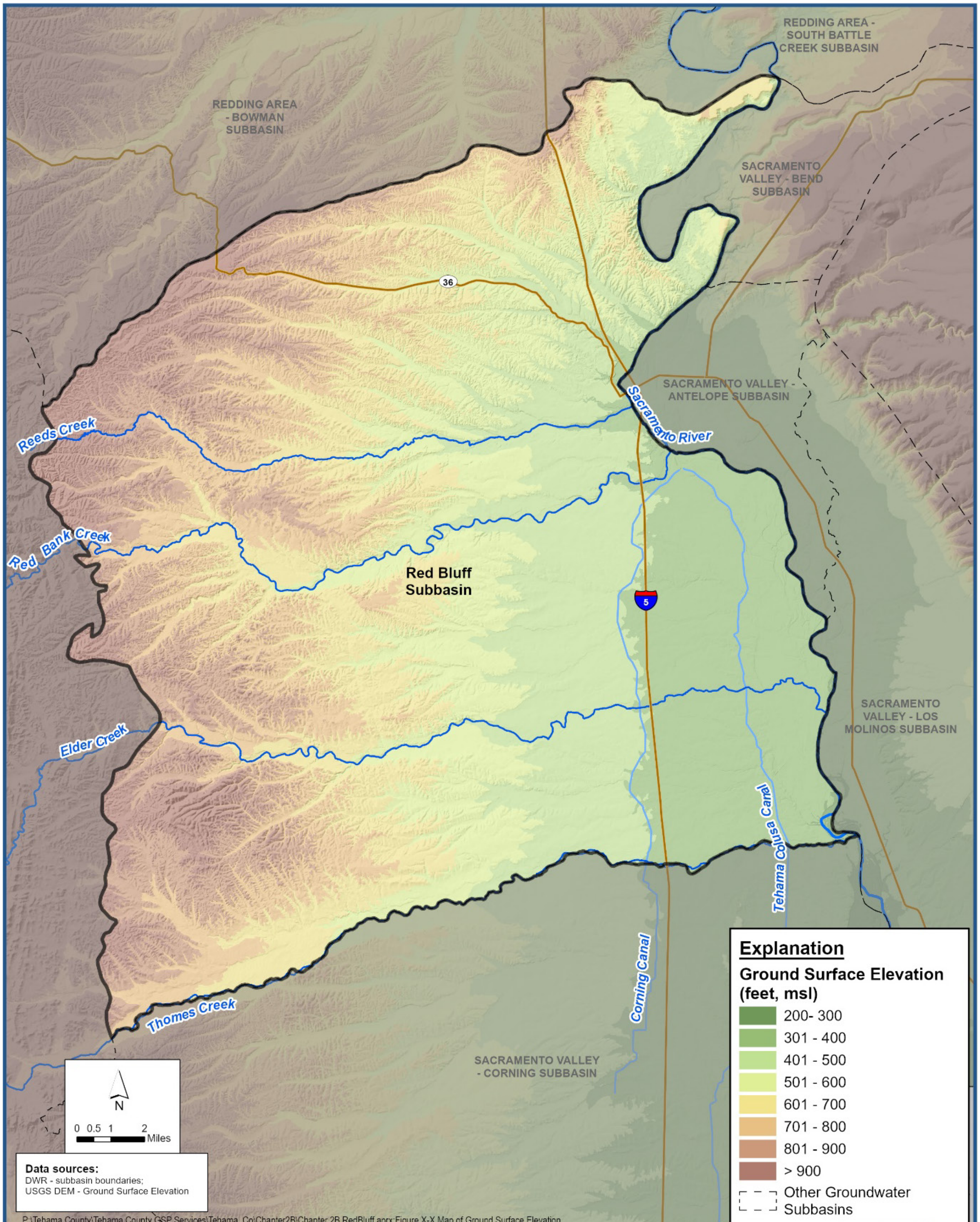
**Map of Topographic Slope**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-18**

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**Map of Ground Surface Elevation**

*Groundwater Sustainability Plan*
*Red Bluff 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**).

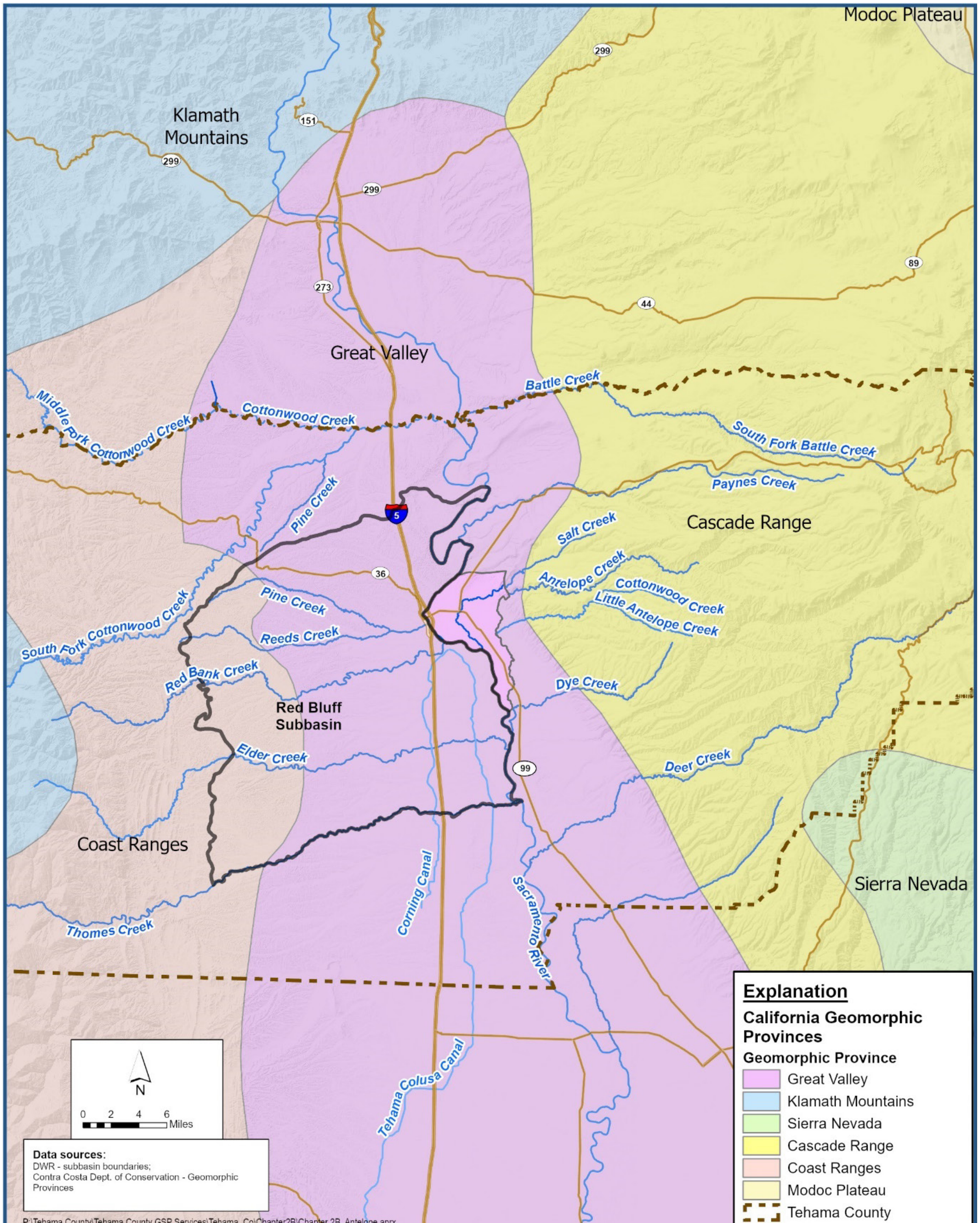
##### Klamath Geologic Province

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). No 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**

*Groundwater Sustainability Plan*
*Red Bluff 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 Willows fault 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 Range and to a lesser extent, the Klamath Mountains, during the Pliocene (Blake et al., 1999). These Pliocene sediments were later cut and filled by younger streams and tributaries (Blake et al., 1999). Outcrops of these younger sediments often occupy currently active streams and tributaries (Blake et al., 1999).

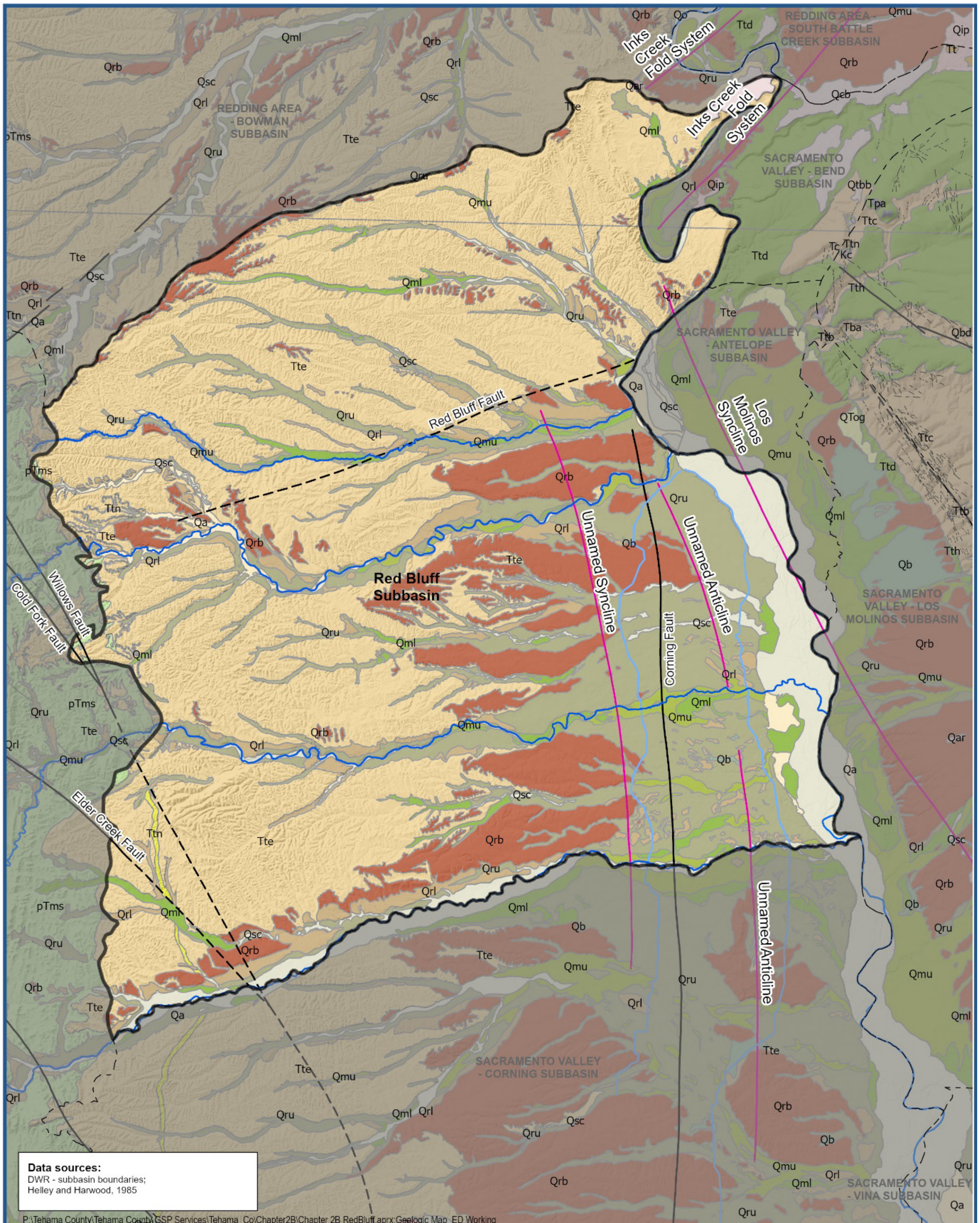
The topography on the east side of the Province is similar to that of the west. It has steeply sloping drainages in the east that shallow into alluvial fans in the vicinity of the Sacramento River. The major difference between the west and the east side is the provenance of the Pliocene sediments. The 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** through **Figure 2-26**. In addition, two DWR cross sections (DWR, 2003; DWR, 2008) that include the Subbasin and extend into neighboring subbasins, are presented as **Figure 2-27**, **Figure 2-28,** and **Figure 2-27B and 2-28B Combined**. 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 over 3,500 ft bgs in the Subbasin (**Figure 2-27**). The source material was the ancestral Sierran-Klamath terrane (Ojakangas, 1968; Dickinson and Rich, 1972; Mansfield, 1979; Ingersoll and Dickerson, 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).




**Geologic Map with Faults**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-21**

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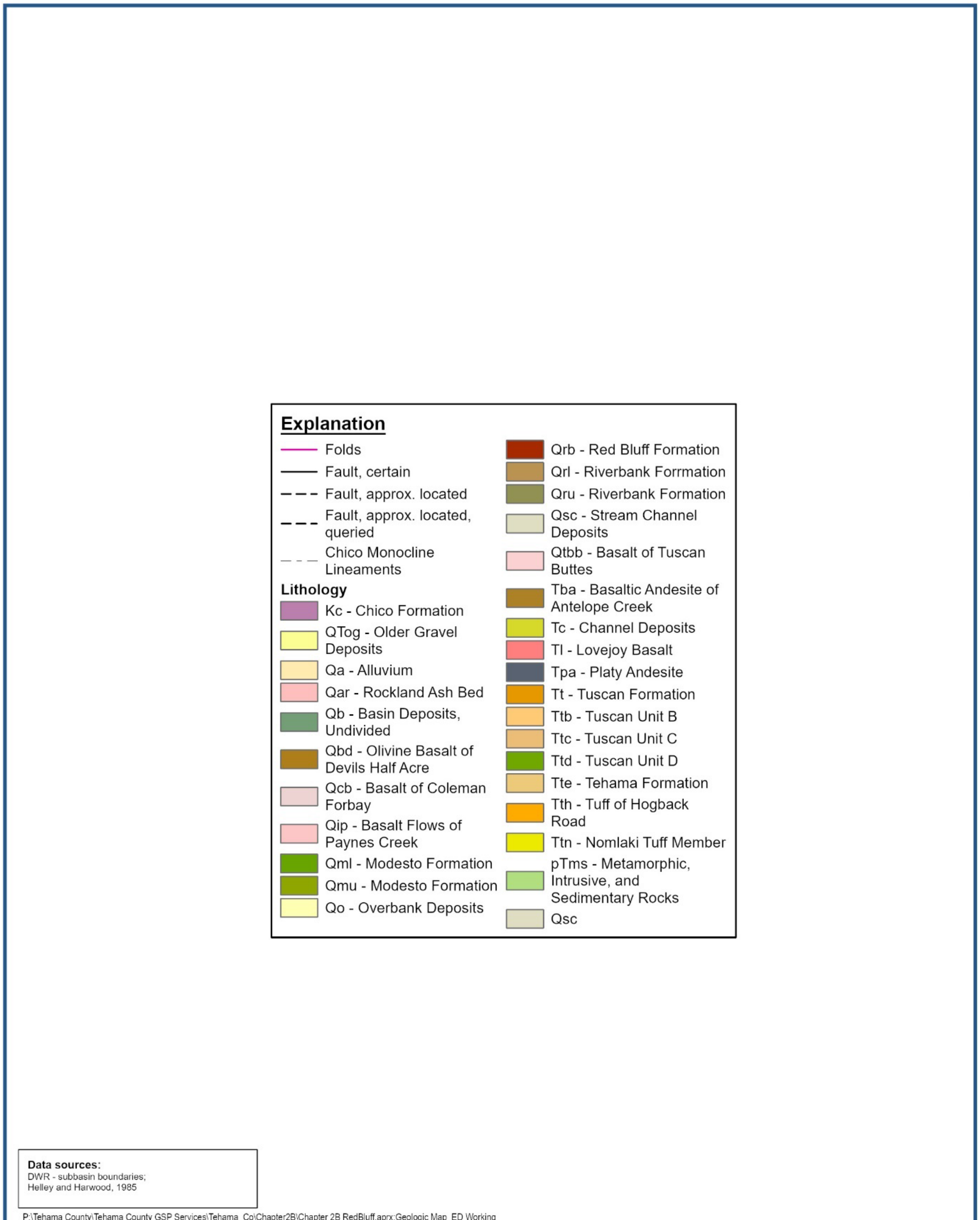


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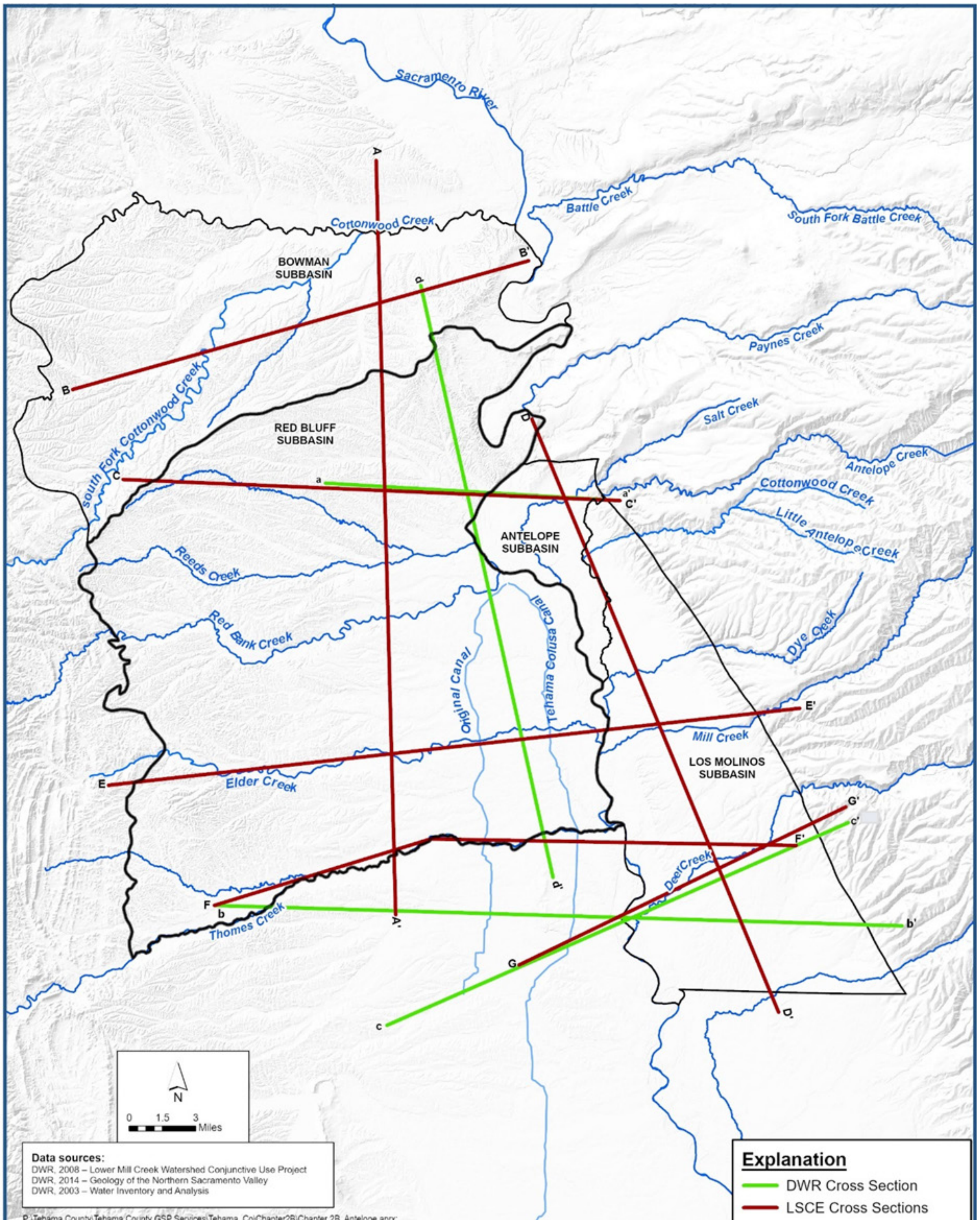
**Geologic Map with Faults**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-21B**

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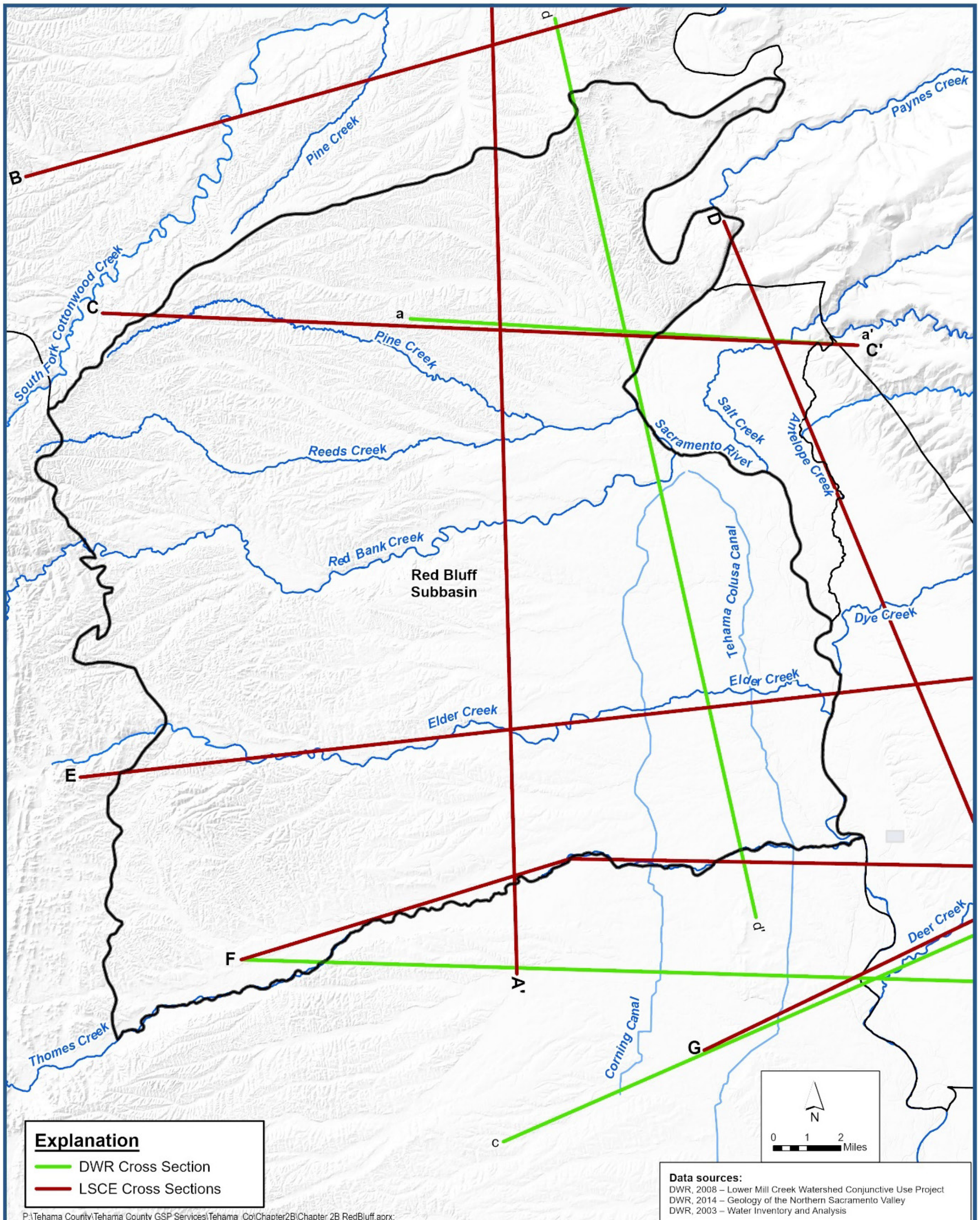
**Map of Cross Section Locations**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-22**

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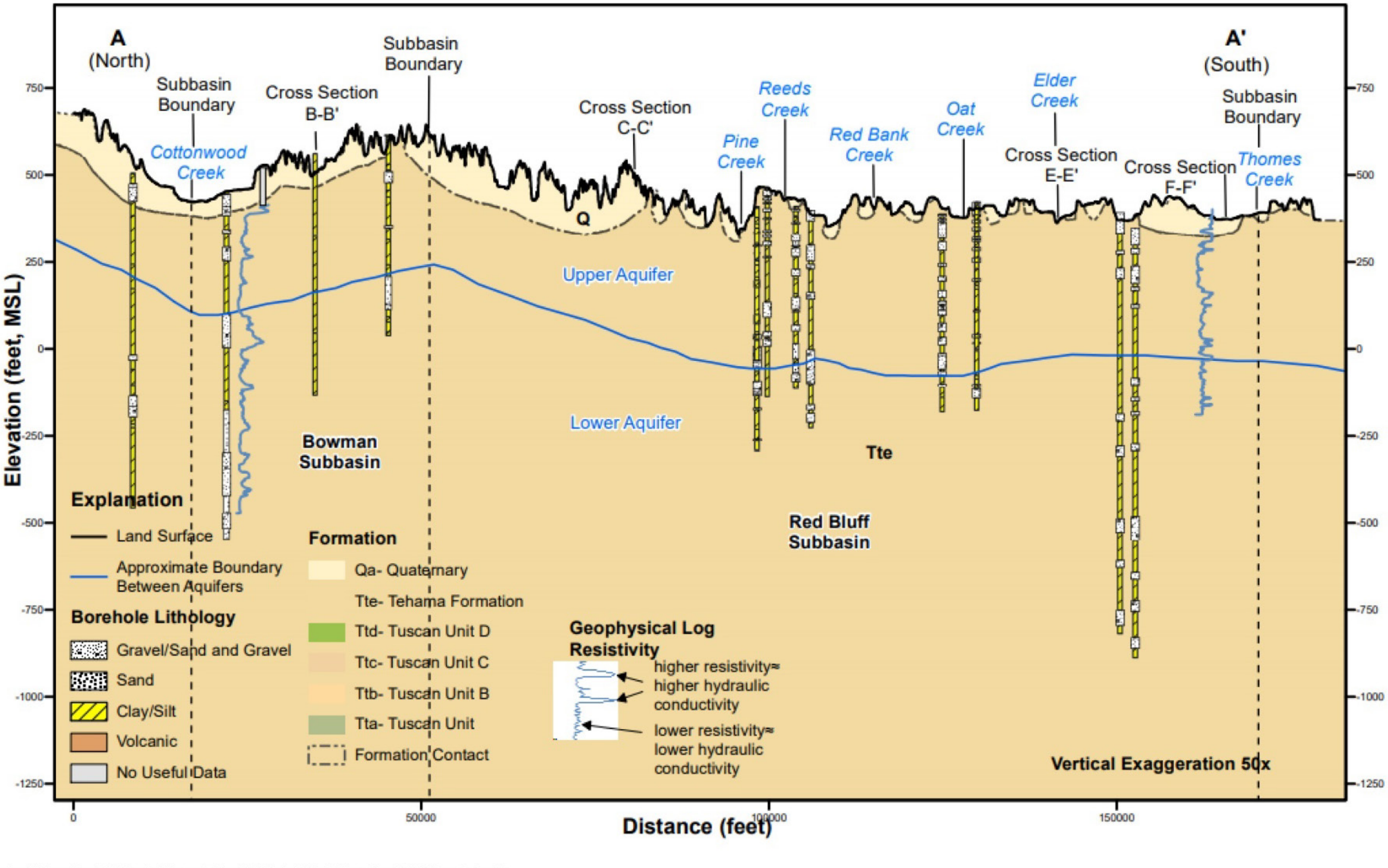
**Map of Cross Section Locations**

*Groundwater Sustainability*
*Red Bluff Subbasin*

**Figure 2-22B**

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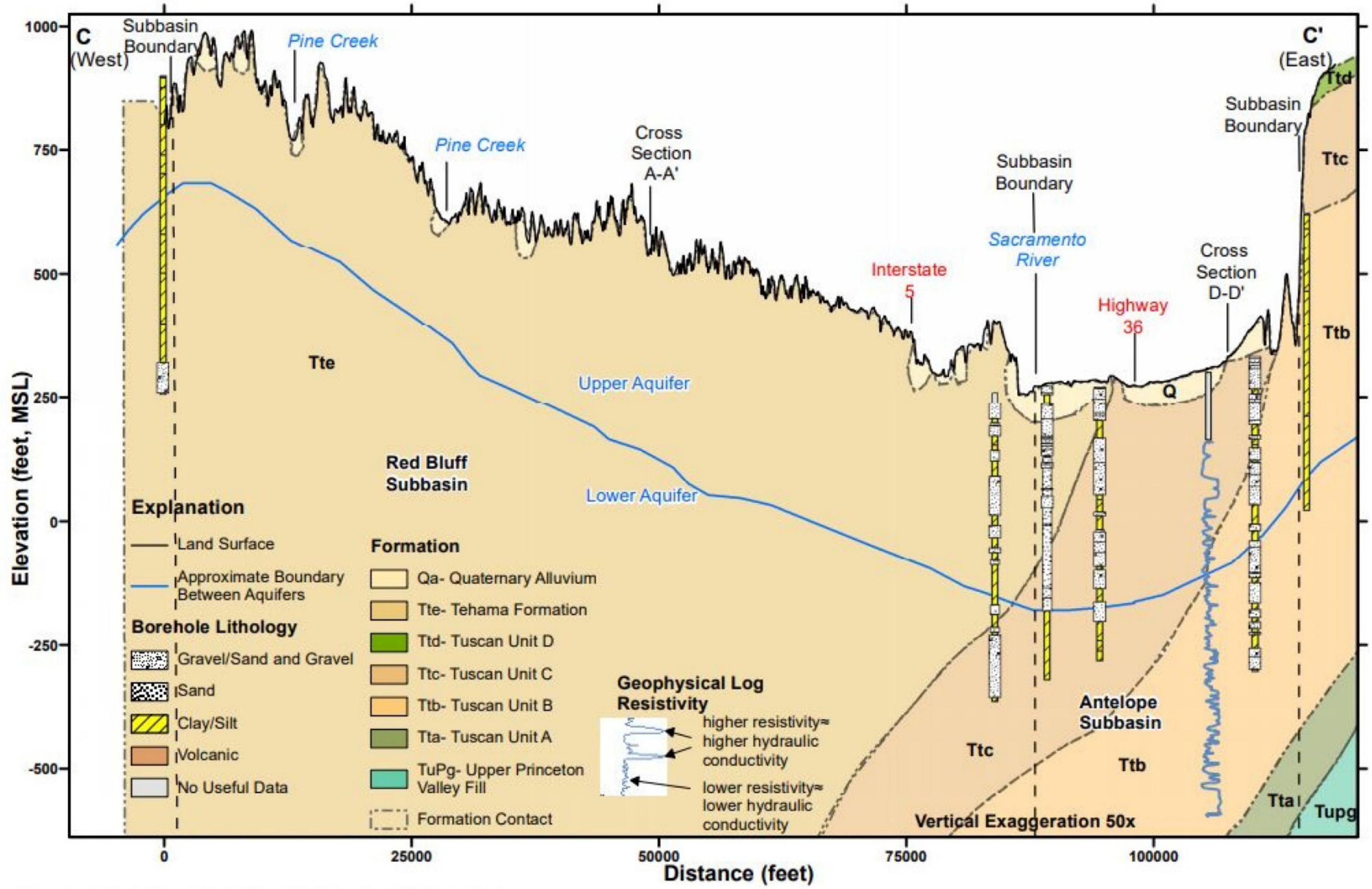
**Cross Section A-A'**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-23**




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

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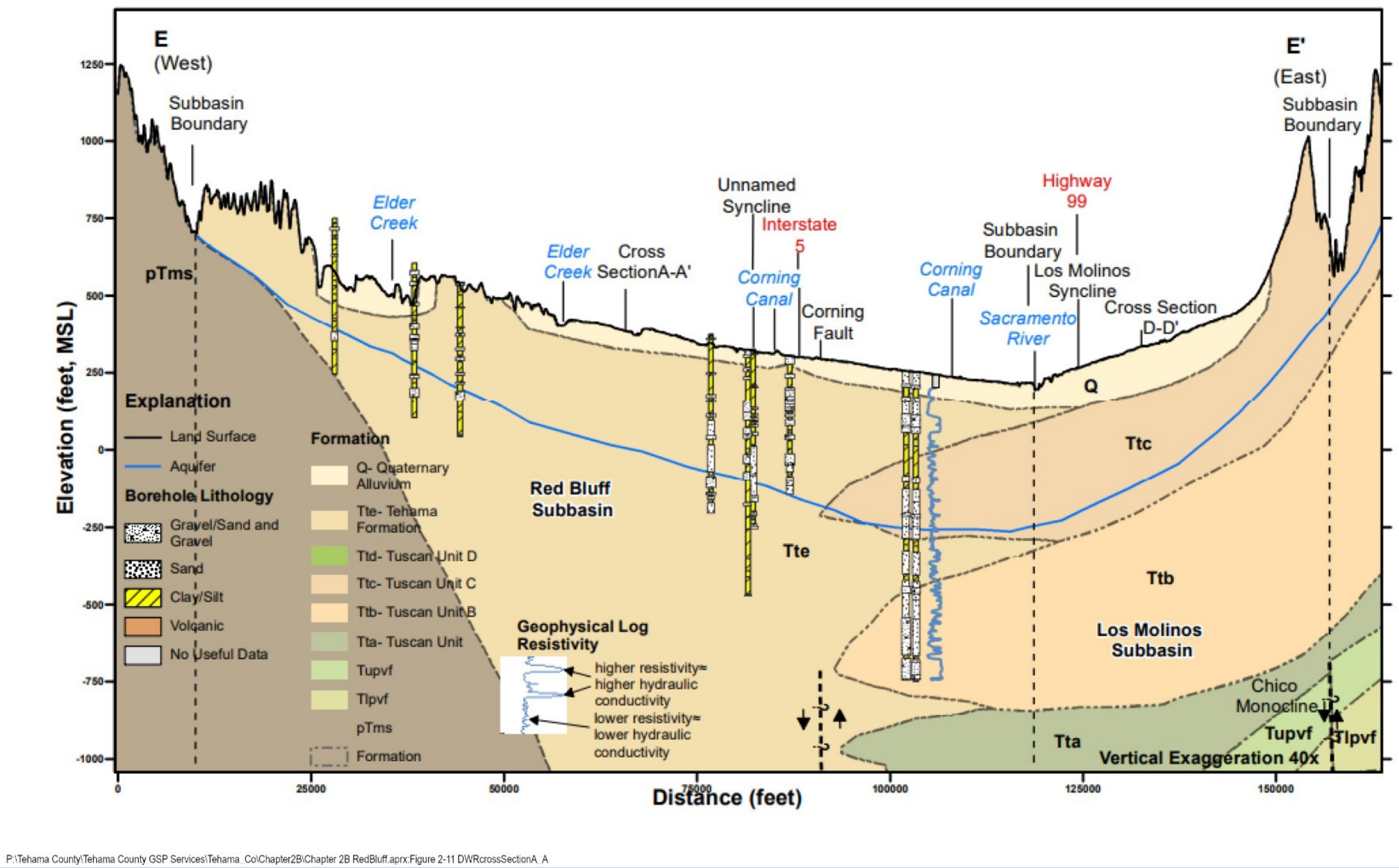
**Cross Section C-C'**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-24**

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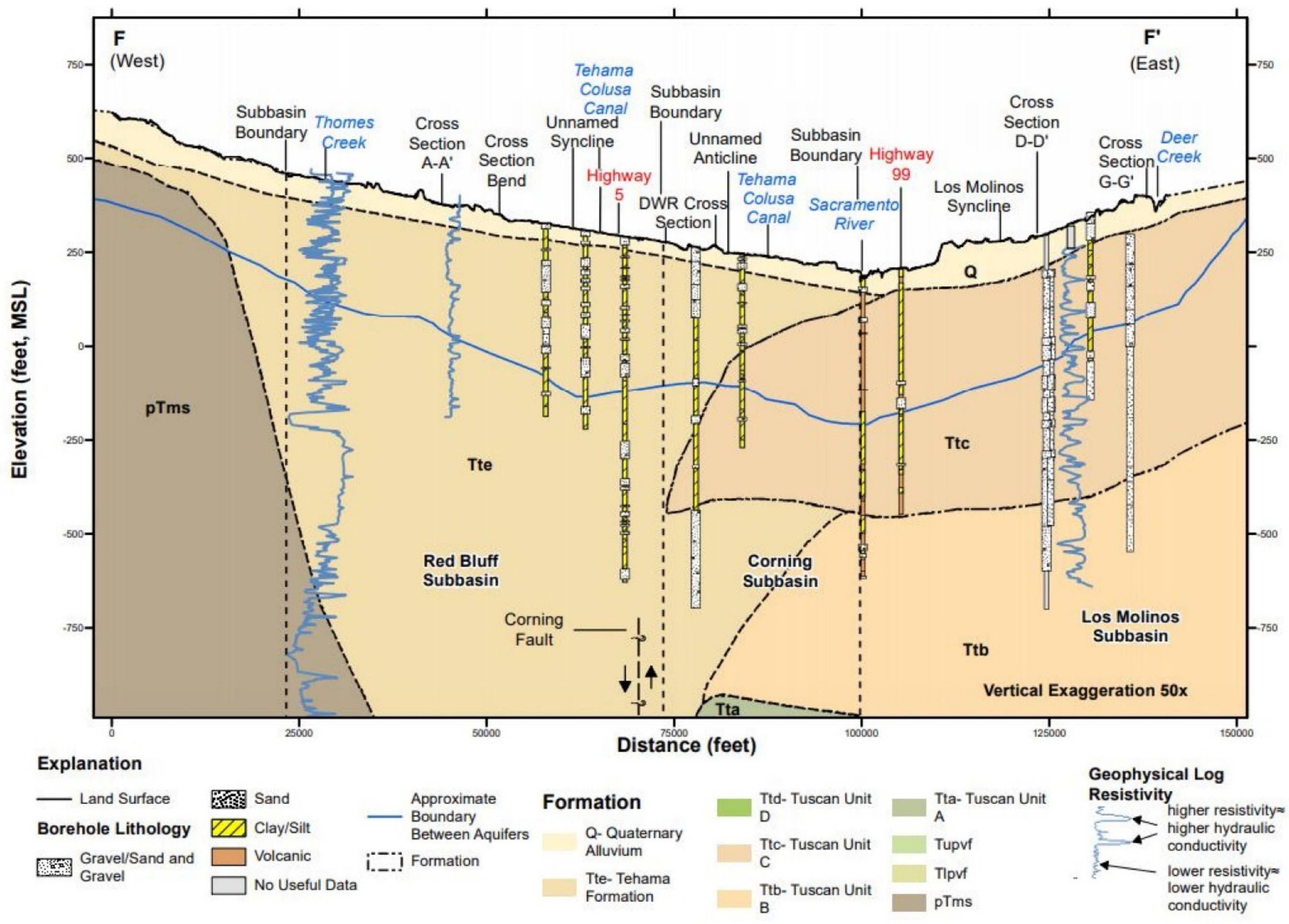
**Cross Section E-E'**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-25**

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**Cross Section F-F'**

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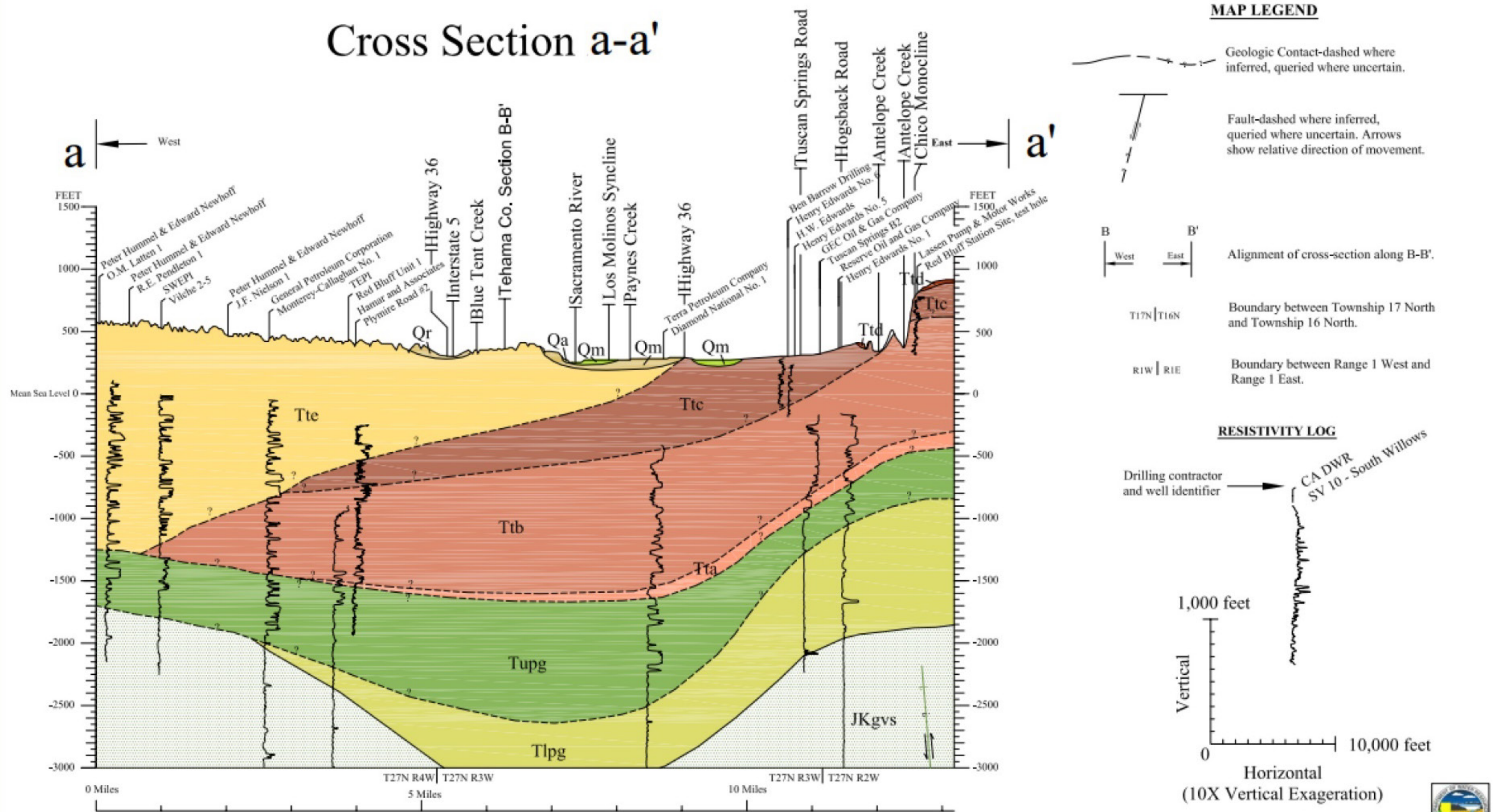
*Red Bluff Subbasin*

**Figure 2-26**




**Data sources:**
DWR, 2008 - Lower Mill Creek Watershed Project Conjunctive Use Study

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

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**DWR Cross Section a-a'**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-27**

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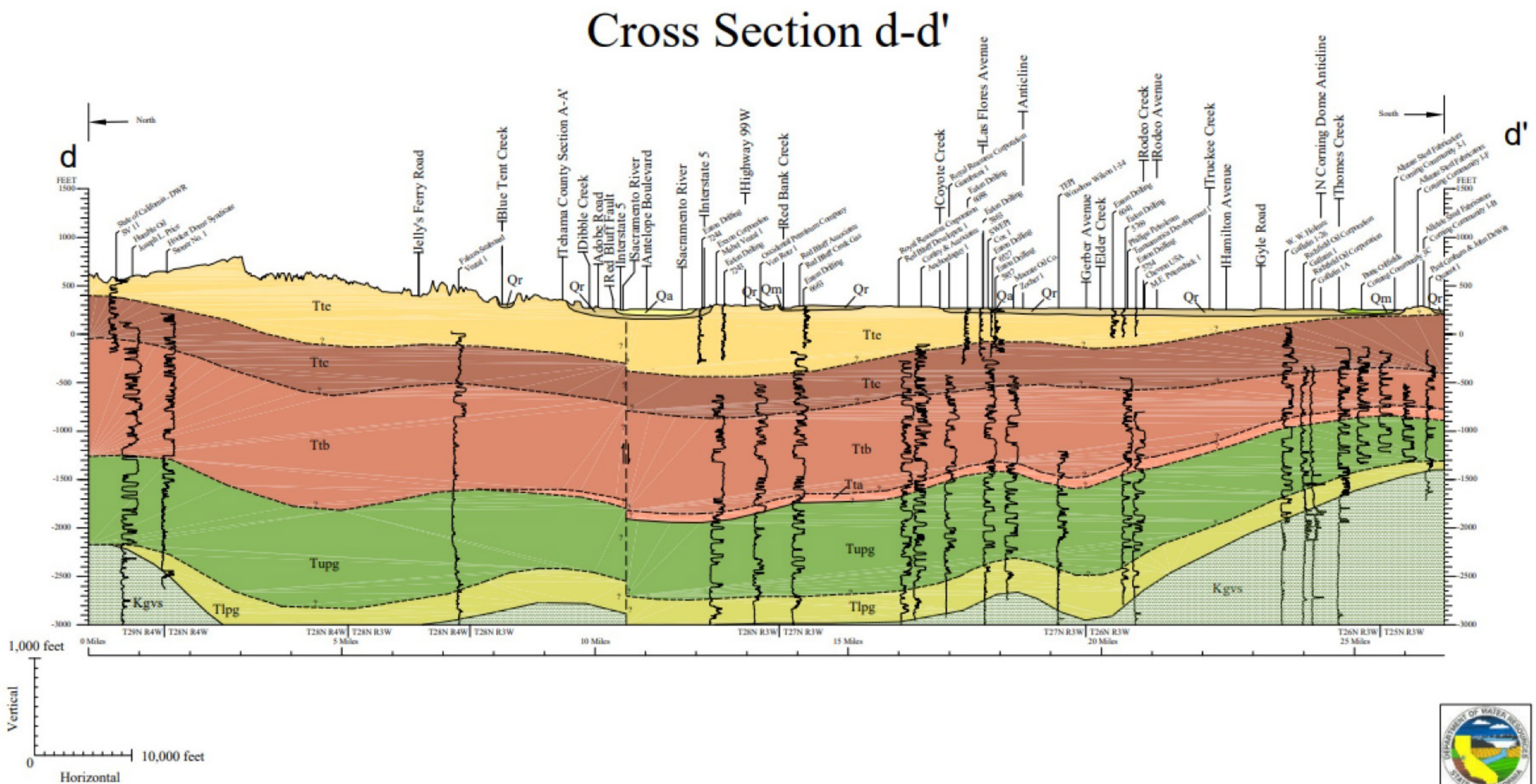


Data sources:
DWR, 2003 - Water Inventory and Analysis

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

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**DWR Cross Section d-d'**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-28**

# 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).* |

**Data sources:**
DWR, 2008 - Lower Mill Creek Watershed Project Conjunctive Use Study

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

TEHAMA COUNTY
FLOOD CONTROL AND WATER CONSERVATION DISTRICT

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**Description of Map Units for**
**DWR Cross Section a-a' and d-d'**

*Antelope Subbasin Groundwater Sustainability Plan*
*Tehama County, California*

**Figure 2-27B and 28 B Combined**

**Table 2-8. Stratigraphic Summary with Hydrogeologic Properties**

| AGE: PERIOD | AGE: EPOCH | GEOLOGIC UNIT | LITHOLOGY DESCRIPTION | APPROXIMATE THICKNESS INTERPRETED IN SUBBASIN | AQUIFER UNIT | HYDROGEOLOGIC CHARACTER |
|---|---|---|---|---|---|---|
| Quaternary | Holocene | Surficial Alluvium | Unweathered gravel, sand, and silt (DWR, 2014) | 25-50 ft (DWR, 2008) | Upper | Moderately permeable but not a significant source of groundwater in the Subbasin due to limited extent (DWR, 2004) |
| Quaternary | 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; DWR 2008) | Upper | Moderately to highly permeable. Limited source of groundwater due to limited thickness and extent in the Subbasin (DWR, 2004). |
| Quaternary | Pleistocene & Pliocene | Riverbank Formation | Alluvial fan and terrace deposits consisting of unconsolidated to semi-consolidated gravel, sand, and silt (DWR, 2014) | 100 ft (DWR, 2008) | Upper | Moderately to highly permeable. Limited Source of groundwater due to limited thickness and extent in Subbasin (DWR, 2004) |
| Quaternary | Pleistocene & Pliocene | Red Bluff Formation | Thin veneer of highly weathered, bright red gravels (DWR, 2014) | | Upper | Water is available only where local perched conditions exist. Provides limited water due to limited extent and thickness in the Subbasin (DWR, 2004). |
| Neogene | Pleistocene & Pliocene | Tehama Formation | Pale green, gray, and tan sandstone, and siltstone with lenses of pebble and cobble conglomerate (DWR, 2014) | 750 ft (DWR, 2008) | Upper/Lower | Low to moderate permeability with localized areas of high permeability (DWR, 2003). Well yields can range from 475 gpm to 950 gpm (DWR, 2003) |
| Neogene | Pleistocene & Pliocene | Tuscan Formation | Interbedded lahars, volcanic conglomerate, volcanic sandstone, siltstone, and pumiceous tuff (DWR, 2014) | 1500 ft (DWR, 2004) | 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) | 1100 ft (DWR, 2008) | Brackish | |
| Paleogene | Eocene | Lower Princeton Submarine Fill | Marine Sandstone, conglomerate, and interbedded silty shale (DWR, 2014) | 350 ft (DWR 2008) | Saline | |
| Cretaceous | | Great Valley Sequence | Marine clastic sedimentary rock consisting of siltstone, shale, sandstone, and conglomerate (DWR, 2014) | 1100 ft (DWR, 2008) | Saline | |

### Lower Princeton Submarine Valley Fill

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

### Upper Princeton Valley Fill

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

### Tuscan Formation

The late Pliocene Tuscan Formation is comprised of interbedded lahars, volcanic conglomerate, volcanic sandstone, siltstone, and pumiceous-tuff sourced from ancestral Cascade Volcanoes (DWR, 2014; Helley and Harwood, 1985; Lydon 1968). The formation can be seen in outcrops along the eastern side of the Sacramento Valley groundwater basin from the Redding area in the north to near Oroville in the south (DWR, 2014). In the subsurface, the volcanic sourced deposits of the Tuscan interfinger with the metamorphic sourced sediments of the Tehama Formation in the vicinity of the Sacramento River, forming the western extent of the Tuscan Formation (Garrison, 1962; Lydon, 1968). The westward extent of this interfingering can be west of the Sacramento River (DWR, 2014). Beneath the valley sediments, the Tuscan Formation is relatively flat lying, dipping 2 to 3 degrees on the western side of the valley (Olmstead and Davis 1962). Thicknesses of the formation ranges from 300 ft at the westward extent to 1,700 ft in the east (Lydon, 1968). In the Subbasin, the thickness can be 1,500 ft.

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 (Tehama County FCWCD, 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 (DWR, 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 up to 1,700 ft in the Subbasin (**Figure 2-27**).

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

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

### *Red Bluff*

The Red Bluff Formation (Qrb on **Figure 2-21**) is composed of sandy gravels on 0.45 to 1.08 mega-annum (Ma) 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 south 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, and Oat 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 100 ft based on cross sections constructed by DWR (2003), (**Figure 2-28**). 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-million-year-old 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; Figure 2-28)**. 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 (Qsc, Qo, and QTog 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 that was 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). Based on cross sections from DWR, (2008), the maximum thickness in the Subbasin is interpreted to be up to 25 ft (**Figure 2-27**). 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 Corning Fault, Red Bluff Fault, Willows Fault, Elder Creek Fault, and the Red Bluff Arch are 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 million years ago (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

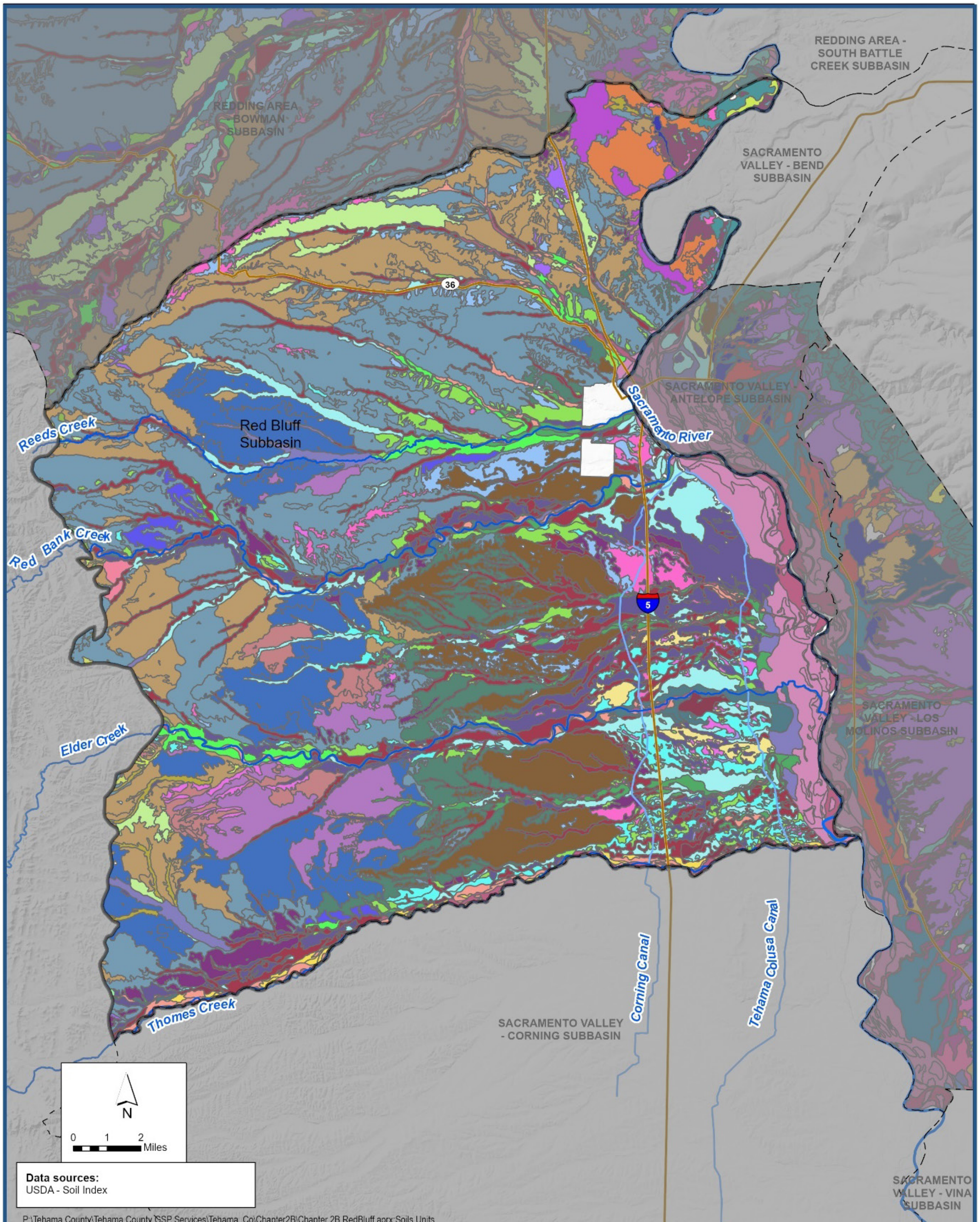
The characteristics of a soil influence the movement of surface water (e.g., water sourced from rainfall, stream flow, or anthropogenic activities such as irrigation). Coarse, porous soils promote infiltration of surface water, while relatively impermeable soils promote surface runoff. Chemical properties 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 Red Bluff Subbasin belong to 131 unique map units. These soil types are grouped into 36 soil series and shown in **Figure 2-29** and **Figure 2-29B**. The most dominant soil series in the Subbasin is the Newville series. The Newville series is abundant in uplands in the northern area (north of the Red Bank Creek) and along the western boundary covering about 32% of the Subbasin. These soils are moderately deep, well drained, and formed from weathering of calcareous shale and sandstone. The Corning series soils are abundant in foothills south of the Red Bank Creek. These soils are very deep, well or moderately well drained, and composed of gravelly alluvium derived from mixed rock sources. The Arbuckle series soils occur throughout the Subbasin in narrow terraces. These soils are very deep, well drained and formed in alluvium from sedimentary and metamorphic rocks. Most low terraces in the Subbasin are covered by Hillgate, Tehama, and Perkins series soils. These soils collectively account for about 14% of the Subbasin area. All other soil series that exist in the Subbasin collectively cover about 19% 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 Red Bluff Subbasin are shown in **Figure 2-30**. 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 60% of the surface area and exists throughout the Subbasin. Silty clay loam (loam soil with abundant silt and clay) predominantly exists in the valley floor along the southeastern boundary covering about 15% of the Subbasin. Loam covers about 10% of the surface and predominantly occurs in highlands in the western areas. All other soil textures make up 5% or less of the land cover each.




TEHAMA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT

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**Soils - Type by Soil Series**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-29**

**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
- No Available Data
- 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

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TEHAMA COUNTY
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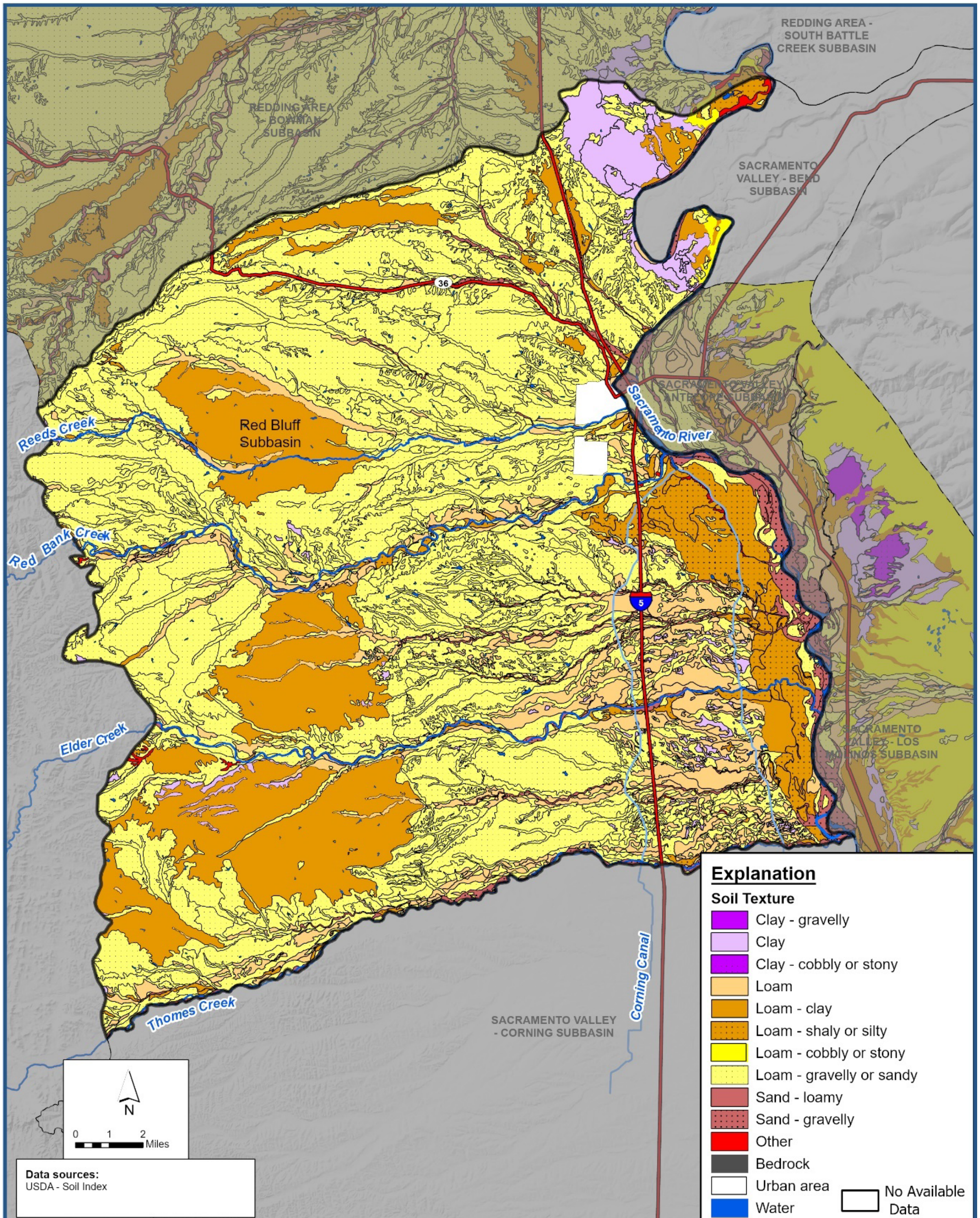
**Soils - Type by Soil Series**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-29B**

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**Soils - Texture**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-30**

### 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 0.5 ft/d to 26 ft/d in the Red Bluff Subbasin (**Figure 2-31**). 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 of flood plains and natural levees of streams, where soils with gravelly sand texture are common (about 13% of the Subbasin area). Approximately 14% of the Subbasin is characterized by soils with values ranging from 1.0 ft/d to 2 ft/d. About 73% 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

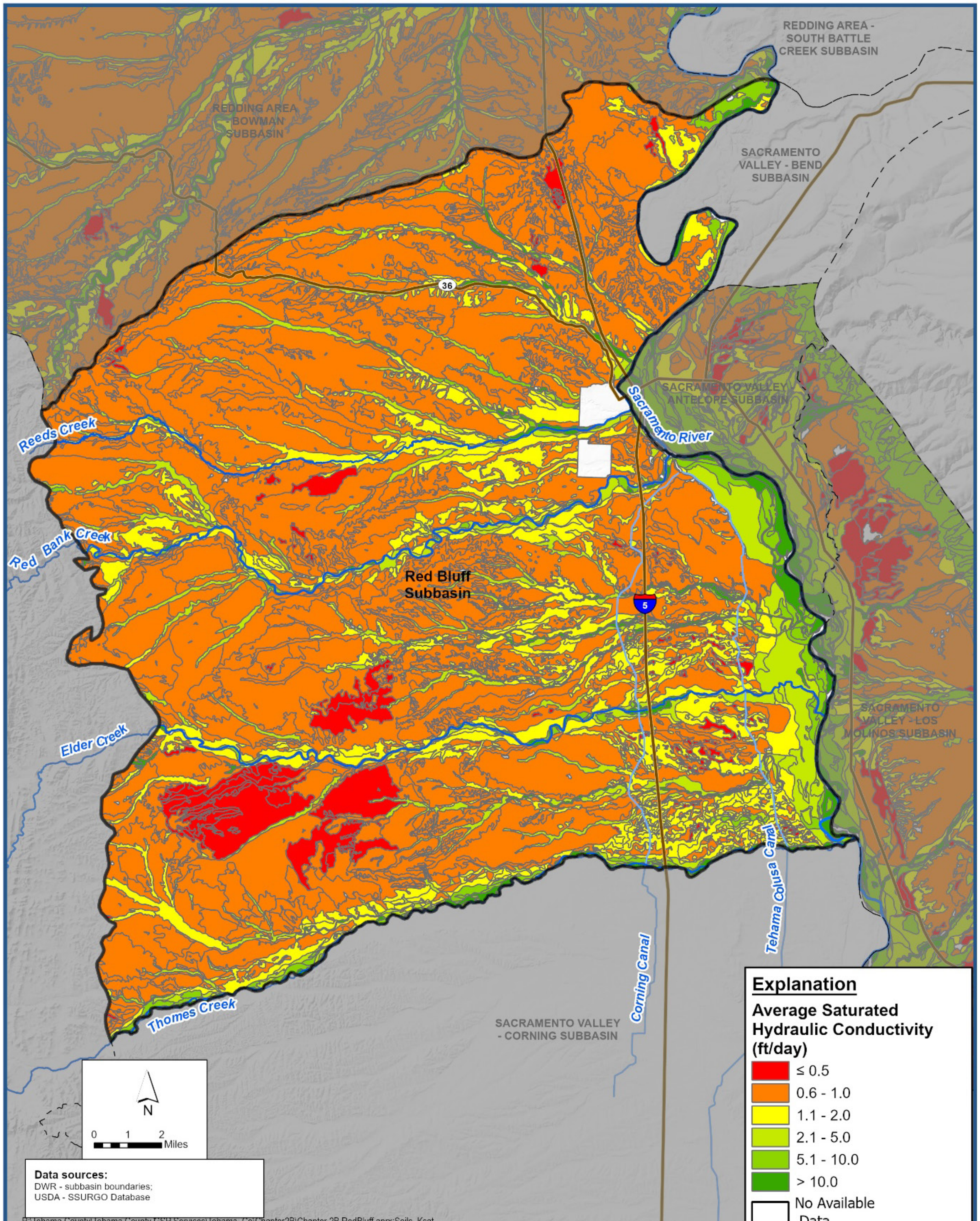
Soil drainage classes indicate the ability of a soil to drain water. Spatial distribution of soil drainage properties in the Red Bluff Subbasin closely resembles the distribution of saturated hydraulic conductivity and soil texture (**Figure 2-32**). About 88% of the Subbasin area is categorized as well drained soils, while about 9% of the area (mostly where Corning series soils exist) 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 4% of the area. Small patches of poorly drained soils cover less than 1% of the Subbasin.

### 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 Red Bluff Subbasin fall into non-saline class, where EC values are less than 2 decisiemens per meter (dS/m) (2,000 µmhos/cm). As per NRCS soil data, EC of surficial soils in more than 90% of the Subbasin is zero dS/m, while that of soils in the remaining areas is 1 dS/m (1,000 µmhos/cm) (**Figure 2-33**).

### 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 Red Bluff Subbasin ranges between 5.0 and 7.9, but the range is between 5.6 and 7.0 in about 80% of the area (**Figure 2-34**). Soils with pH values less than 5.6 occur throughout the Subbasin in small patches (about 6% of the area), but these soils are more common in the valley floor close to the southeastern boundary. The remaining 14% of soils are alkaline, ranging from 7.0 to 8.0 and generally occur in the west of the Subbasin. 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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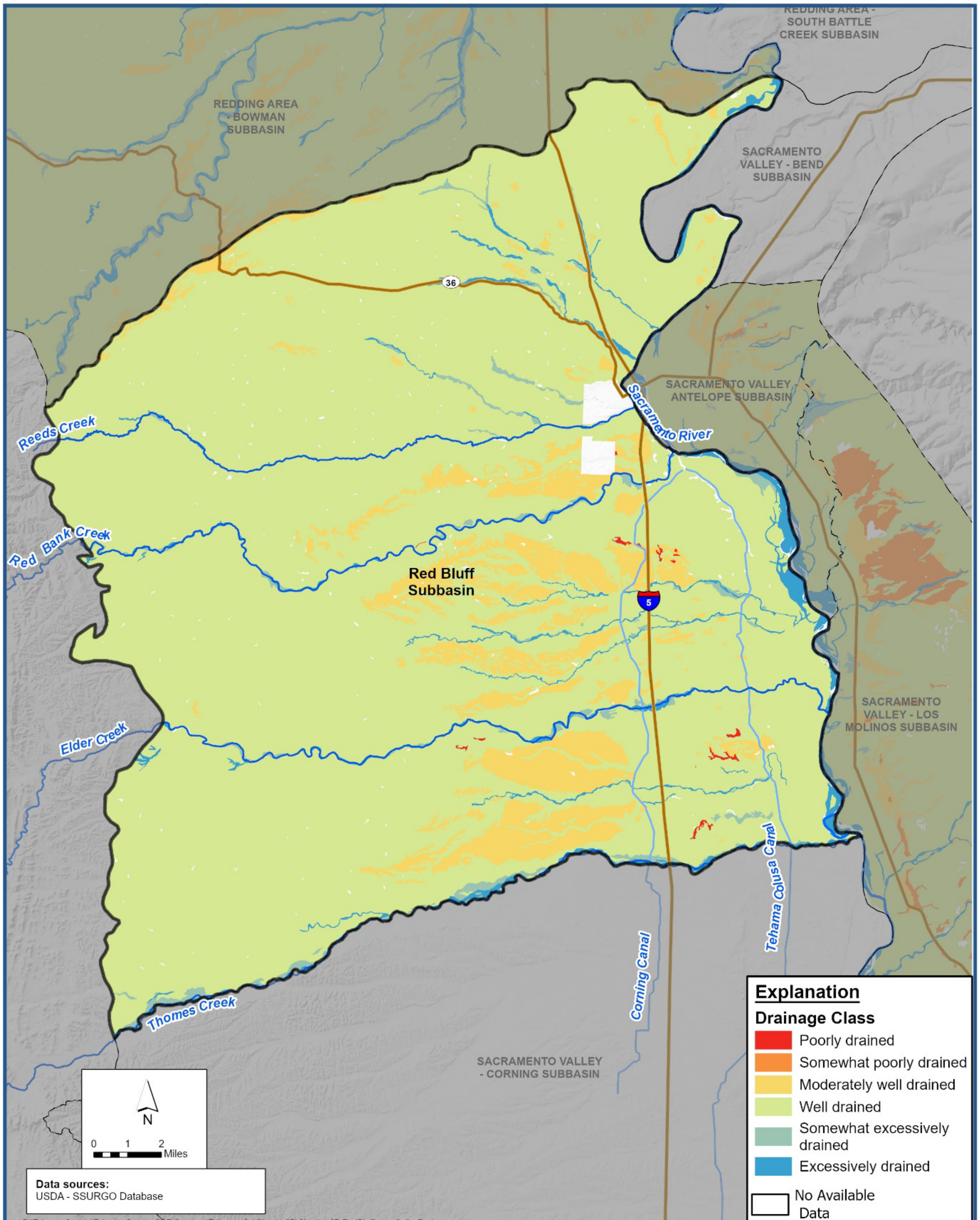
**Soils - Saturated Hydraulic Conductivity**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

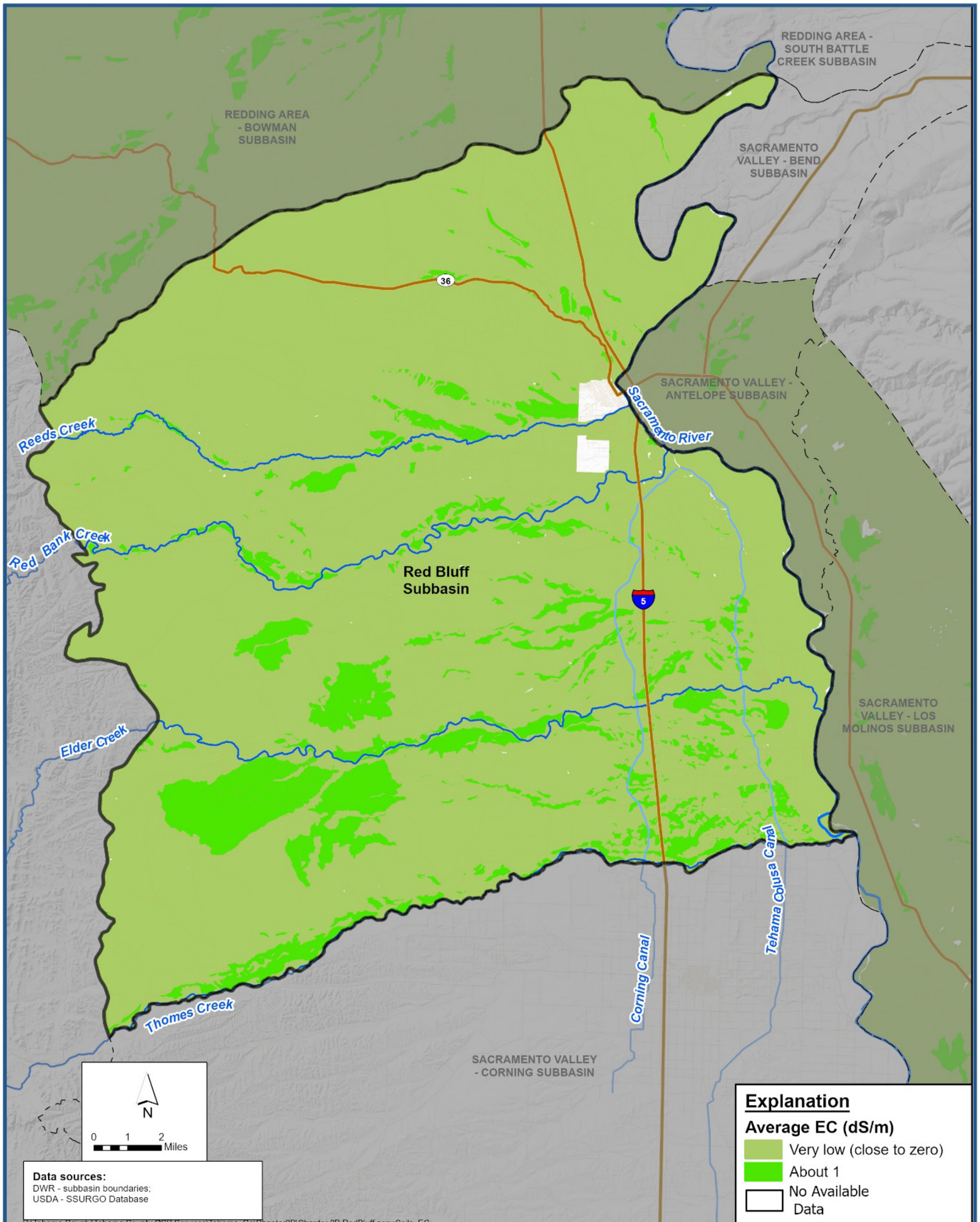
**Figure 2-31**




**Soils - Drainage Class**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-32**

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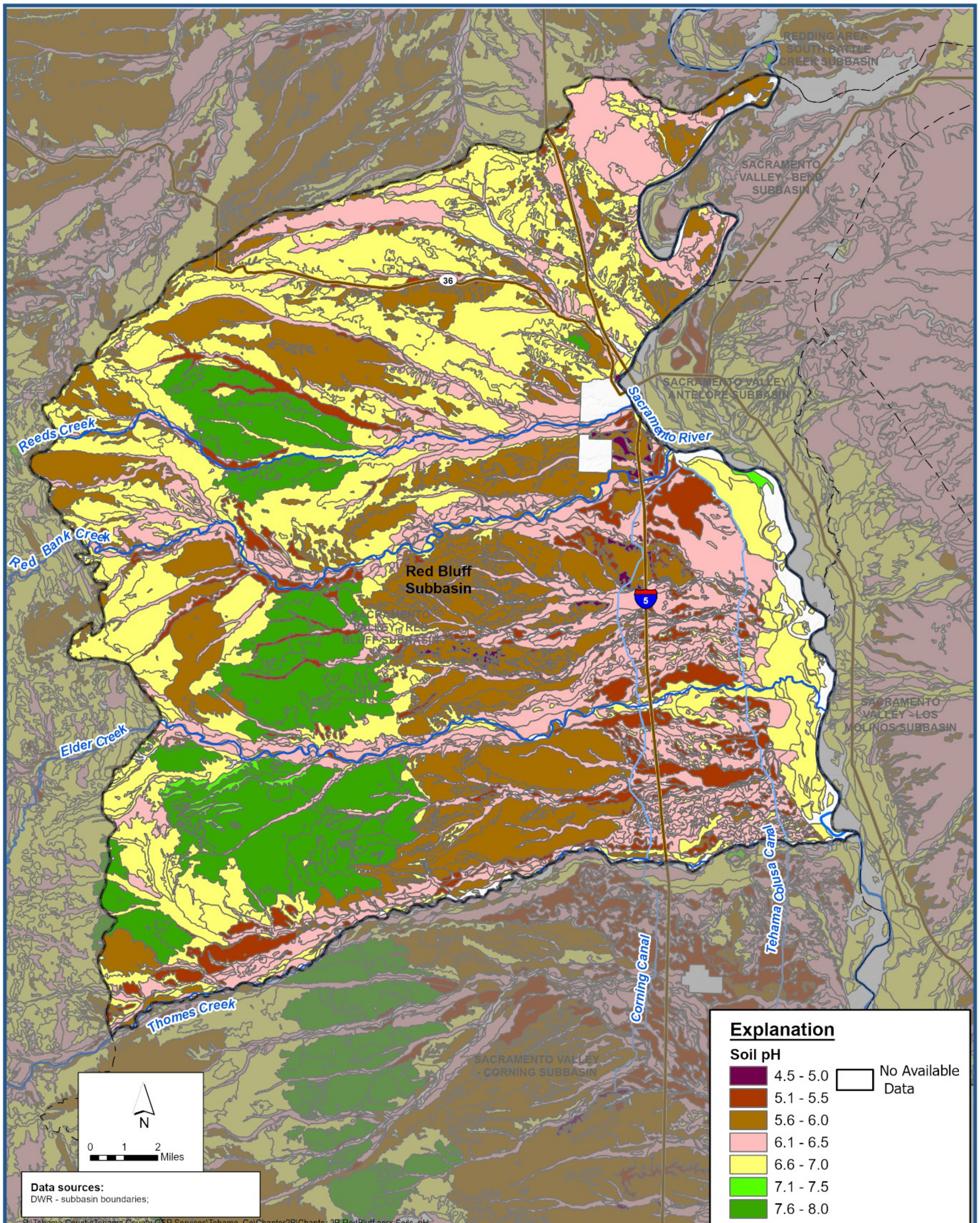
**Soils - Electrical Conductivity**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-33**

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**Soils - pH**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-34**

### 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 through Figure 2-26**). 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 2-22 through Figure 2-28**). The storage capacity of the Red Bluff Subbasin Upper Aquifer is estimated to be approximately 4,200,000 acre-feet to a depth of 200 feet (DWR, 2004).

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 Rancho Tehama Reserve and in neighboring subbasins. 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 (McManus, 1993; DWR, 2003). In the Los Molinos 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). The studied interval of the Tuscan Formation extends past the bottom of the Upper Aquifer however, the majority of the studied depth does fall within the boundaries of the Upper Aquifer.

#### 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. The Tehama Formation has an average transmissivity of 4,341 $ft^2/d$, an average storativity of 0.00089, and an average hydraulic conductivity of 120 feet per day (ft/d) based on a 1989 constant discharge aquifer test at the Rancho Tehama Reserve in the Red Bluff Subbasin (McManus, 1993; DWR, 2003). 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) have been estimated in the Los Molinos Subbasin ranging from 5,415 $ft^2/d$ to 49,986 $ft^2/d$ (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

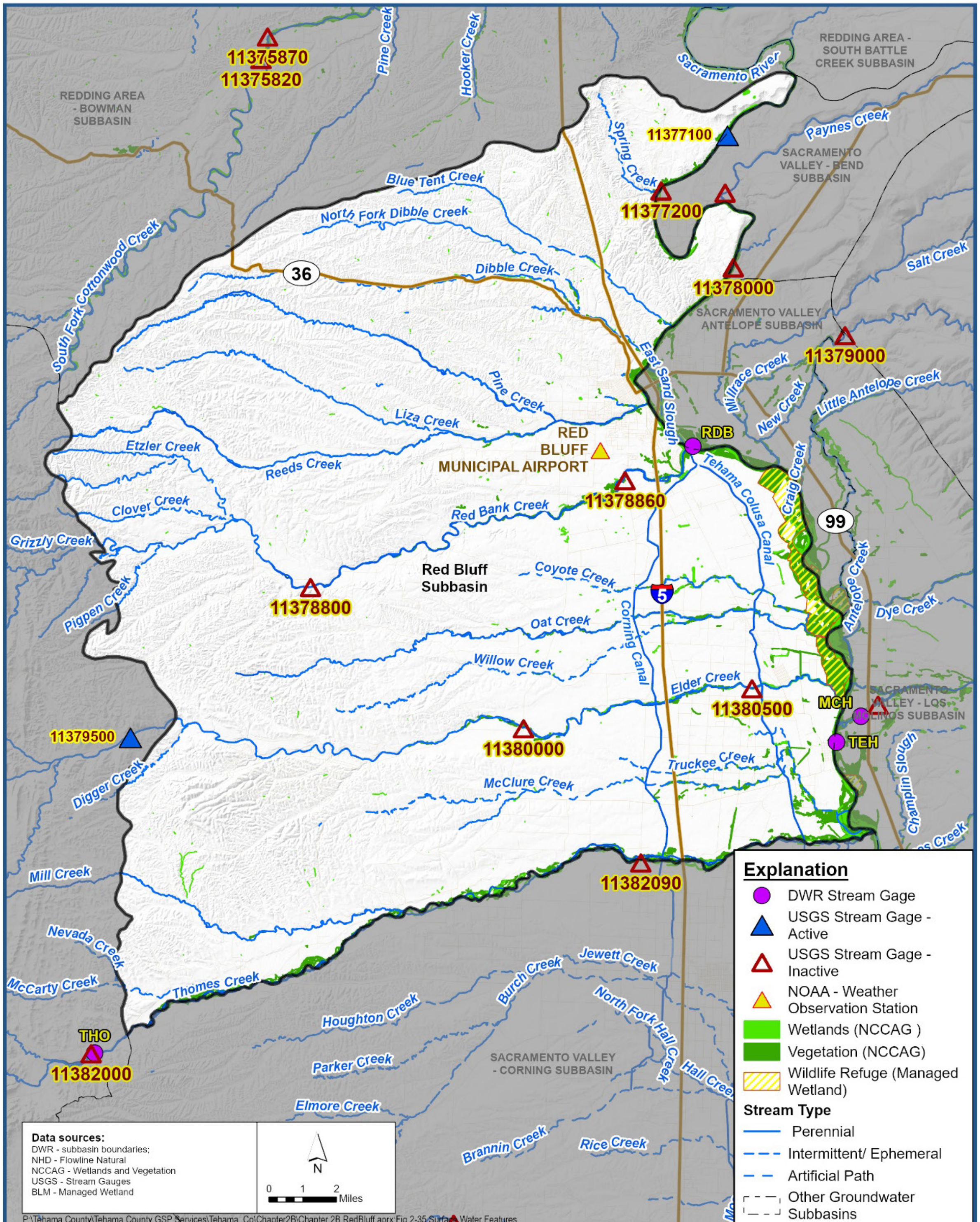
The base of the post-Eocene continental deposits is defined as the bottom of the basin. The post-Eocene deposits are the deepest locations where fresh water may exist. Contours of the base of post-Eocene deposits (**Figure 2-17)** are on the base of the Upper Princeton Valley Fill in the majority of 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 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 -2,400 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, Pine Creek, Reeds Creek, Red Bank Creek, Oat Creek, Elder Creek, Mill Creek, and Thomes Creek (**Figure 2-35**). There are also a multitude of smaller streams within the Subbasin. In addition, the Tehama Colusa and Corning canals, which convey water diverted from the Sacramento River at Red Bluff pumping plant to irrigate lands in Red Bluff, Corning, and Colusa Subbasins, also run through the Subbasin. The Sacramento River and Thomes Creek flow throughout the year (perennial), but Elder Creek, Oat Creek, Red Bank Creek, Reeds Creek, and Pine Creek flow seasonally. The Sacramento River flows southward along the eastern boundary of the Subbasin. The other streams flow eastward draining the east side of the Coast Ranges and entering 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.

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 2-32**). 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” and “very poor” deep percolation rating to many areas of flood plains and natural levees of streams despite the presence of highly conductive surficial soils (**Figure 2-36**). 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.

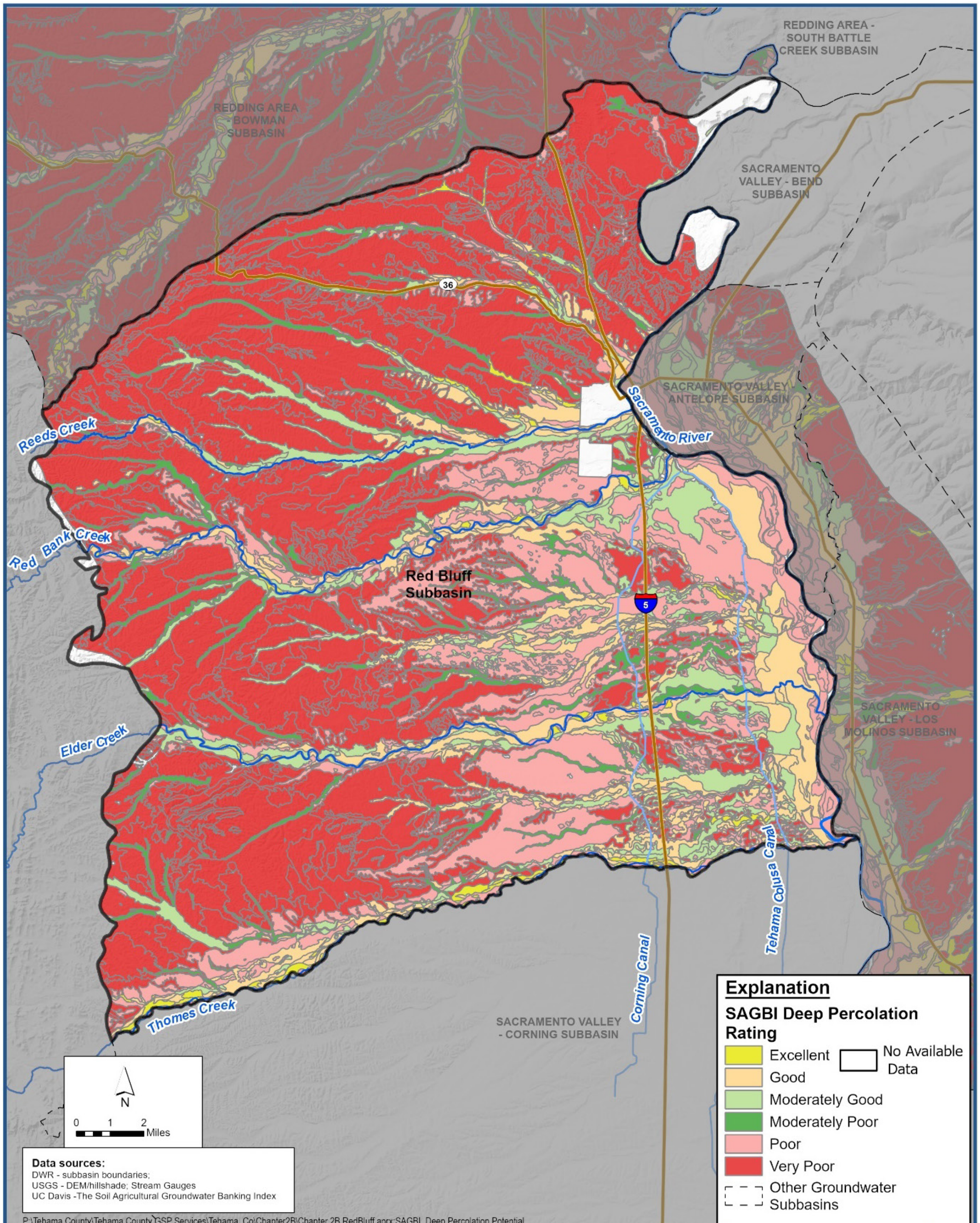
Seasonal wetlands exist adjacent to many streams, and most notably along the Sacramento River, Thomes Creek, and lower reaches of Elder Creek (**Figure 2-37**). A portion of the Sacramento River National Wildlife Refuge, a managed wetland, also exists at the southeastern part of the Subbasin (**Figure 2-35**). 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).




**Map of Surface Water Features**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-35**

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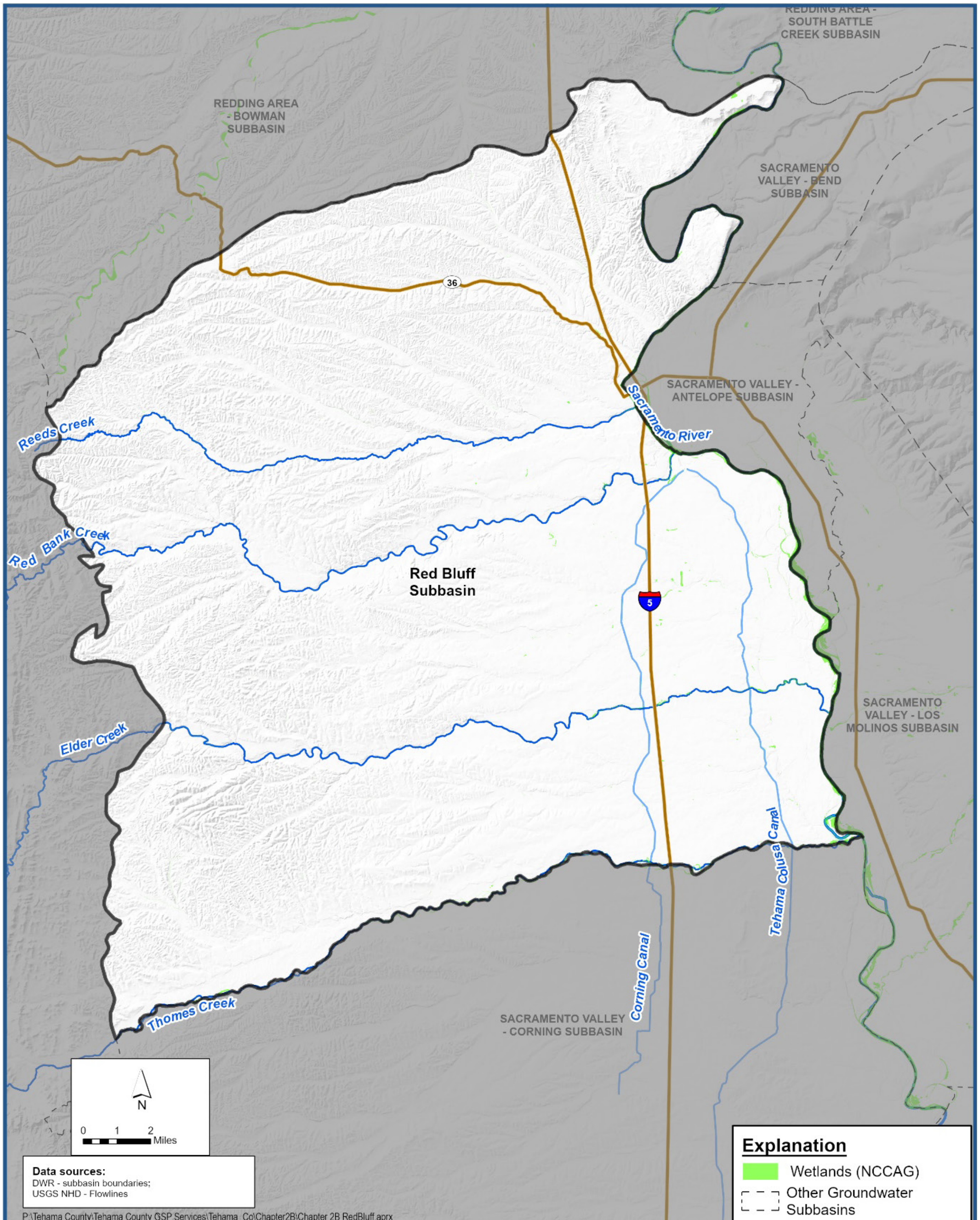
**SAGBI Groundwater Recharge Rating**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-36**

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**Map of Discharge Areas – Wetlands, Springs, Seeps**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-37**

### 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.

#### 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.

The following discussion on groundwater levels, flow directions, and groundwater quality are mostly limited to the Upper Aquifer due to the lack of data from the Lower Aquifer. Data from wells that were completed or screened entirely within the Upper Aquifer were selected to characterize groundwater conditions of the Upper Aquifer. Only five wells that were completely or partially constructed in the Lower Aquifer had groundwater level or quality data. Lack of data to characterize conditions in the Lower Aquifer is identified as a data gap.

### 2.2.2.1. Groundwater Levels and Flow Direction

#### *2.2.2.1.1. Groundwater Levels*

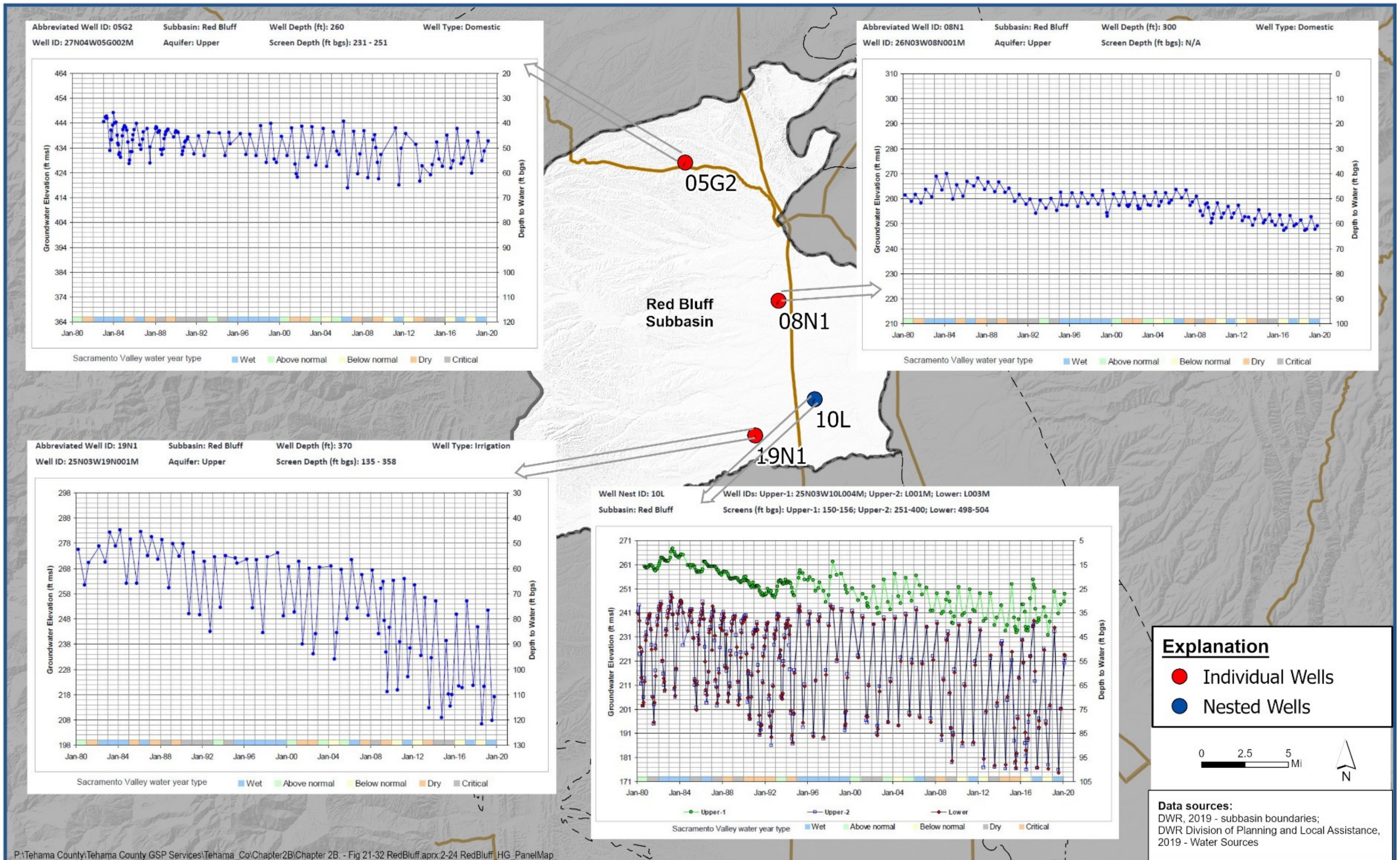
To gain a historical perspective of trends in groundwater levels, hydrographs were generated for wells with historical time series data of sufficient period of record. Representative hydrographs and the locations of corresponding wells are shown in **Figure 2-38**, while all hydrographs used for the groundwater level evaluation are in **Appendix 2-F**. A graphical illustration that describes information shown on a hydrograph is also included in **Appendix 2-F**. Trends of groundwater levels can be observed over various time periods when data is available. The time-series data also show seasonal variations and changes that correspond to wet and dry periods of the Subbasin. The total annual precipitation measured at the Red Bluff Municipal Airport (RBF) shows a strong positive correlation with the Sacramento Valley Water Year Index (Pearson's correlation coefficient = 0.72). **Figure 2-35** shows the location of the rain gage, and **Figure 2-39** shows the annual precipitation and cumulative departure curve of precipitation. Between water years of 1990 and 2018 (representative base period of this GSP that represents long-term average annual hydrologic conditions), 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 in the Sacramento Valley (**Table 2-9**).

##### Upper Aquifer

Seasonal high-water levels in the Upper Aquifer (in winter/spring seasons) ranges from about 10 to 110 ft bgs during wet periods. Most wells with water levels deeper than about 80 ft bgs exist in the areas west of Paskenta Road, north of Red Bank Creek, and south of Pine Creek. 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 30 ft compared to previous wet periods. Recent data indicate that the groundwater levels partially or completely recovered to pre-drought levels since then. Seasonal water level fluctuation at any well during a water year ranges from a few feet to about 50 ft depending on well location, construction, and local water use. In general, magnitude of seasonal fluctuations is less than 10 ft at wells shallower than about 200 ft, and fluctuations are higher at wells screened below 200 ft.

##### Lower Aquifer

Seasonal high-water levels of the Lower Aquifer in the southeastern area (depths deeper than about 450 ft bgs) range from 20 to 40 ft bgs during wet periods. In dry periods, water levels in the shallow part of the Lower Aquifer decreased by about 10 ft, but the decrease in the deeper part of the aquifer (at a depth of about 950 ft bgs) was less than five feet. During seasonal low conditions, groundwater elevation in the shallow part of the Lower Aquifer can decrease by up to 50 ft, but the decrease in the deep part is about 20 to 30 ft. Groundwater elevations in the Lower Aquifer are only available from three Lower Aquifer wells in the southeastern area near Gerber (in two separate sets of nested wells located about 1.5 mile apart). Hydrographs of these nested wells (**Appendix 2-F**) show similar temporal water fluctuations in the shallow part of the Lower Aquifer and deep part of the Upper Aquifer, which indicates hydraulic connection between the two aquifers.

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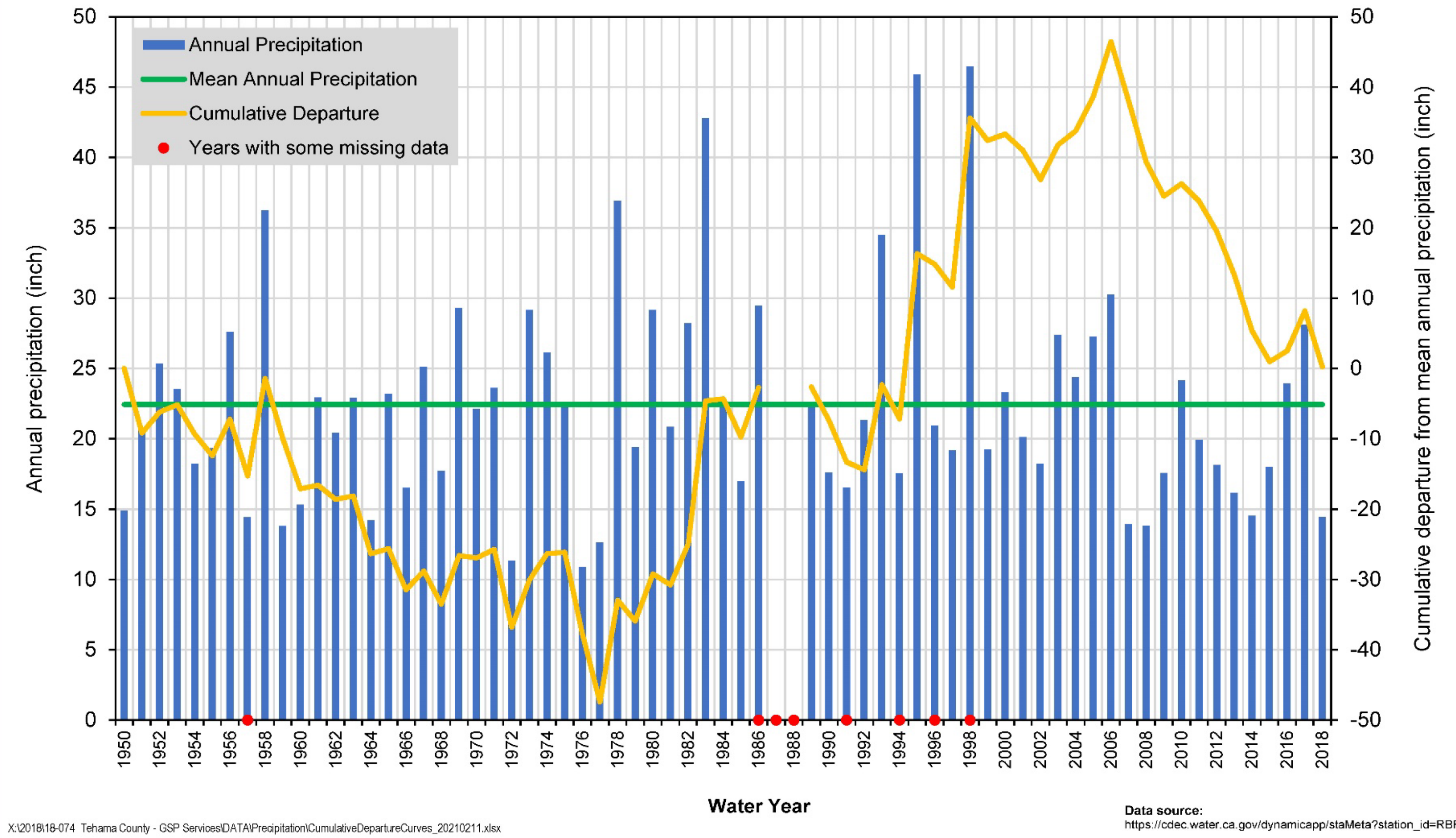
**Panel Map of Selected Groundwater Elevation Hydrographs**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-38**




**Annual Precipitation and Cumulative Departure at Red Bluff Municipal Airport**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-39**

**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

### Trends in Groundwater Levels

Statistical analysis of data from 18 wells (17 in the Upper Aquifer and one in the Lower Aquifer), that have data that span the entirety of the 1990 through 2018 hydrologic base period, show small declines in seasonal high groundwater levels. Fifteen of these wells exist east of Paskenta Road and south of Reeds Creek, limiting our understanding of long-term water levels in the northern and western portions of the Subbasin. Five Upper Aquifer wells in the southeastern area (south of Oat Creek and east of Paskenta Road) show declines ranging from approximately nine feet to 25 ft during the 1990-2018 period (about 0.5 to 0.9 ft/year). Water level declines of the other wells, including the Lower Aquifer well in the southeastern area, are less than nine feet during this period (less than 0.5 ft/year). Results of the groundwater level trend analysis, which used both parametric (Ordinary least squares regression) and nonparametric (Mann-Kendall and Theil–Sen) methods, are included in **Appendix 2-F**. The trend of groundwater levels is not an indication of overdraft, but likely due to removal of temporary surplus of groundwater. Temporary surplus removal is the extraction of a volume of aquifer storage to enable the capture of recharge and reduction in subsurface outflow from the Subbasin without impacting beneficial users of groundwater to an unreasonable degree.

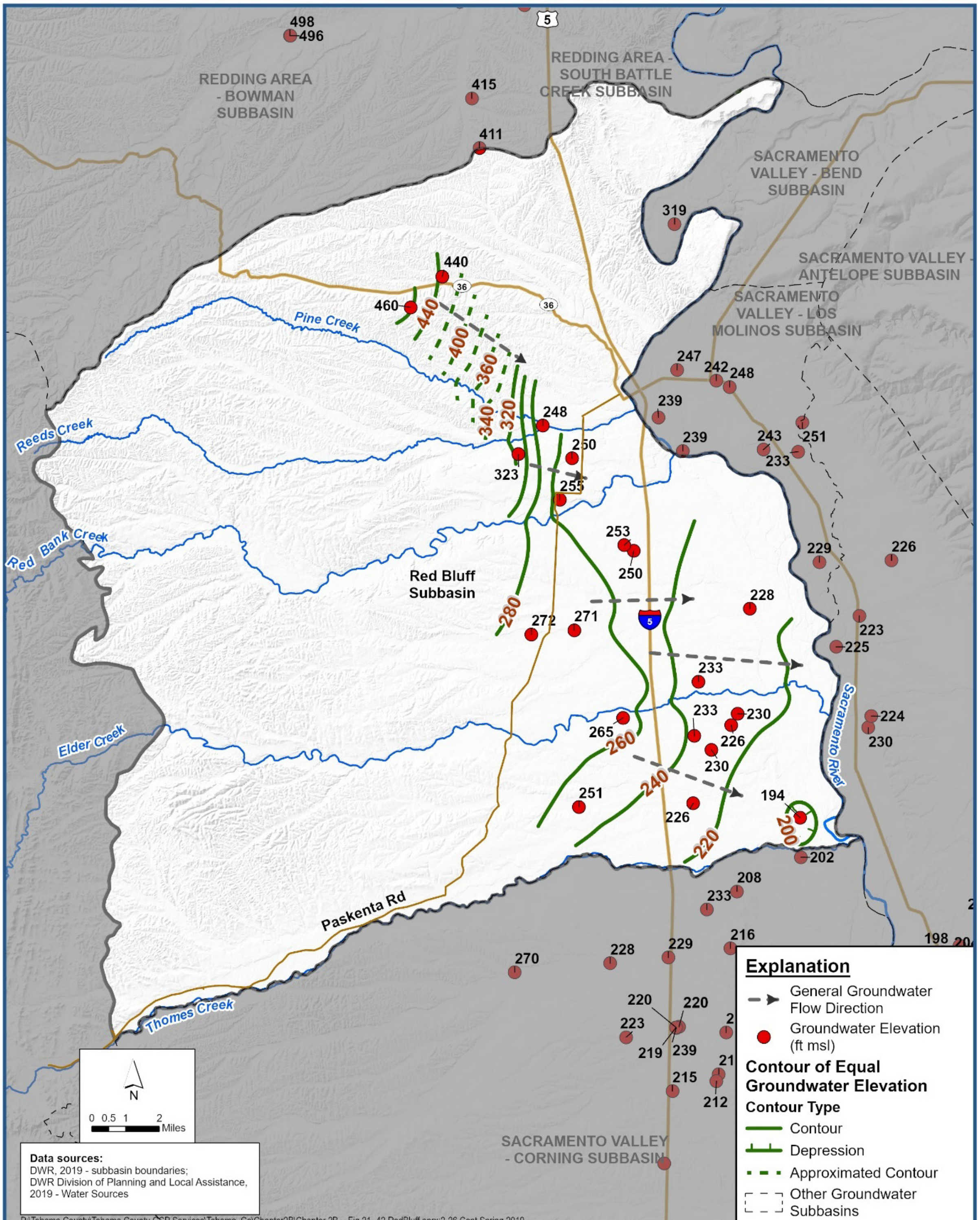
A factor in trends observed in groundwater elevation change is the potential gradual increase of groundwater withdrawal. Even though the actual amount of extracted groundwater from wells is not metered or directly measured, changes in land use and the number of wells constructed over time could be used to indicate an increase in groundwater withdrawal in the Subbasin. Well completion reports obtained from DWR show that approximately 3,080 new wells (all types, domestic, irrigation and public supply) were constructed from 1970 to 1999. Construction continued into the last two decades, 2000-2009 and 2010-2019, with approximately 1,180 and 500 new wells, respectively. The increase of total wells in the Subbasin suggests increased total pumping (withdrawal) contributing to observed declining groundwater level trends. Land use details are presented in Section 2.2.2.1, and water budgets are discussed in detail in Section 2.3.

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

Groundwater elevation contour maps were created to evaluate general groundwater flow directions in 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 those areas of the Subbasin where data was lacking (most areas west of Paskenta Road and north of Beegum Road/Highway 36W). 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 2-40 and 2-41**). 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 2-42 through 2-47**).

Groundwater elevations are highest in the northern and western highland areas of the Subbasin and lowest in the southeastern portion. During a wet year, seasonal high groundwater elevations in the Upper Aquifer range from about 200 ft (in southeast) to 470 ft msl (in north) (**Figure 2-42**). However, during seasonal low conditions (**Figure 2-33**), groundwater elevations in the northern area decrease by five feet to 15 ft at different locations, but in some areas of the southeast the decrease is about 50 ft. In a dry year, groundwater elevations are about 10 ft deeper in the southeastern portion compared to a typical wet year (**Figures 2-44** and **2-45**), but the elevation differences in the other areas of the Subbasin are unnoticeable. Groundwater elevations in a critical year remains nearly similar to elevations of a dry year (**Figure 2-46** and **Figure 2-47**). Water levels in the western portion of the Subbasin are very sparse and limited to measurements at one Upper Aquifer well near the southwestern boundary of the Subbasin since the fall of 2014. Seasonal high groundwater elevations of this well remained between 581 and 586 ft msl, while the seasonal low elevations remained between 570 and 574 ft msl.

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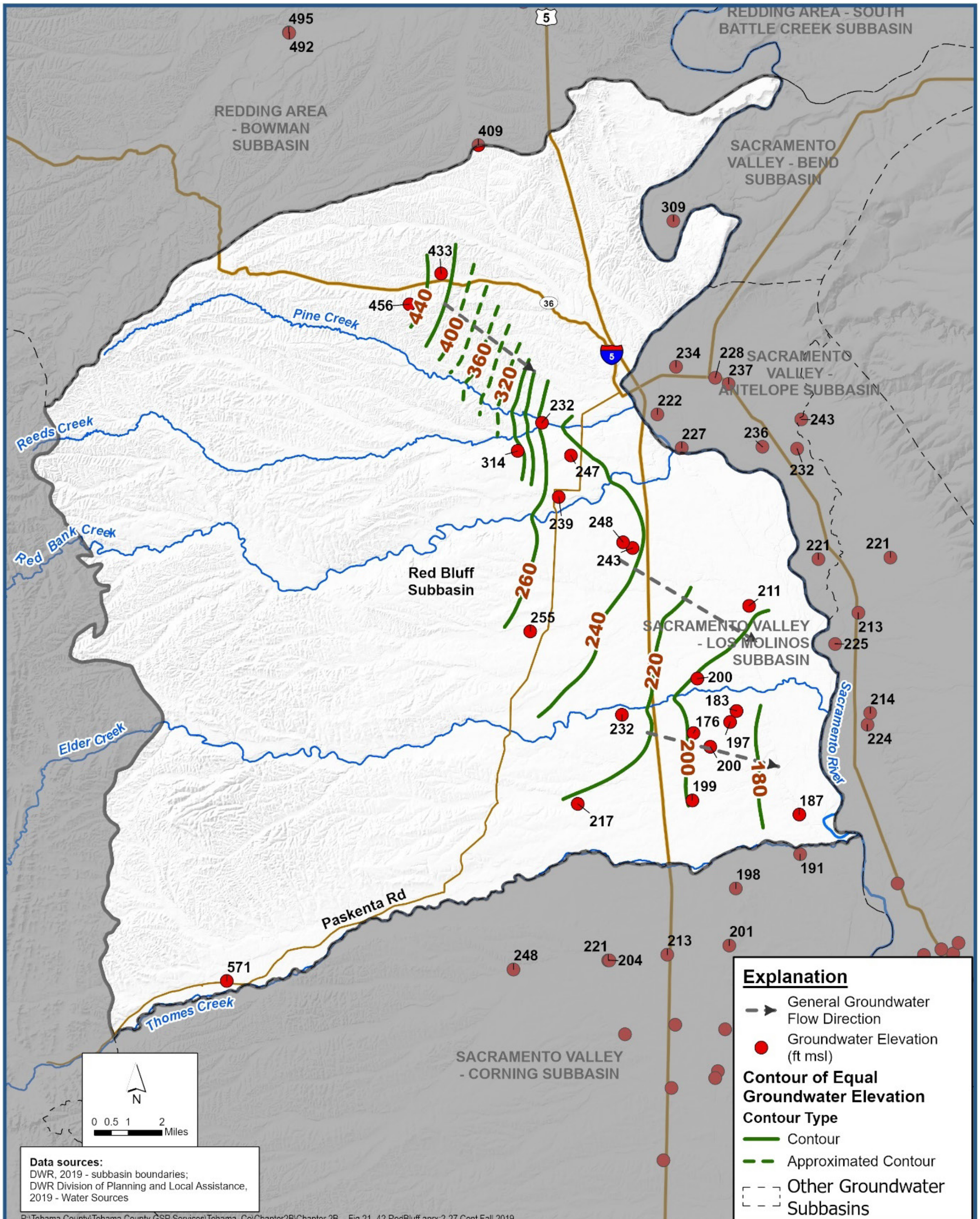
**Contours of Equal Groundwater Elevation, Upper Aquifer - Seasonal High of 2019**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

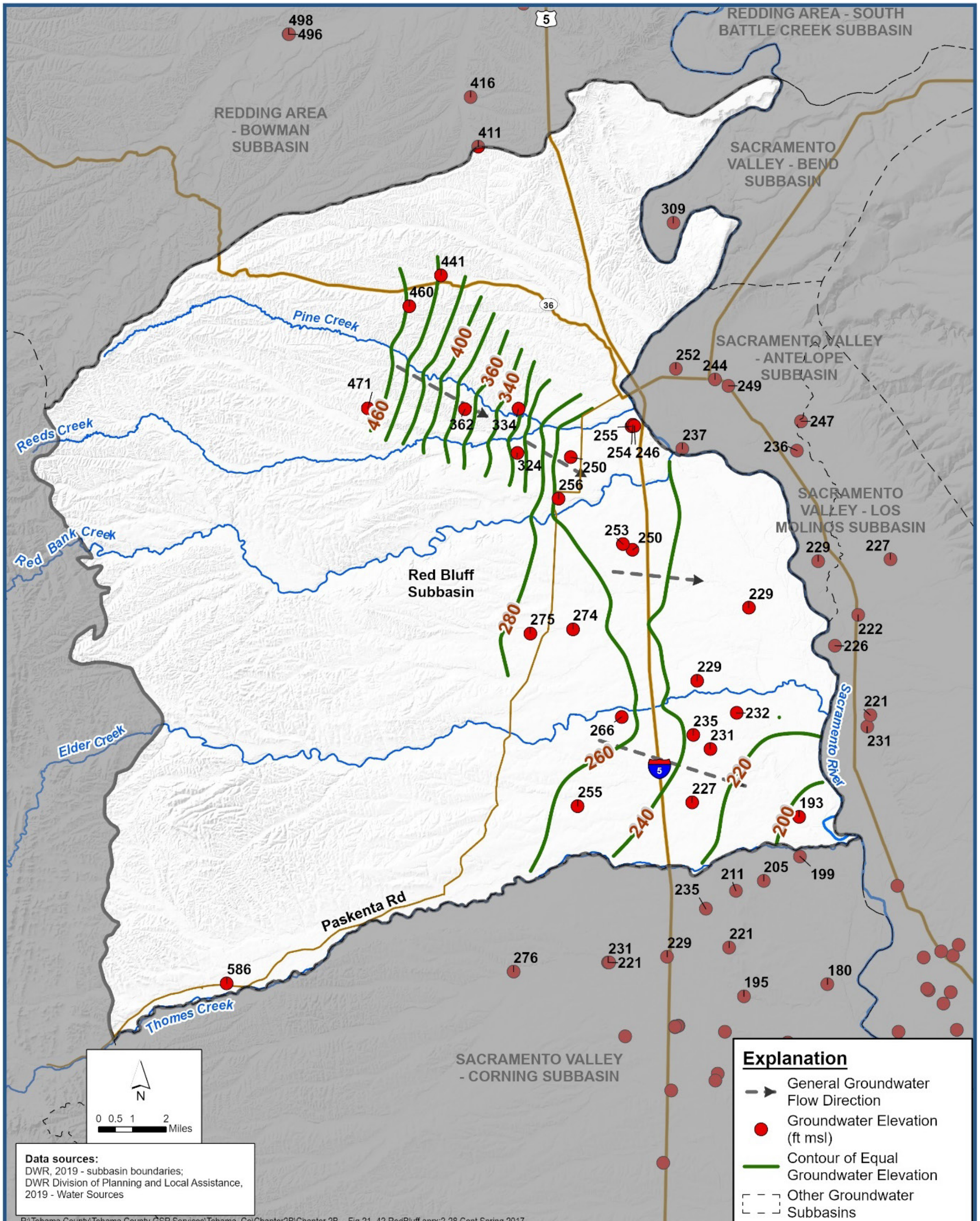
**Figure 2-40**




**Contours of Equal Groundwater Elevation, Upper Aquifer - Seasonal Low of 2019**

*Groundwater Sustainability Plan*
*Bowman Subbasin*

**Figure 2-41**

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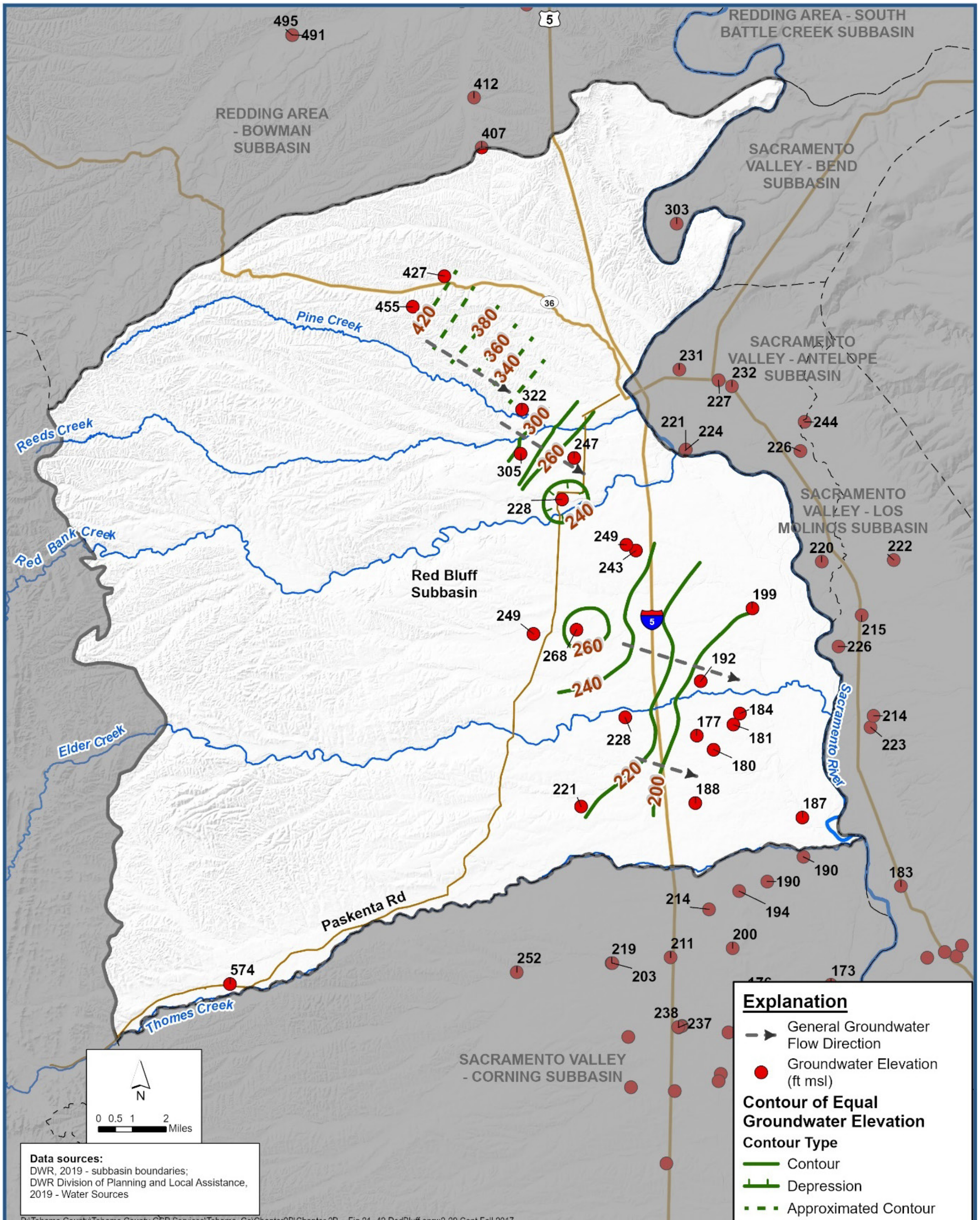
**Contours of Equal Groundwater Elevation, Upper Aquifer - Seasonal High of 2017**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-42**

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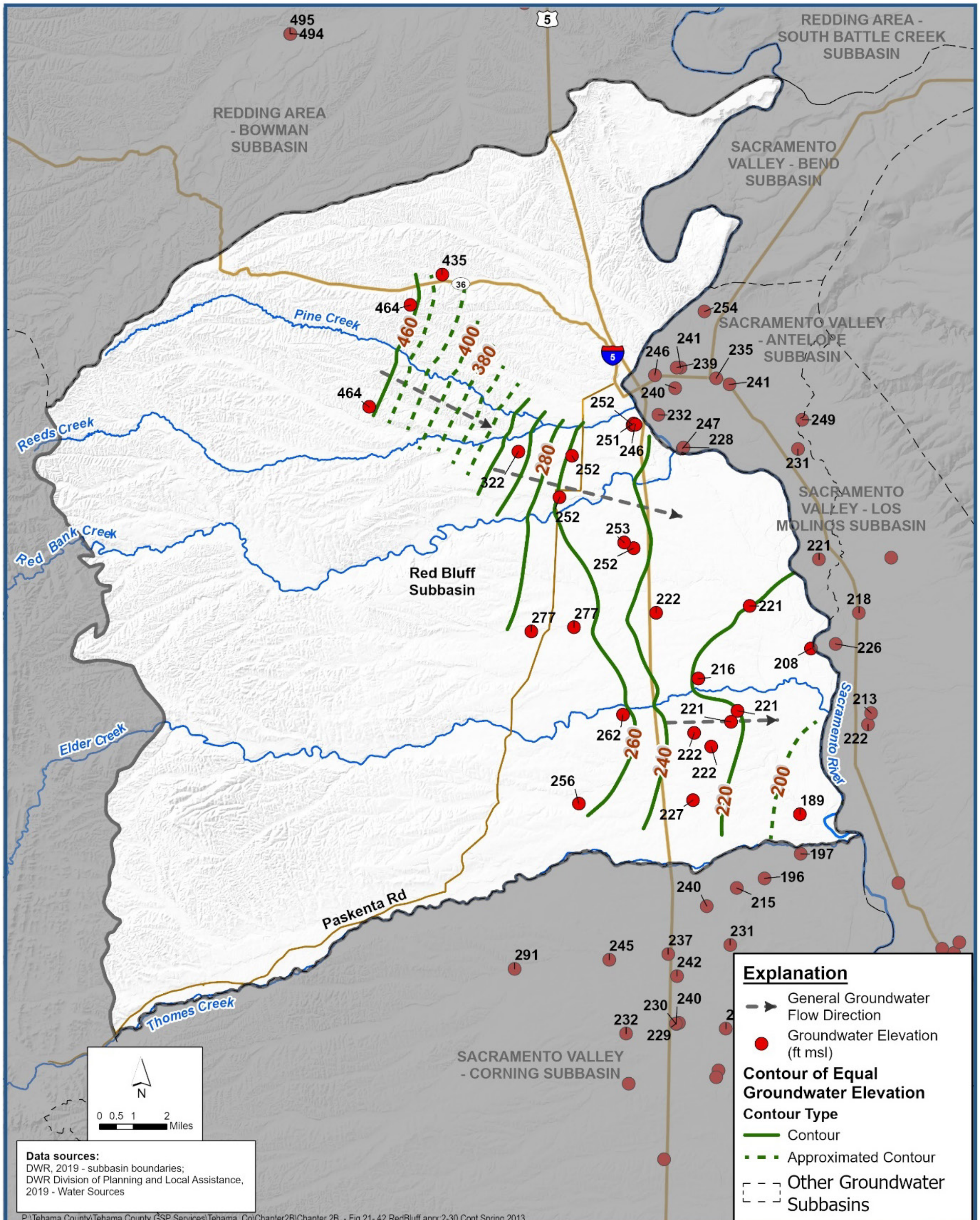
**Contours of Equal Groundwater Elevation, Upper Aquifer - Seasonal Low of 2017**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-43**




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

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-44**

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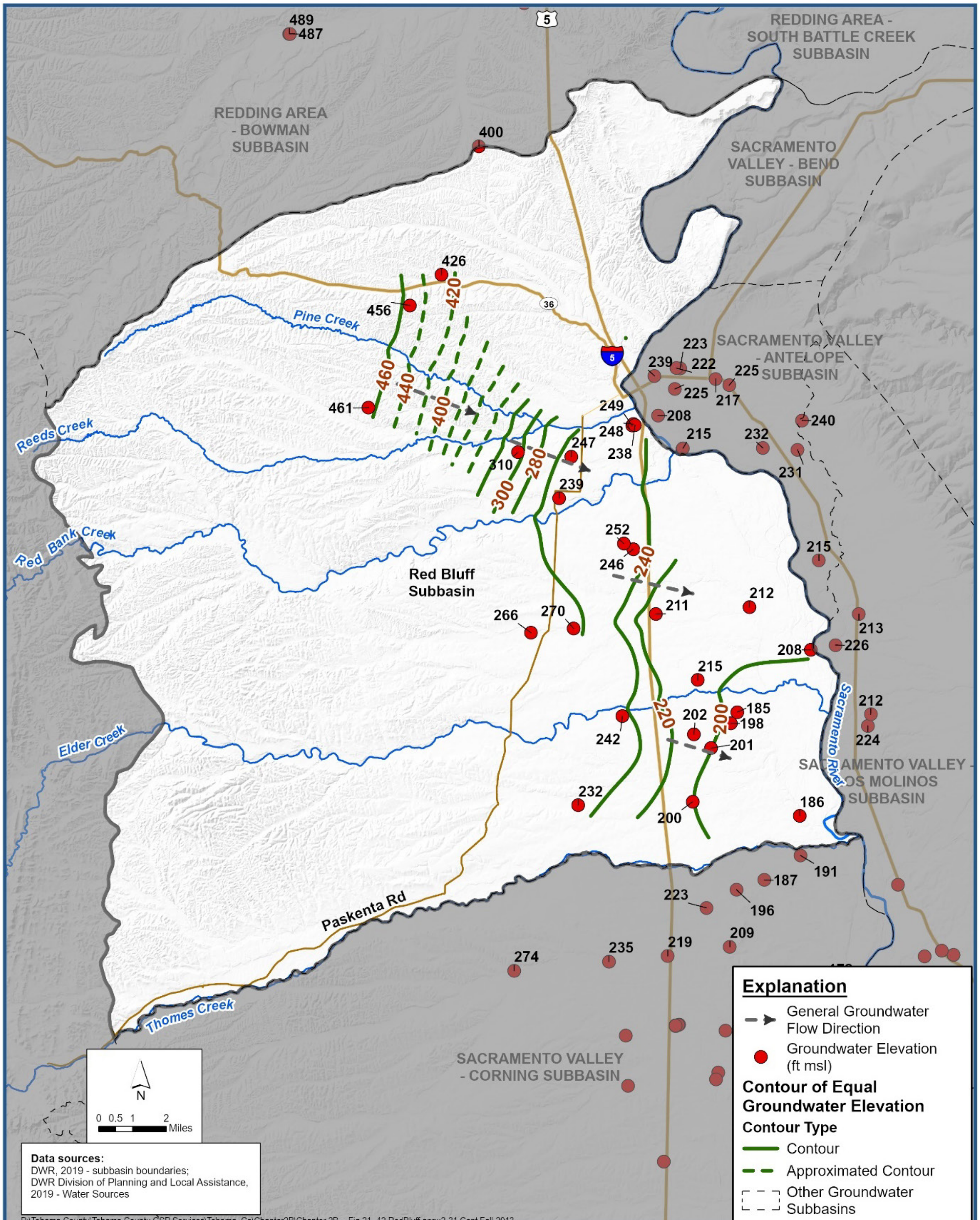


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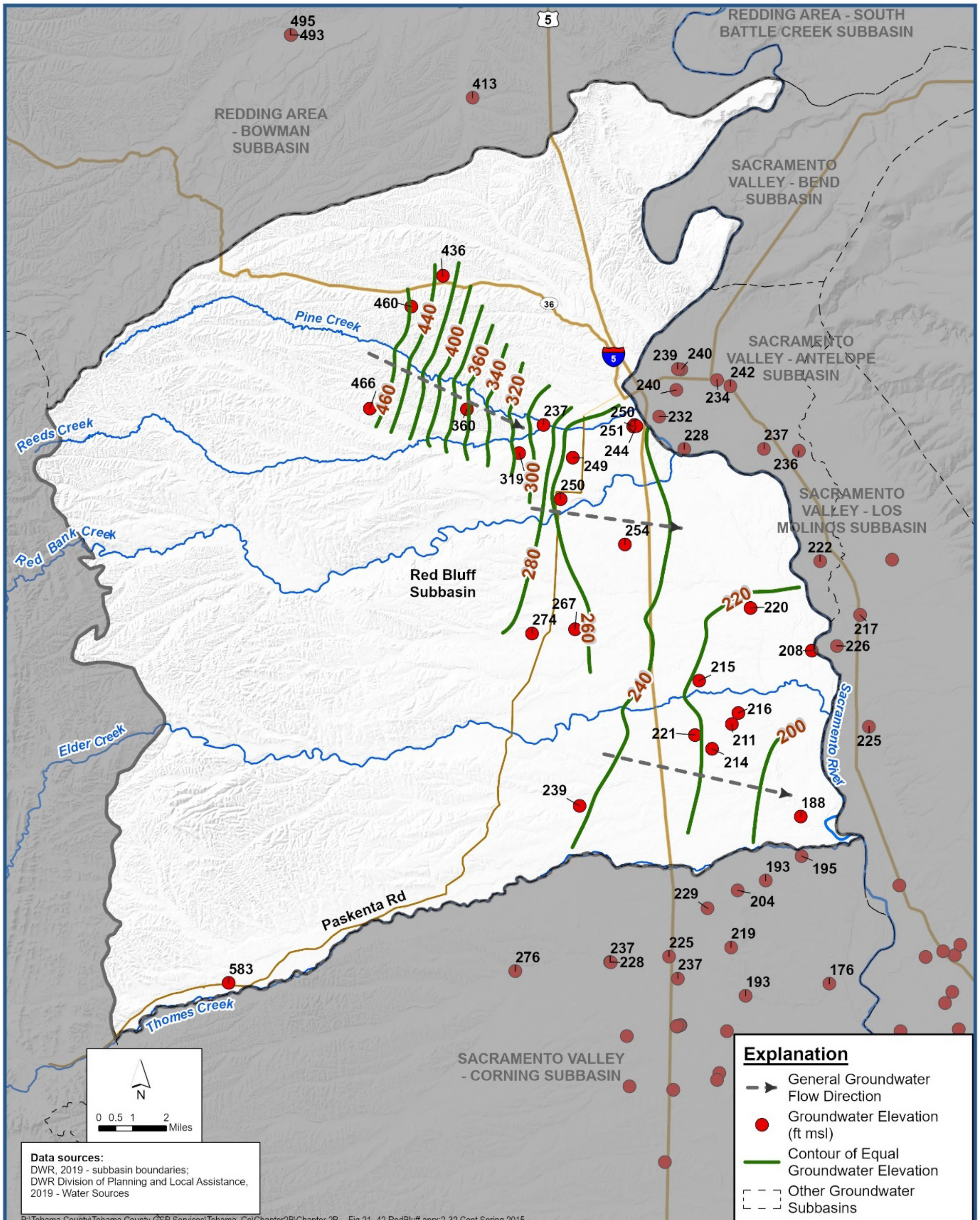
**Contours of Equal Groundwater Elevation, Upper Aquifer - Seasonal Low of 2013**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-45**

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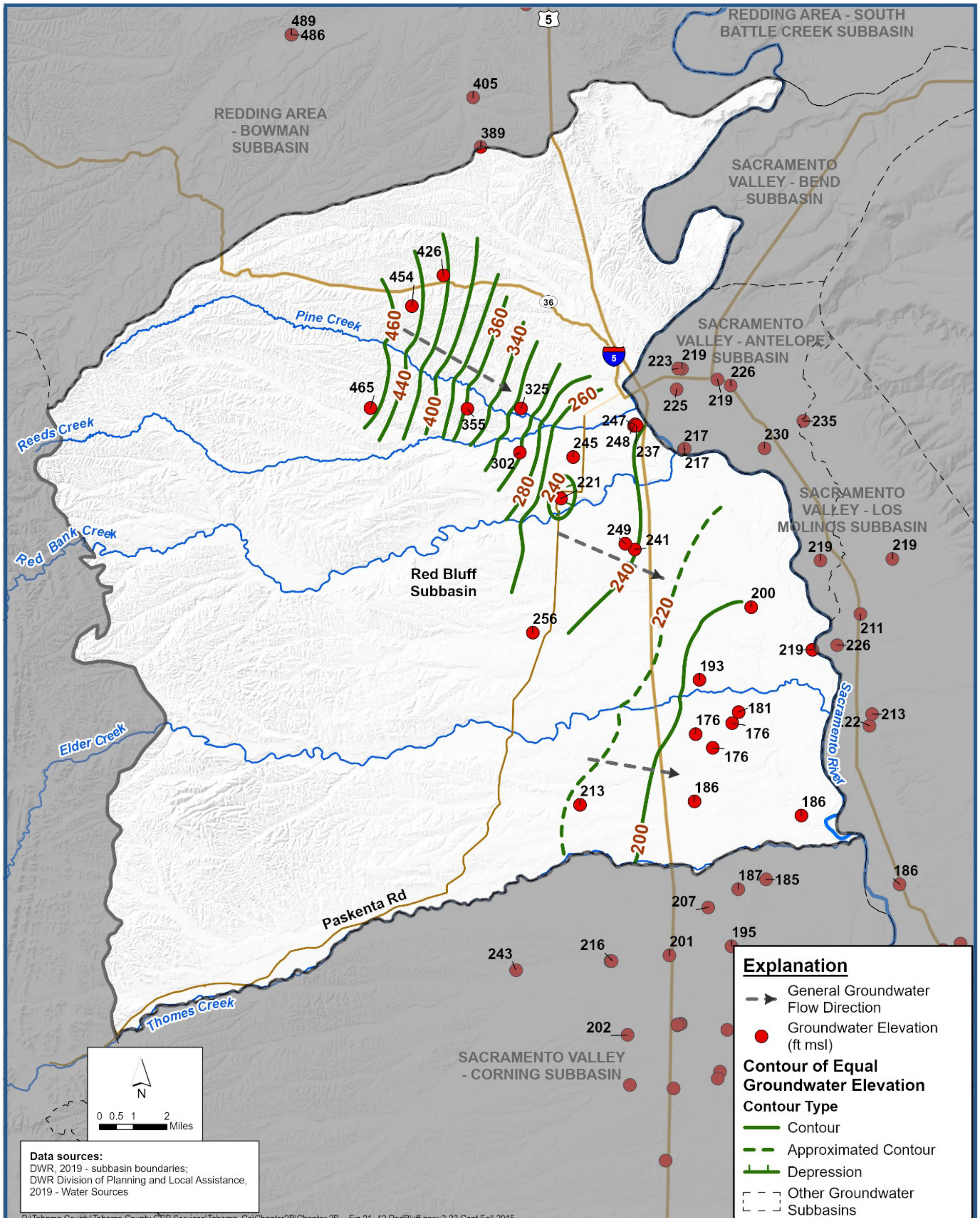
**Contours of Equal Groundwater Elevation, Upper Aquifer - Seasonal High of 2015**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-46**

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

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

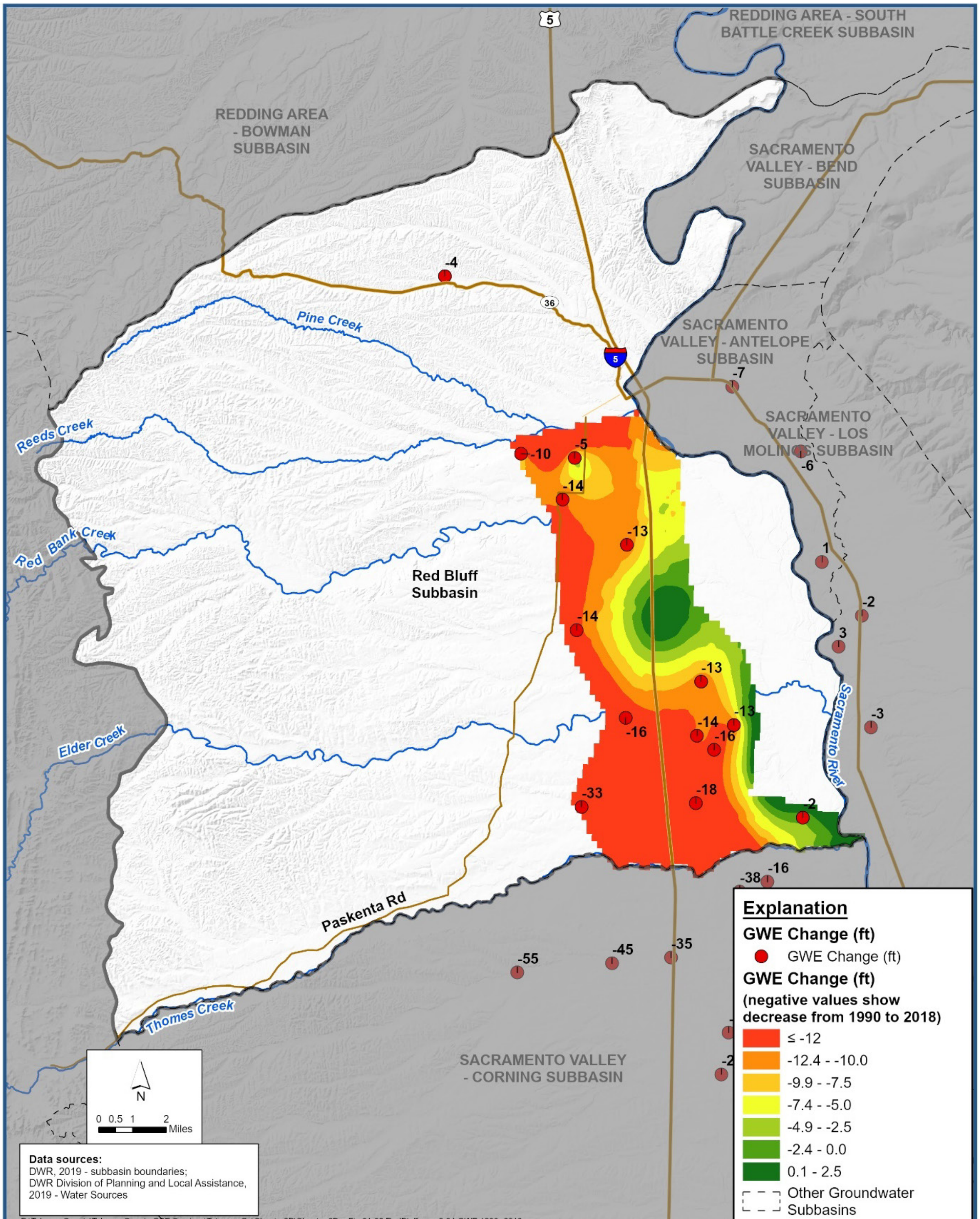
**Figure 2-47**

Groundwater contour maps of the Upper Aquifer indicate an easterly (in areas south of Reeds Creek) and southeasterly (in areas north of Reeds Creek) general flow from the elevated areas of the valley towards the Sacramento River in the valley floor. General groundwater flow directions in the Subbasin are primarily determined by the topography and influenced by local-scale groundwater withdrawal and recharge. Groundwater contour maps also show that the general horizontal hydraulic gradient in the eastern and southeastern areas of the Subbasin (east of Paskenta Road and south of Reeds Creek) increase from the winter/spring to fall within a water year, as well as from a wet year to a dry or critical year. In a wet year, hydraulic gradient in these areas ranges from about 9 to 12 feet per mile (ft/mile) during the winter/spring, and from about 12 to 15 ft/mile during the fall. During a dry or critical year, horizontal gradient ranges from about 10 to 20 ft/mile throughout the year without distinct seasonal changes. Horizontal gradient in the highlands north of Reeds Creek and south of Beegum Road/Highway 36W remain between 30 and 38 ft/mile without distinct variations corresponding to seasons or climatic conditions.

Water level data from nested wells near Gerber indicate a vertically downward hydraulic gradient in the Upper Aquifer ranging between about 0.07 and 0.12 in the winter/spring and between 0.2 and 0.3 in the summer/fall. The direction of vertical hydraulic gradient between the Upper Aquifer and the Lower Aquifer changes; upward gradients up to 0.03 over multi-year periods usually during and after dry climatic conditions, and downward gradients up to 0.01 at other times. The vertical gradient within the Lower Aquifer typically remained downward (up to 0.02) during the winter/spring, and upward (between 0.02 and 0.07) during the summer/fall.

#### 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 for 1990 and 2018 were separately created by interpolating available water levels in each year; the difference between these two surfaces (**Figure 2-48)**, 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 southeastern portion of the Subbasin shown in **Figure 2-48**. Between 1990 and 2018, groundwater elevations decreased by approximately 13 ft in this part of the Subbasin (mainly areas east of Paskenta Road, west of Tehama Colusa Canal and south of Reeds Creek. The area where groundwater elevation change was estimated is approximately 40,200 acres, which is about 15% of the Subbasin area. However, this area includes about 54% of all irrigated lands in the Subbasin (2018 land use data). The change of groundwater elevations corresponds to a decrease of approximately 41,000 acre-feet of groundwater in the Upper Aquifer of this area, using the volume between the two groundwater surfaces and a specific yield of 0.079 (DWR, 2004). The specific year-to-year historical groundwater storage changes are also estimated using a surface water-groundwater flow model discussed in the Chapter 2C.

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**Change of Groundwater Elevation from Spring 1990 to Spring 2018**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-48**

### 2.2.2.3. Groundwater Quality

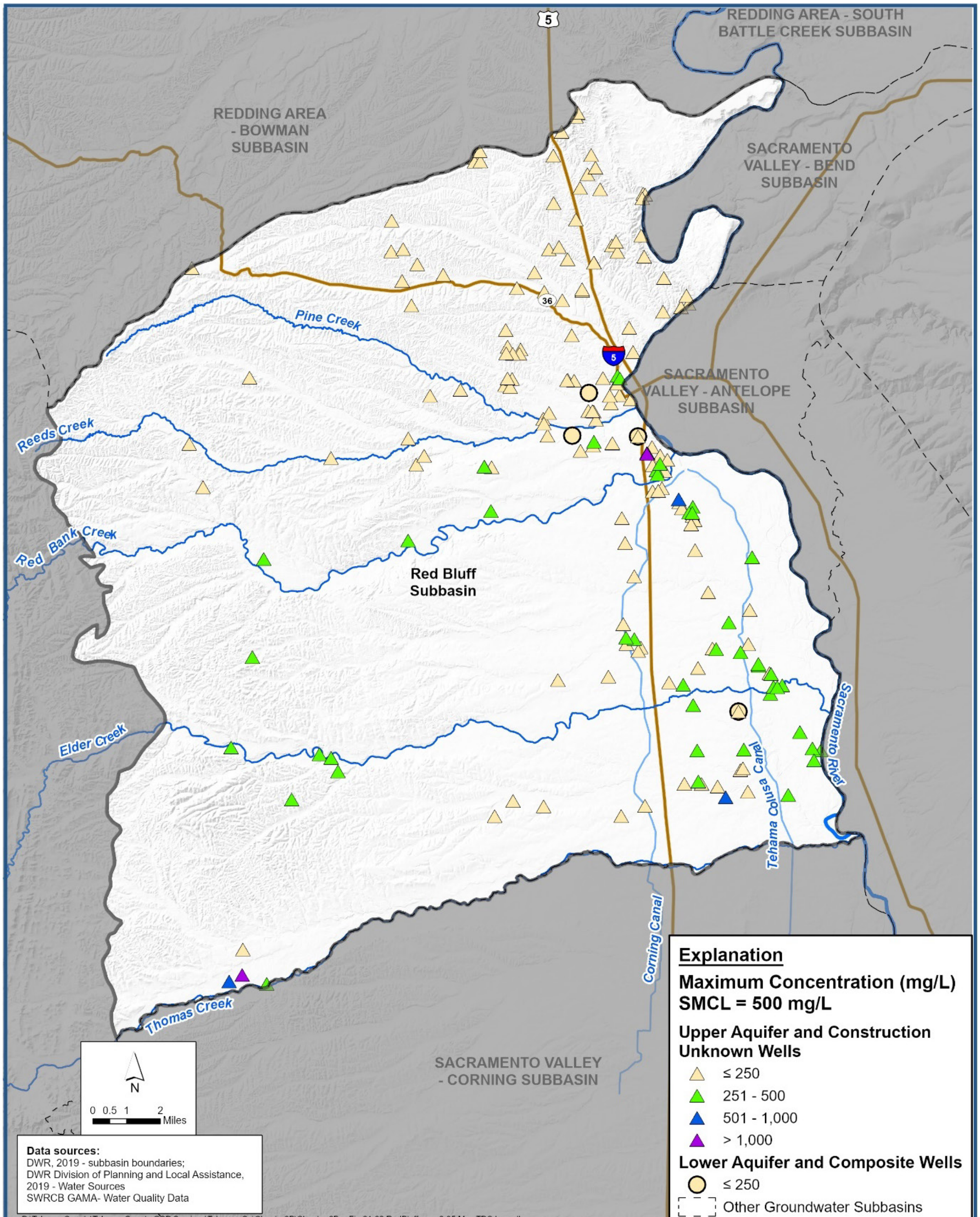
The evaluation of groundwater quality in the Subbasin included a literature review (e.g., Bennett et al., 2011; DWR, 2020; SWRCB, 2009 and Tehama County FCWCD, 2012) and evaluation of groundwater quality data collected from SWRCB GeoTracker and GeoTracker GAMA databases. SWRCB GeoTracker database identifies eight currently open groundwater clean-up sites within the Subbasin (shown in **Figure 2-12** in Chapter 2.1). Five of these sites, including three land disposal sites that are currently being monitored, are not currently in operation. The other three sites are currently being monitored and/or undergoing remedial actions. Occurrence of synthetic organic compounds and volatile organic compounds associated with industrial products and pesticides, as well as chemicals associated with disinfectant byproducts at concentrations higher than their Maximum Contaminant Levels (MCL), 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, arsenic, iron, and manganese concentrations in the Subbasin.

#### Total Dissolved Solid (TDS)

The occurrence of Total Dissolved Solids (TDS) at undesirable concentrations is not a concern at present. Long term TDS records show temporal fluctuations within narrow ranges without any noticeable trend. A total of 799 groundwater samples were tested for TDS since 1952; only 12 sample results exceeded the Secondary Maximum Contaminant Level of 500 milligrams per liter (mg/L). These 12 samples were collected from six Upper Aquifer wells: one sample in 2018 and all others between 2003 and 2008 (**Figure 2-49**). TDS concentrations of 22 samples collected from eight Lower Aquifer and composite (screened in both Upper Aquifer and Lower Aquifer) wells since 1989 have not exceeded 250 mg/L.

#### Nitrate

Occurrence of nitrate (nitrate, expressed as nitrogen) concentrations that exceed the Maximum Contaminant Level (MCL) of 10 mg/L is not widespread in the Subbasin. Results of 88 of 2,698 samples tested since 1952 exceeded the MCL. Samples exceeding the MCL were collected from 11 of the 322 tested wells. These 11 wells are predominantly (10 of 11) about five miles south from the City of Red Bluff (**Figure 2-50**); however, construction details are only known for three wells (Upper Aquifer). Test results of a municipal well in this area (Well 5200525-001) show a trend of decreasing nitrate concertation since 2009 without distinct seasonal fluctuations (**Appendix 2-G**). However, results from another municipal well (well 5200655-001) show an increasing trend of nitrate concentrations, as well as substantial seasonal fluctuations (concentrations over 10 mg/L in the summer and below 5 mg/L in the winter/spring). Elevated levels of nitrate in drinking water pose a serious health risk for infants. Potential sources of nitrate in the Subbasin include sewage disposal systems and fertilizer used in agriculture.

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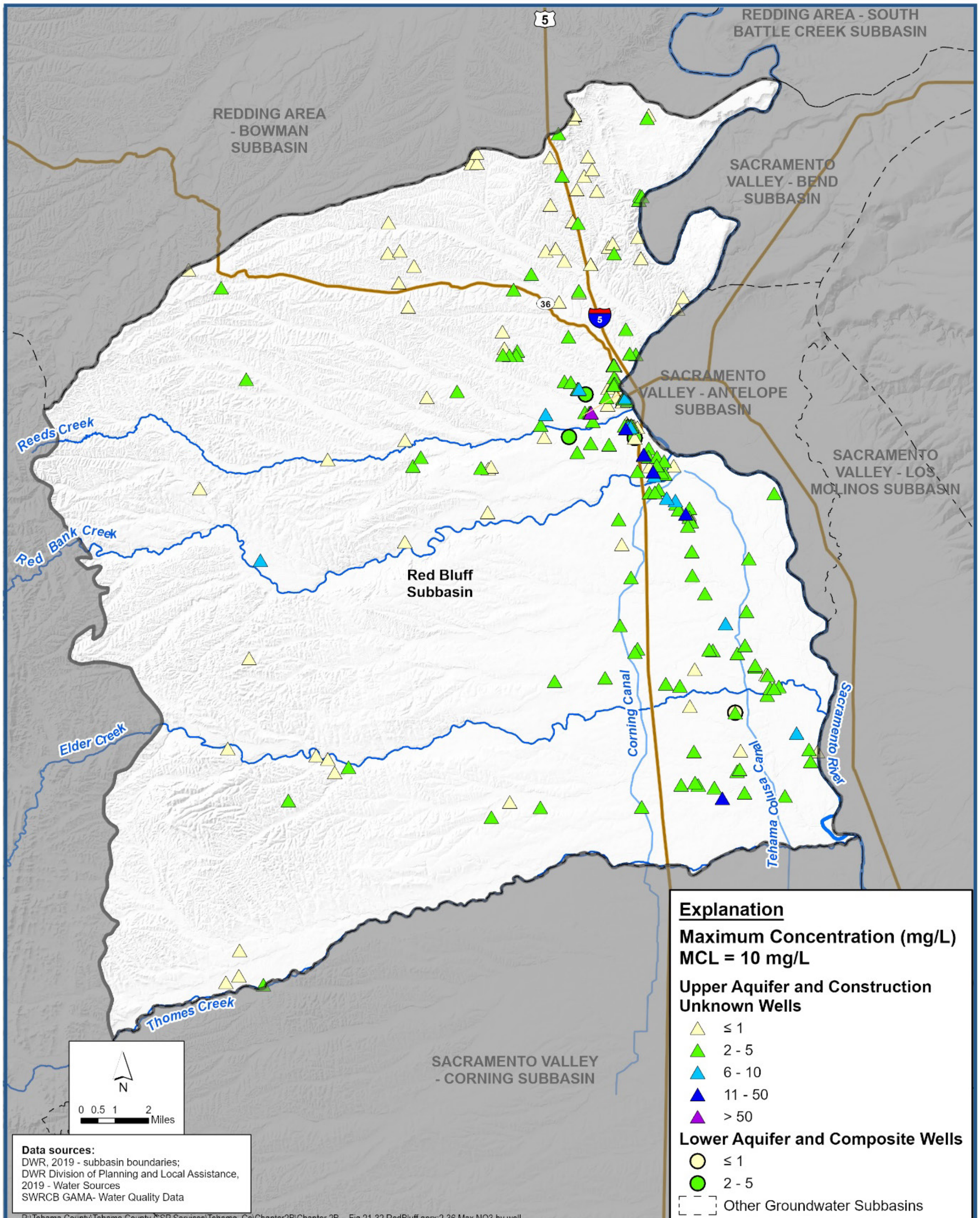
**Maximum Historical TDS Concentration by Well**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-49**




**Maximum Historical Nitrate Concentration by Well**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-50**

### Arsenic

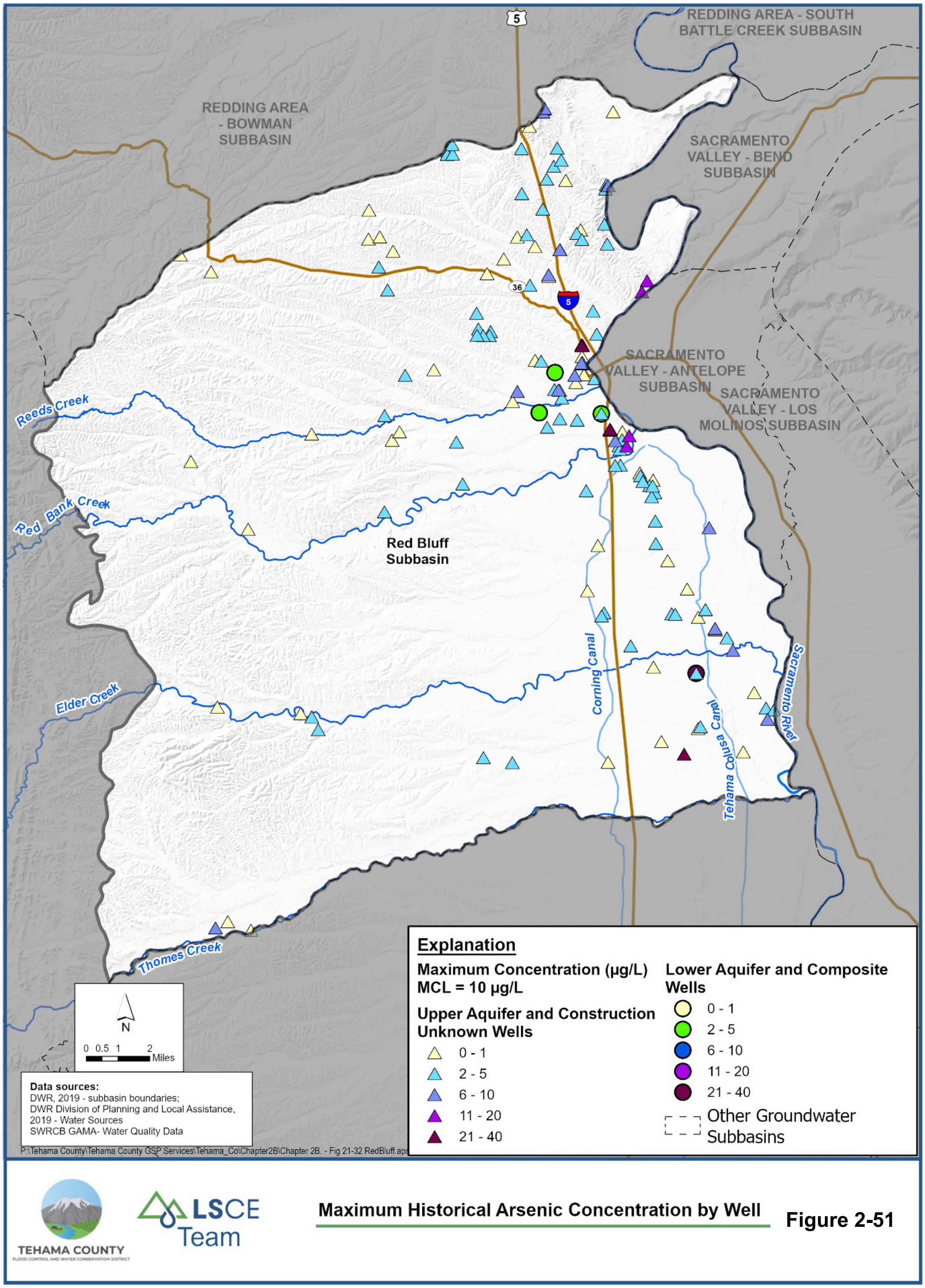
The occurrence of arsenic at concentrations exceeding the MCL of 10 micrograms per liter (µg/L) is not a widespread groundwater quality concern in the Subbasin, however there are several wells with test results exceeding the MCL. Since 1956, 642 samples collected from 2,020 wells were tested and only 30 samples from 15 wells exceeded the MCL (**Figure 2-51)**. All five samples from two nested wells screened in the Lower Aquifer (25N03W11B002M and 25N03W11B003M) close to Gerber have arsenic concentrations between 10.6 and 28.9 µg/L (sampled between 2005 and 2015). Five of eight test results (sampled between 2003 and 2007) of an Upper Aquifer municipal well located about three miles south from these two wells exceeded the MCL, with four values between 31 and 36 µg/L. However, no identifiable trend can be determined from any well based on analysis of timeseries data (**Appendix 2-G**). Arsenic is a naturally occurring chemical that originates from volcanic rocks of the Tuscan formation (Tehama County FCWCD, 2012).

### Iron and Manganese

Groundwater samples with iron and manganese concentrations that exceed the Secondary Maximum Contaminant Level of each chemical (SMCL) are common in the Subbasin. Exceedances of SMCL values do not present a risk to human health but may indicate aesthetic conditions like taste, color, or odor. A total of 719 samples were tested for iron since 1959 and 174 sample results exceeded the SMCL of 300 µg/L. A total of 1,125 samples were tested for manganese since 1956 and 570 sample results exceeded the SMCL of 50 µg/L. About 35% of wells tested for iron (83 of 238) and 26% of wells tested for manganese (64 of 245) have exceeded the corresponding SMCL at least once. All samples with above-SMCL concentrations are from Upper Aquifer wells and wells without construction details. Iron and manganese in groundwater may originate from weathering of minerals in rocks (Tehama County FCWCD, 2012). High concentrations of iron and manganese also can be an artifact of steel well casings; therefore, these test results may not accurately represent the ambient concentrations in groundwater (DWR, 2020).

## 2.2.2.4. Seawater Intrusion

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




Maximum Historical Arsenic Concentration by Well

Figure 2-51

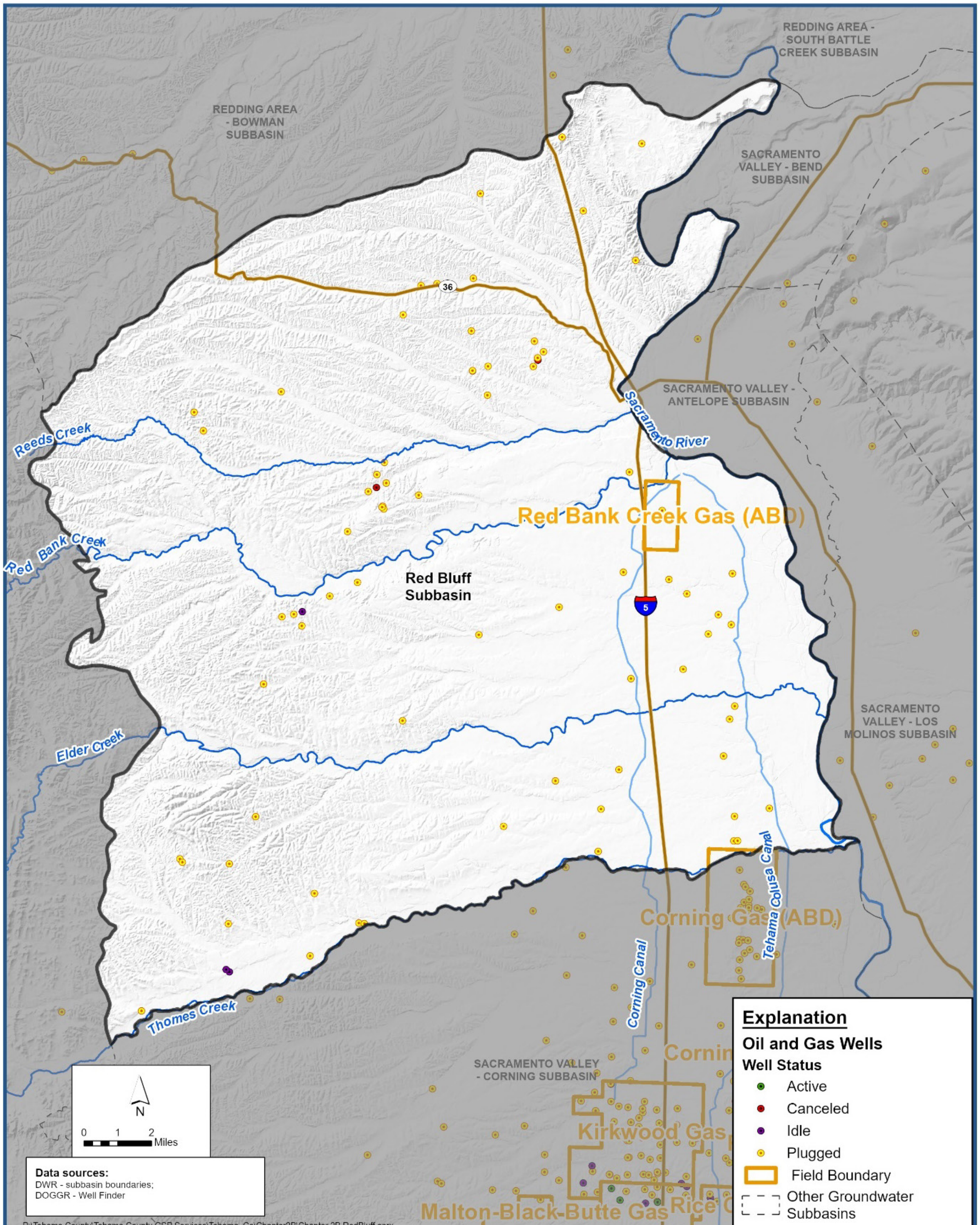
### 2.2.2.5. Subsurface Compaction and Land Subsidence

Red Bluff 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 2-52**). Subsidence monitoring in the Subbasin is available from three main surveys conducted by DWR and UNAVCO. The subsidence measured in these studies is likely elastic, meaning the land surface can recover (rise) if groundwater is recharged and again fills the pore spaces. Negative subsidence measurements indicate a downward vertical movement of the land surface and positive values indicate an upward movement.

In 2018 DWR released a report on land subsidence from 2008-2017 using Global Positioning systems (GPS) survey methods. In 2008, DWR contracted the installation of a series of survey monuments across 11 counties; 11 survey monuments are within the Subbasin boundaries (**Figure 2-53**). 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 -0.095 ft at the station near I-5 and Oat Creek to -0.027 ft at the station near Elder Creek and the Sacramento River (**Figure 2-53**). On average, subsidence in the Subbasin was -0.0061 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 2-54**). Maximum vertical displacement measured using the InSAR approach from July 2015 to June 2019 was <-0.15 ft in the Subbasin over the entire period of study (**Figure 2-54**).

Between 2003 and 2008, UNAVCO installed GPS survey stations to record lateral and vertical land surface movement as part of their Plate Boundary Observatory (PBO) project. The GPS stations for the PBO record movement on a centimeter to millimeter scale. There is one PBO monitoring station within the Subbasin (P345) (**Figure 2-55**). Since recording at P345 began in 2005, there has been an overall decrease in ground surface elevation of approximately 0.1 ft. On average, in the last 14 years, ground surface elevation decreased 0.007 ft/yr at station P354. This station recorded large fluctuations (>-0.2 ft) between 2006 and 2009. These measurements are questionable and likely not representative of subsidence in those years.

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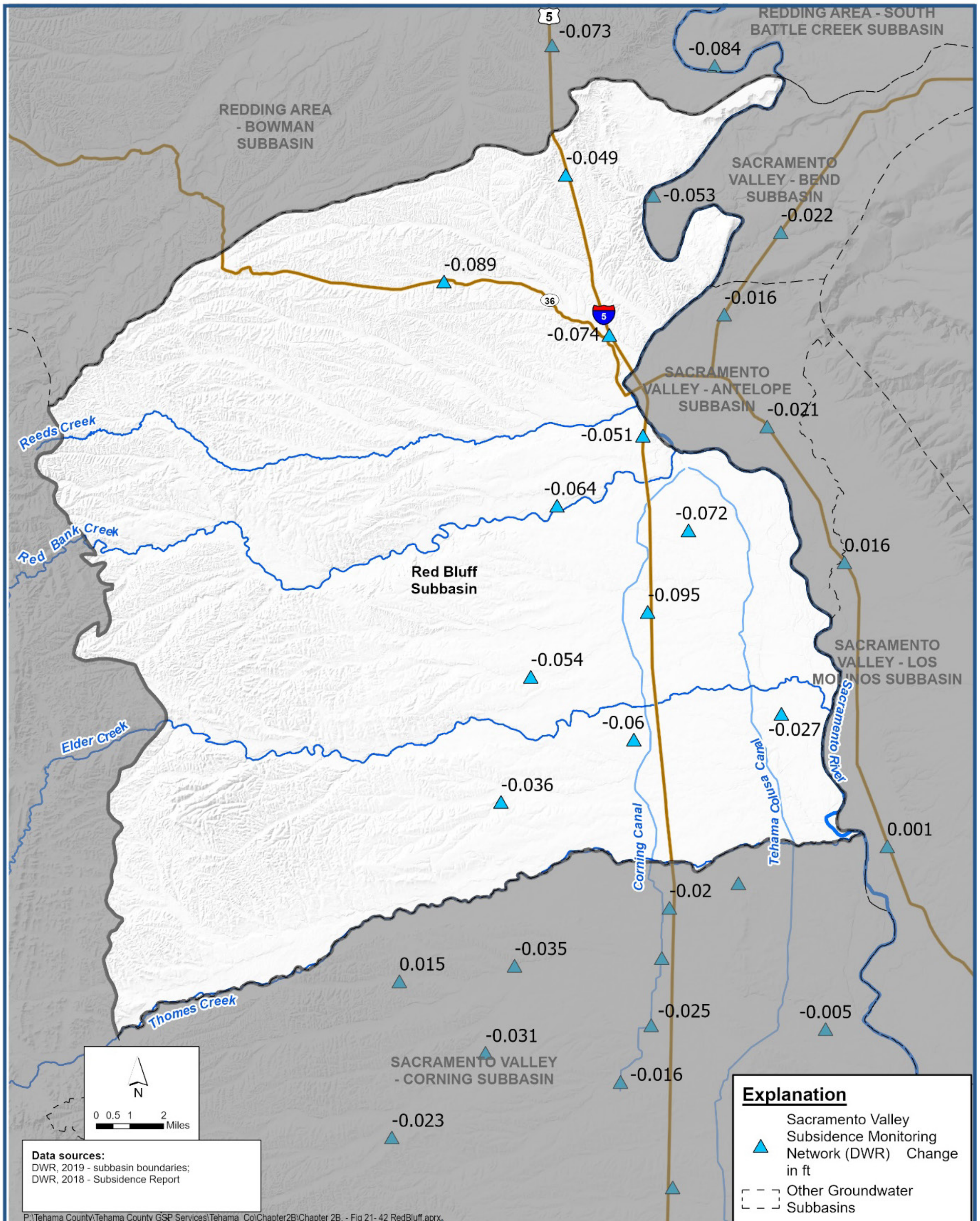
**Map of Oil and Gas Fields and Wells**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

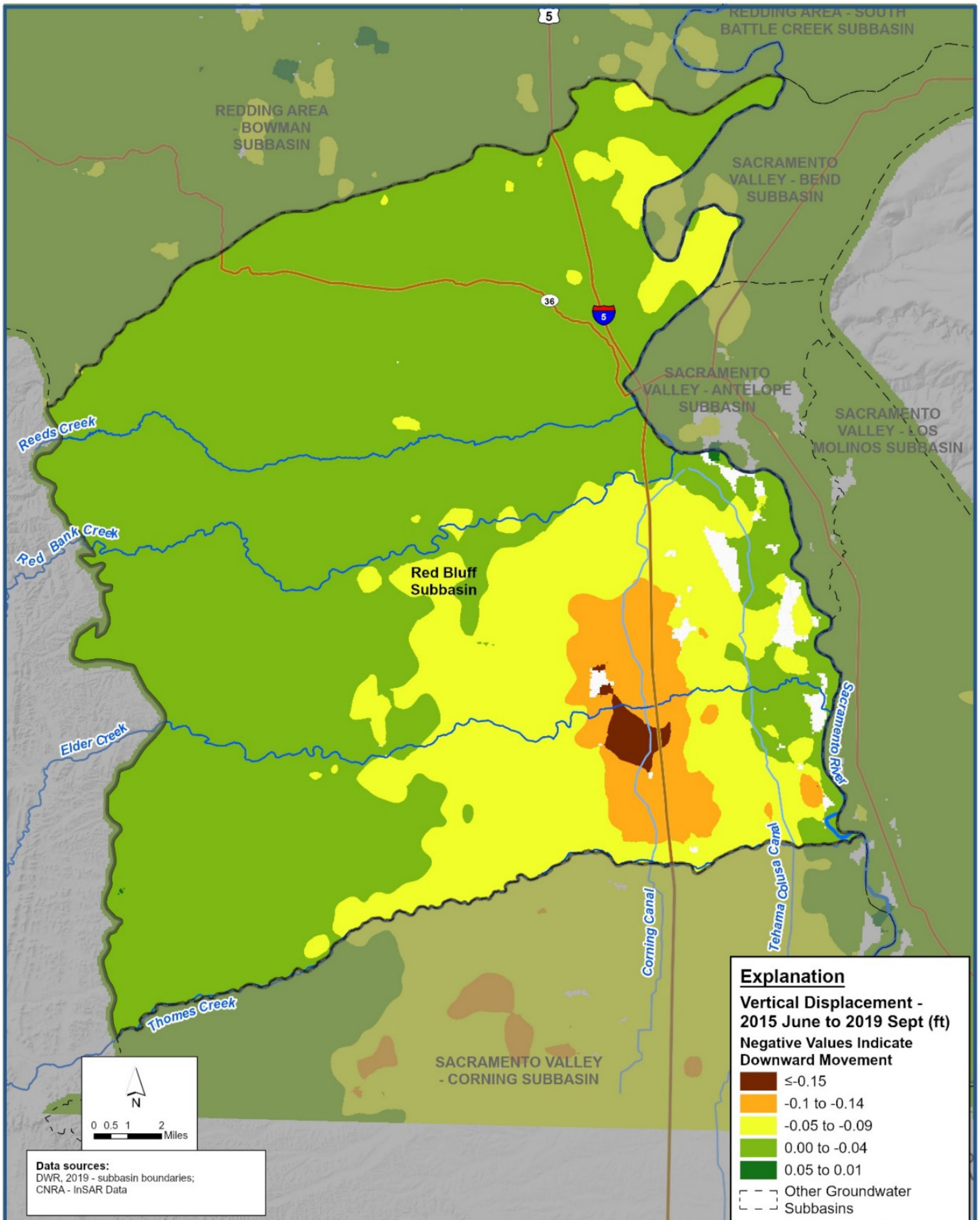
**Figure 2-52**




**Subsidence Measurements Between 2008 and 2017**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

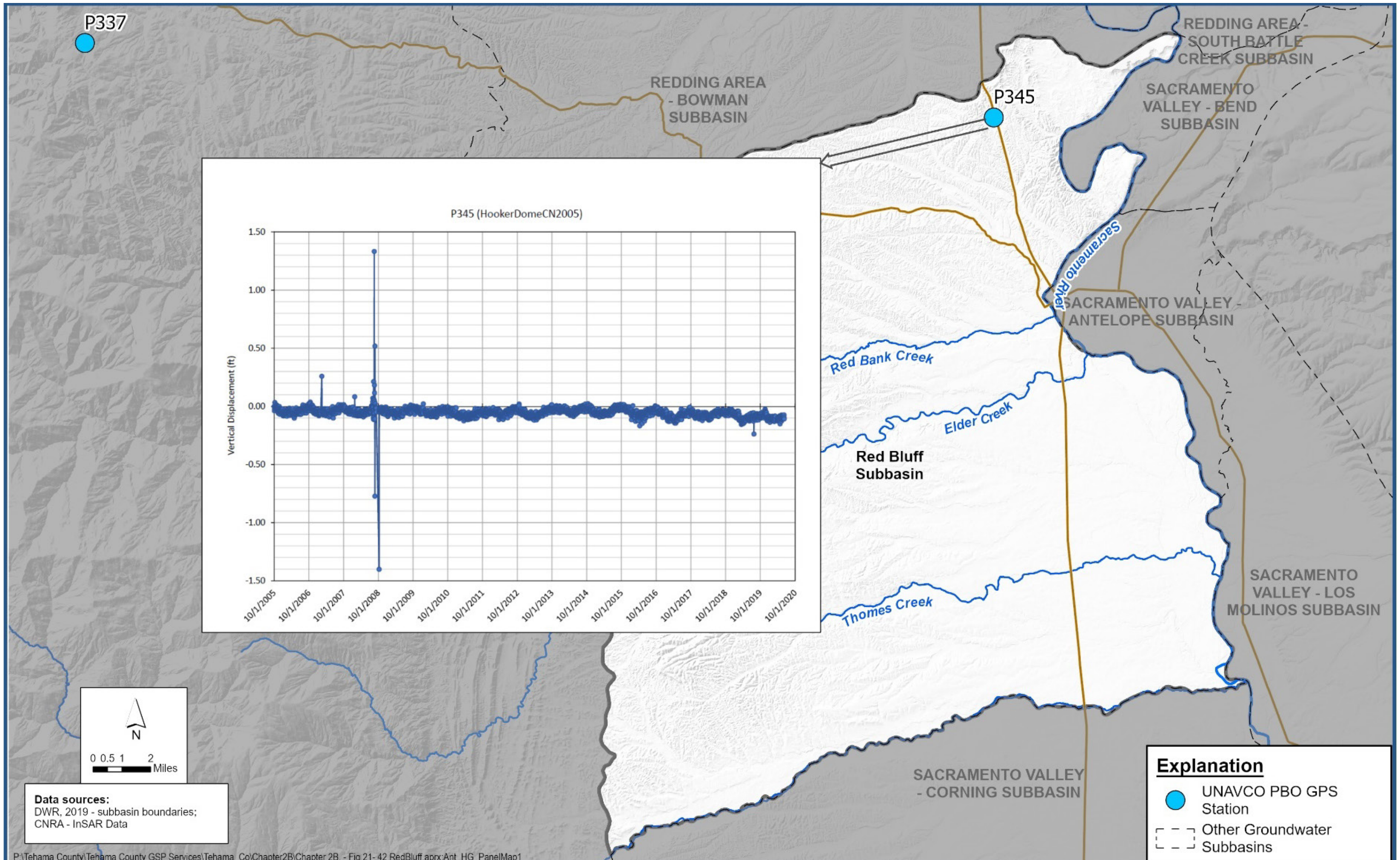
**Figure 2-53**




**DWR InSAR Subsidence Map**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-54**

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**UNAVCO PBO GPS Measurements**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-55**

#### 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, Thomes Creek, Elder Creek, Oat Creek, Red Bank Creek, Reeds Creek, and Pine Creek are the main surface water features. The Sacramento River and Thomes Creek flow throughout the year (perennial), but Elder Creek, Oat Creek, Red Bank Creek, Reeds Creek and Pine Creek flow seasonally. Only the Sacramento River has active stream gages within the Subbasin (**Figure 2-35**). Thomes Creek and Elder Creek have currently active gaging stations just to the west of the Subbasin boundary (**Figure 2-35**).

The Sacramento River has three currently active gaging stations close to the Subbasin; USGS/USBR station #11377100 at Bend Bridge (BND), USBR station at Red Bluff Diversion Dam (RDB), and DWR station at Tehama Bridge (TEH). USGS/USBR station #11377100 (BND) is located about a mile downstream of the northern boundary of the Subbasin (**Figure 2-35**) with a daily record since 1963. Historical data from BND shows a mean annual flow rate of 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). Station RDB is located at the eastern boundary of the Subbasin (**Figure 2-35**) and TEH is located about three miles upstream from the southern boundary of the Subbasin. Stations RDB and TEH are only equipped with stage sensors and only directly measure stage; however, CDEC's website presents flow data (assumed to be calculated from stage).

Flow of Thomes Creek is currently measured at Paskenta (station THO operated by DWR) about a mile upstream of the western boundary of the Subbasin. The mean annual flow rate is about 300 CFS according to flow records from THO (1997 to 2020) and historical data of currently inactive USGS station # 11382090 located close to THO (1921 to 1996). In general, the flow is highest in January and February (mean of over 700 CFS), and it is lowest in August and September (mean of less than 10 CFS). Based on historical data from USGS station #11382090 (located approximately 7 miles west of the Sacramento River; 1978 to 1980) the mean annual flow rate is about 389 CFS, with highest flow in January and February (mean of about 1,210 CFS), and typically no flow from July through September.

Flow of the Elder Creek has been measured since 1949 at USGS station #11379500 located about a mile upstream of the western boundary of the Subbasin. The mean annual flow rate of is about 170 CFS, with highest flows in January and February (mean of about 250 CFS), and the lowest flows in August and September (mean of about 3 CFS). Additional historical data for Elder Creek is available from two USGS stations. Station #11380000 located approximately 9 miles west of the Sacramento River, with available historical data from 1931 to 1941 has a mean annual flow rate of about 106 CFS, with highest flow in February and March (mean of about 291 CFS), and mostly no flow from July to October. Station #11380500 located approximately 3 miles west of the Sacramento River, (historical data from 1950 to 1969) has a mean annual flow rate of about 110 CFS, with highest flow in January and February (mean of about 326 CFS), and mostly no flow from July to October.

Red Bank Creek was measured at a USGS station about eight miles downstream of the western boundary of the Subbasin (#11378800) (1960 to 1982) with a mean annual flow rate of about 70 CFS, with highest flow in January (mean of about 180 CFS), and mostly no flow from July to October. Additional historical flow data of Red Bank Creek (1965 to 1967) are available from a USGS station approximately two miles upstream from where Red Bank Creek enters the Sacramento River (#11378860). The mean annual flow at this location is about 64 CFS, with highest flow in January (mean of about 285 CFS), and typically no flow from July to October.

#### *2.2.2.6.1. Interconnected Surface Water Systems*

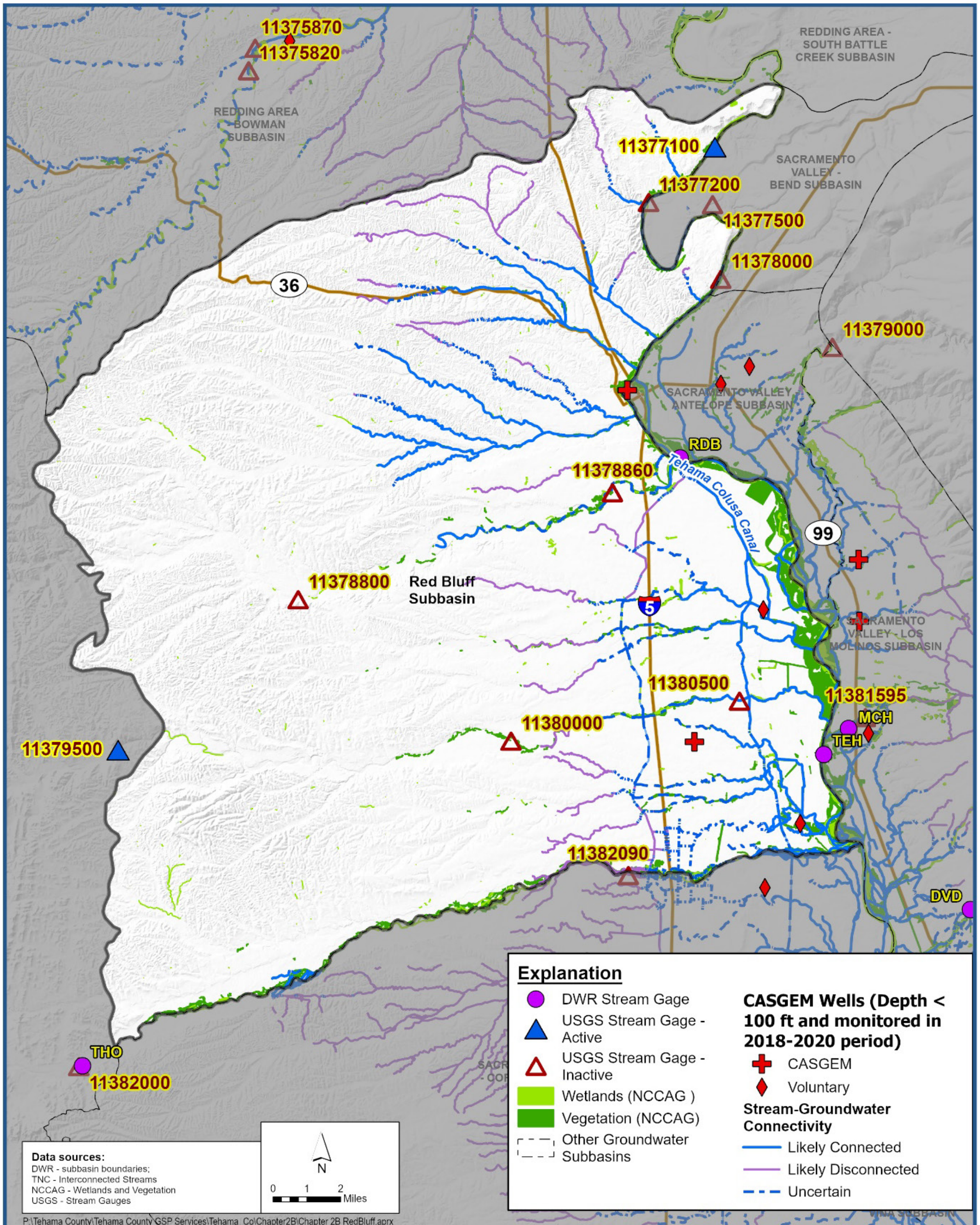
Characterizing the connectivity of the surface water systems in the Subbasin is challenging due to the limited data. Modeling surface water and groundwater interaction will also be a means to address the connectivity and is discussed in chapter 2.3. When a stream stage is higher than that of the groundwater table the stream will lose water to the ground via infiltration of water through the streambed (losing conditions). If losing conditions are present but the depth of the water table is too deep, the stream is considered losing and disconnected. Losing conditions with groundwater just below the stream are connected. When the water table elevation is higher than the stream stage, groundwater will infiltrate into the stream causing the stream to gain water (gaining conditions). Groundwater and surface water are always connected under gaining conditions. 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 2-56**). As discussed in section 2.2.2.6, USGS station #11377100 (BND), DWR station RDB, and DWR station TEH are the only currently active sources 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 two miles away from TEH. Of the several inactive gages one has an overlapping record with a well on a tributary of the Sacramento River **Table 2-10**. Installation of shallow monitor wells near currently active gage stations would help to characterize the interconnectivity of the Sacramento River and the groundwater in the Subbasin.

**Figure 2-56** 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. Details of the Stream Gage and Well with Overlapping Historical Record Periods**

| STREAM GAGE | | | GROUNDWATER MONITORING WELL | | |
|---|---|---|---|---|---|
| Station Number | Start Year | End Year | State Well Number | Start Year | End Year |
| 11380500 | 1949 | 1979 | 25N03W03L001M | 1952 | 1970 |




**Surface water and Shallow Groundwater Monitoring Stations**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-56**

### 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 Red Bluff 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 2-57**). The process used to identify potential GDEs in the Subbasin was accomplished by:

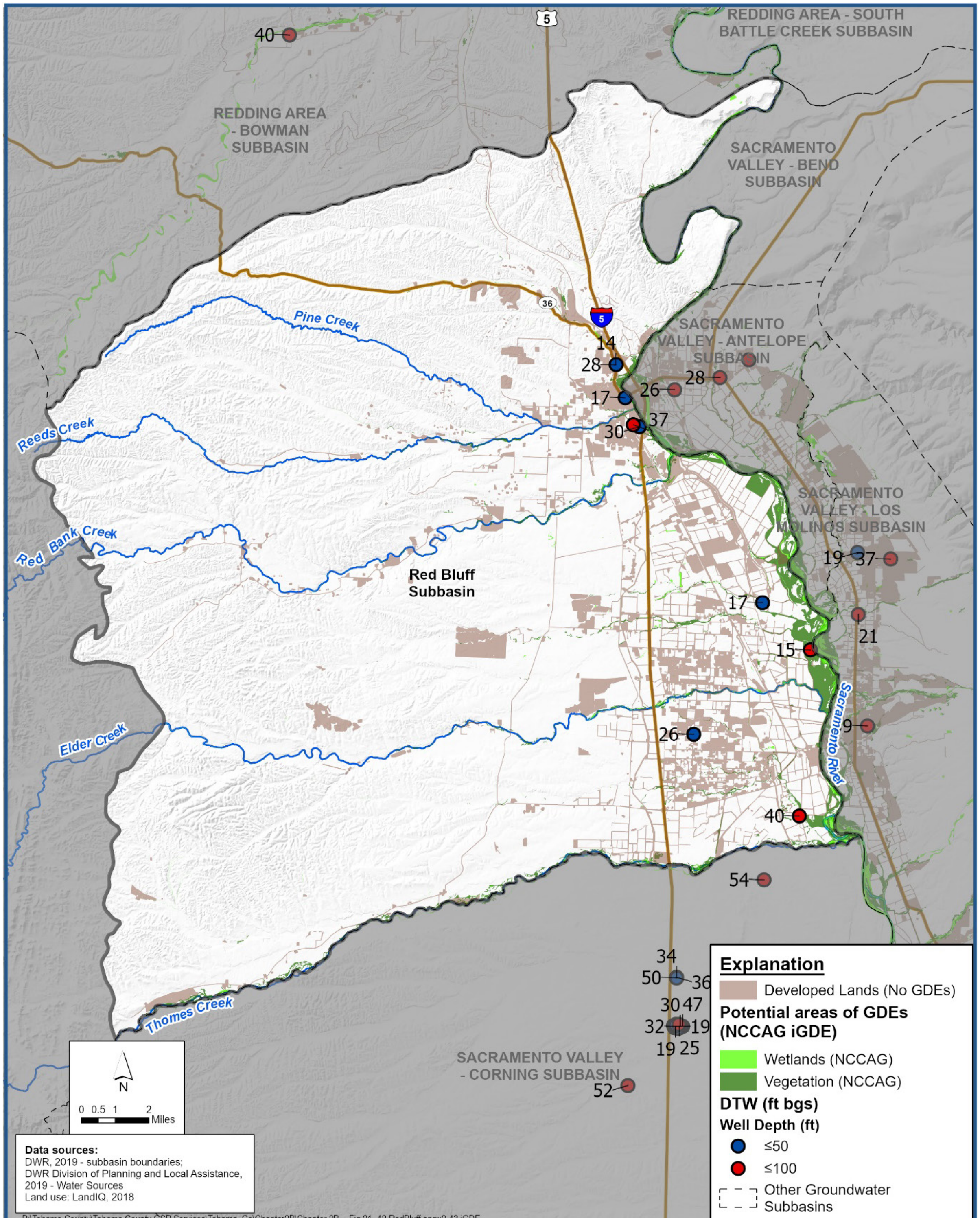
- a comparison of iGDEs with recent land cover data to update the map of iGDEs. This step is required because some iGDEs given in the NCCAG dataset are sourced from datasets mapped many years before 2015, which is the baseline year of SGMA. IGDEs found to exist within developed or irrigated lands were 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 4,800 acres to 4,333 acres of GDEs, a reduction of 10%.

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 404 acres within the

Subbasin (**Figure 2-58**). 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. None of the wells that met above criteria had sufficient historical water level data to identify correlations with vegetation metrics of high priority GDEs. Considering the lack of groundwater level monitoring close to high priority GDEs at present, installation of shallow groundwater monitoring wells near or within these GDEs is recommended.

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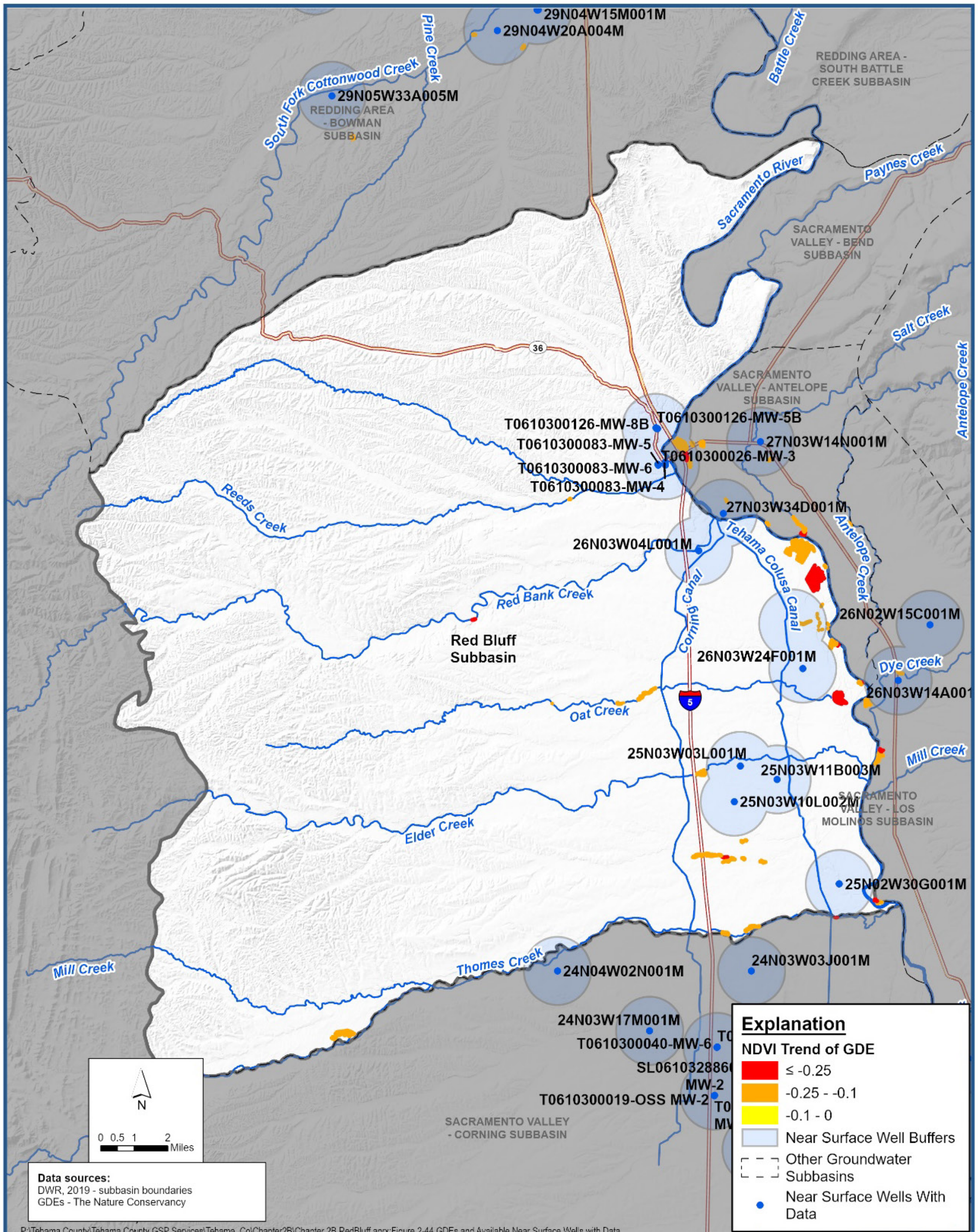
**Map of Potential Groundwater Dependent Ecosystems** **Figure 2-57**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*




**NDVI Trend of GDEs**

*Groundwater Sustainability Plan*
*Red Bluff Subbasin*

**Figure 2-58**

### 2.2.3. Basin Setting Summary

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

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 Red Bluff Subbasin is bounded to the north by the Red Bluff Arch, to the east and southeast by the Sacramento River, to the south by Thomes Creek, and to the west by the Coast Ranges Geologic Province.
- Fresh water occurs as groundwater to a maximum depth of over -2,400 ft msl in the east 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 west of the Subbasin.
- Widespread presence of contaminants at undesirable levels has not been reported in groundwater samples in the Subbasin.
- Red Bluff Subbasin has little to no reported evidence of subsidence, with recent rates of -0.0061 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 2C.
- Recharge of the Subbasin primarily occurs from the flow of the Sacramento River and the other streams and tributaries in the Subbasin (Pine Creek, Reeds Creek, Red Bank Creek, Oat Creek, Elder Creek, Mill Creek, Thomes Creek etc.).
- Subsurface geologic formations can be recharged directly where they outcrop in the Subbasin.
- Groundwater contour maps of the Upper Aquifer indicate an easterly/southeasterly general flow from the elevated areas of the valley towards the Sacramento River in the valley floor.
- Horizontal groundwater gradient magnitude ranges from about 9 ft/mile to 20 ft/mile in the valley floor, and 30 and 38 ft/mile in hillslopes.
- Seasonal high-water levels of the Upper Aquifer range between about 10 and 110 ft bgs during wet periods, and seasonal water level fluctuation ranges from a few feet to about 50 ft.
- Seasonal high-water levels of the Lower Aquifer in southeastern area range from 20 to 40 ft bgs during wet periods, and seasonal fluctuation ranges from a about 20 to 50 ft.
- Dry year to a wet year comparison indicates groundwater elevations are up to 30 ft deeper in the Upper Aquifer and up to about 10 ft deeper in the Lower Aquifer.
- A vertically downward hydraulic gradient (0.07 to 0.12 in the winter/spring and 0.2 to 0.3 in the summer/fall) exists in the southeastern area of the Upper Aquifer.
- Direction of vertical hydraulic gradient between the Upper Aquifer and the shallow part of the Lower Aquifer has changed over time (upward gradients up to 0.03 typically during and after dry conditions, and downward gradients up to 0.01 at other times).
- Vertical gradient within the Lower Aquifer has predominately remained downward (up to 0.02) during the winter/spring, and upward (between 0.02 and 0.07) during the summer/fall.
- Wells with long-term water level data show small declines of groundwater levels over time (1990 to 2018) with rates up to about 0.50 ft/year in most wells (a decline of less than nine feet in 1990-2018 period).
- At present, groundwater quality is good with no widespread presence of contaminants at undesirable levels reported in groundwater samples in the Subbasin.

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